Frequently Asked Questions (FAQ's) Regarding Empirical Demonstrations and Related Issues

Implementation Memorandum No. 15

Date: June 21, 2016

To: Interested Persons

From: Jeff Johnston, Section Manager
Information & Policy Section
Toxics Cleanup Program

Contact: Policy & Technical Support Unit, Headquarters

Attachment: A – Technical Considerations When Evaluating Whether Measured Soil Concentrations are Protective of Groundwater

---

Accommodation Requests: To request ADA accommodation including materials in a format for the visually impaired, call Ecology's Toxics Cleanup Program at 360-407-7170. Persons with impaired hearing may call Washington Relay Service at 711. Persons with speech disability may call TTY at 877-833-6341.

Table of Contents

Figures, Tables, and Example Problems

This page left intentionally blank.

1.0 Purpose and Applicability

Empirical demonstrations contain information and conclusions based on data rather than theory. The Washington State Department of Ecology (Ecology) has compiled this list of frequently asked questions that are intended to address several policy issues related to using empirical demonstrations for contaminated site cleanups, and provide sufficient information for completing an empirical demonstration in accordance with the provisions in WAC 173-340-747(9).

This document can be used at any cleanup site that meets the requirements for empirical demonstrations (see Background), including Ecology-supervised sites and independent cleanup sites.

When an empirical demonstration is used to document that the measured soil concentrations have not and will not cause an exceedance of the applicable groundwater cleanup level, the measured soil concentrations will be either Method B or Method C soil cleanup levels that are protective of the leaching pathway. These soil cleanup levels are site-specific and can’t be applied to other sites pursuing an empirical demonstration. Other potential pathways of concern must still be evaluated, which could result in a lower concentration than was determined for the soil to groundwater pathway.

Questions 1 through 7 apply to any site where an empirical demonstration is used, while **Questions 8 and 9** are specific to those sites with petroleum contamination. When an empirical demonstration is used to document that existing soil concentrations have not caused and will not cause an exceedance of the applicable groundwater cleanup levels at any time in the future, questions often arise about whether an environmental covenant will be needed for the site. **Questions 10 and 11** provide information on when an environmental covenant is necessary.

2.0 Background

In 2001, revisions to the Model Toxics Control Act (MTCA) were promulgated. One of the changes added the option to use site-specific soil and groundwater data to empirically demonstrate that the soil concentrations measured at a site have not caused and will not cause an exceedance of the applicable groundwater cleanup levels. The requirements for performing an empirical demonstration are found in WAC 173-340-747(9). Specifically, the rule requires that:

a. The measured groundwater concentrations must be less than or equal to the applicable groundwater cleanup levels; and

b. The measured soil concentrations will not cause an exceedance of the applicable groundwater cleanup levels at any time in the future.

This requires applicants to demonstrate a) that enough time has elapsed for hazardous substances to migrate from soil to groundwater, and b) that the characteristics of the site (e.g. depth to groundwater and infiltration) are representative of future site conditions. Demonstrations may include a measurement or calculation of the attenuating capacity of soil between the source of the hazardous substance and the groundwater table using site-specific data.

In 2010, the Toxics Cleanup Program's (TCP) Northwest Regional Office in Bellevue, in consultation with TCP Headquarters in Lacey, developed a draft implementation memorandum outlining the specific information that should be provided when pursuing an empirical demonstration for sites with soil contamination below the water table. That document (Attachment A) has now been expanded to cover situations where the contaminated soil is also located above the water table.

3.0 Example Situations Where Empirical Demonstrations Are Possible

Empirical demonstrations can be pursued at any point in the cleanup process, provided a sufficient site characterization has been completed in accordance with the applicable provisions of WAC 173-340-350(7) and adequate groundwater monitoring data have been obtained. For sites with petroleum contamination, the site characterization information found in Ecology's *Guidance for Remediation of Petroleum Contaminated Sites* (Ecology 2011) should be used.

Following are two example scenarios where an empirical demonstration would be possible:

> ***Example 1.*** Soil and groundwater are being evaluated during a remedial investigation. Monitoring data shows that all contaminants of concern were either not detected or were below the applicable cleanup levels in groundwater. If the empirical demonstration can document that a) sufficient time has elapsed for contamination to have migrated from soil to groundwater, and b) groundwater concentrations will not exceed the cleanup levels at any time in the future, then the measured soil concentrations are protective of the soil to groundwater pathway.
>
> ***Example 2.*** A significant soil removal remedial action has been implemented and confirmation soil testing has been completed. Initial groundwater monitoring results showed contaminant concentrations above the applicable cleanup levels. Groundwater monitoring continued after implementation of the remedy and ultimately groundwater concentrations came into compliance with the applicable cleanup levels. Once a sufficient number of sampling rounds are completed to document compliance with the applicable groundwater cleanup levels, the empirical demonstration has been made.

4.0 General FAQs Applicable to All Empirical Demonstrations

Question No. 1:

Are there situations where groundwater monitoring is not required and as a result, completing an empirical demonstration is not necessary?

Answer:

Yes, in some circumstances. Ecology interprets MTCA to require groundwater testing once a release has been confirmed, unless there is clear evidence that contamination has not reached groundwater. This requires that sufficient technical justification be provided. For sites with petroleum contamination, Section 6.9.1 of Ecology's *Guidance for Remediation of Petroleum Contaminated Sites* (Ecology 2011) can help focus this evaluation. As stated in the guidance, the factors Ecology considers to determine if groundwater contamination is unlikely are:

- Verifiable records documenting that only a small quantity of petroleum product has been released;
- Thorough soil testing that shows soil contamination has not significantly migrated;
- Predominately fine-textured soils in the area of soil contamination (dominated by silt or clay);
- Considerable depth to groundwater (more than 50 feet from the ground surface; and
- Products less prone to migration (diesel or heavy oil).

> **Note:** Each factor should be evaluated in order to provide as many lines of evidence as possible, but every factor does not always need to be demonstrated. For example, lack of records documenting the amount of product released does not necessarily disqualify a site from making a demonstration that contamination has not reached groundwater.

Guidance for Remediation of Petroleum Contaminated Sites specifies that groundwater should be tested if public or private water supply wells are located in the area, regardless of whether groundwater contamination is unlikely. Sampling of the groundwater should be done using properly constructed wells and accepted sampling techniques to ensure that representative samples are obtained. Water samples collected from an Underground Storage Tank (UST) excavation are not considered representative. While this guidance was developed specifically for sites with petroleum contamination, most of the criteria are applicable to other contaminated sites.

Occasionally, older Ecology documents that have not yet been updated to reflect current practices are used to justify a less protective approach, but caution is recommended when using this older material. For example, the 1995 Ecology document *Guidance on Sampling and Data Analysis* (publication no. 94-49) has been cited to support using a smaller separation distance between soil contamination and groundwater. Specifically, this older document states that, "Ecology expects that a hydrogeologic investigation will be conducted at any site where…soil contamination is found within 10 feet of groundwater and there is permeable soil" (p. 39).

But as noted above, more factors need to be considered when evaluating whether or not groundwater monitoring should be required. Throughout Washington State, for example, groundwater levels can fluctuate by more than 10 feet. Contaminant migration can also be highly variable, which makes it difficult to precisely determine how deep contamination has migrated. For these reasons, the 10-foot separation distance referenced in the 1995 document should not be used as justification that contamination would not have reached groundwater.

Based on the preceding discussion, groundwater monitoring data will be necessary at a large majority of sites where a release has been confirmed. When groundwater sampling is not performed, clear justification must be provided to document that the contamination has not reached groundwater.

Question No. 2:

Can an empirical demonstration be used for situations where the contaminated soil is located above the water table?

Answer:

Yes. Empirical demonstrations can be used for situations where contaminated soil is located above the water table, although an extra step of estimating travel time vertically through the unsaturated zone will be necessary to ensure that a sufficient amount of time has elapsed for migration to groundwater to have occurred.

Question No. 3:

How can I demonstrate that sufficient time has elapsed for contaminants in soil in the unsaturated zone to migrate or leach to the water table?

Answer:

Attachment A provides additional direction for completing these types of calculations. It may also be possible to use a qualitative assessment for situations where the release is old and the geology is such that there is a high likelihood that contaminant migration would have reached the groundwater.

Question No. 4:

Is it possible to use a natural attenuation groundwater remedy in conjunction with an empirical demonstration?

Answer:

Yes, subject to several conditions. Ecology's *Guidance on Remediation of Petroleum-Contaminated Groundwater by Natural Attenuation* (Ecology 2005) contains a detailed discussion on how to evaluate the feasibility and performance of cleanup actions using natural attenuation (NA). In general, NA is most appropriate for situations where:

- Significant source control has been implemented;
- Groundwater monitoring shows that the plume is stable or receding;
- The site does not pose an unacceptable threat to human health and the environment while NA monitoring is occurring; and
- A Feasibility Study and Disproportionate Cost Analysis have been conducted, or an Ecology-approved model remedy is used to demonstrate that the NA remedy is permanent to the maximum extent practicable.

If these provisions can be met, it is likely a successful demonstration can be made that NA will achieve groundwater cleanup levels within a reasonable restoration timeframe.

NA monitoring must continue until sufficient data have been collected to document that the groundwater cleanup levels have been met. At that point, the data can be used as part of an empirical demonstration that any remaining residual soil contamination will not cause an exceedance of the applicable groundwater cleanup levels at any time in the future. If soil cleanup levels to protect groundwater were established at the outset of the cleanup, they can be superseded by the empirical demonstration. For sites under Ecology supervision, this may result in the need to modify the Agreed Order or Consent Decree to specify the new soil cleanup levels.

If the applicable groundwater cleanup levels cannot be met, the remedial work will be considered an interim action and additional cleanup may be needed.

Question No. 5:

Can an empirical demonstration be used at a site where a groundwater conditional point of compliance (POC) is used?

Answer:

No. The purpose of an empirical demonstration under WAC 173-340-747(9) is to demonstrate that measured soil concentrations are not causing and will not cause exceedances of the applicable groundwater cleanup levels. This applies to groundwater anywhere on the site, not just where monitoring is taking place. At sites where a conditional point of compliance is used, exceedances of the groundwater cleanup levels will exist between the source and the point at which groundwater is monitored, which is inconsistent with the requirements for an empirical demonstration.

Question No. 6:

Can an empirical demonstration be made if it is not practicable to install groundwater monitoring wells directly beneath or immediately adjacent to the contaminated soil?

Answer:

Yes. For example, there may be a building or dispenser island that precludes installing a monitoring well directly down gradient of the soil contamination. In this case, a well can be drilled as close as practicable to the source and a calculation provided to show that the projected concentration under or adjacent to the source area meets the applicable groundwater cleanup levels. If the contaminated soil is covered by a building or pavement that prevents or limits infiltration, an institutional control would be necessary (see Question No. 10).

Question No. 7:

Can an empirical demonstration be used at sites where the groundwater has been demonstrated to meet the definition of nonpotable?

Answer:

Yes. Making an empirical demonstration does not depend on the cleanup level selected. If it can be demonstrated that the groundwater is nonpotable under WAC 173-340-720(2) then the cleanup levels established under WAC 173-340-720(6) can be used as the target groundwater concentrations for an empirical demonstration.

5.0 FAQ's Specific to Petroleum Contamination

Question No. 8:

Are there certain situations where more than one Method for establishing cleanup levels can be used at a single site (i.e., mixing methods)? Specifically, can a site owner decide to use Method A cleanup levels for some substances or media, and Method B or Method C cleanup levels for others?

Answer:

Yes. WAC 173-340-700(8) contains additional requirements when establishing cleanup standards at a site where there has been a release of total petroleum hydrocarbons (TPH) and hazardous substances associated with a release of TPH. WAC 173-340-700(8)(b)(i) specifically states, "a site owner may decide to use Method A for some substances or media and Method B or C for others, depending upon site conditions and qualifications."

Question No. 9:

What site conditions and qualifications does Ecology consider to be appropriate for using more than one Method for establishing cleanup levels?

Answer:

When sufficient information is provided to document that an empirical demonstration has been made, Ecology allows Method A to be used for some substances or media, and Method B or C for others. The following discussion contains two examples of when this approach is acceptable. These examples assume that discharge of groundwater to surface water—which could result in more stringent groundwater cleanup levels—is not a pathway of concern at these sites.

> ***Example 1 – Mixing cleanup methods for individual petroleum compounds.*** A historic release of gasoline and diesel fuel is found to have contaminated the soil at a site. After remediation, sampling shows that most of the compliance samples meet the Method A soil cleanup levels, which include the TPH numbers. Specifically, the soil concentrations of Gasoline Range Organics (GRO) measured using the NWTPH-Gx Method are less than 30 mg/kg, and the soil concentrations of Diesel Range Organics (DRO) measured using the NWTPH-Dx Method do not exceed 400 mg/kg. These GRO and DRO concentrations are below the Method A TPH cleanup levels and therefore considered protective of groundwater[1].

---

[1] The relevant TPH soil cleanup standards are 30 mg/kg NWTPH-Gx, since benzene is present, and 2,000 mg/kg DRO (total of diesel and heavy oil using the NWTPH-Dx Method).

However, two confirmation soil samples at depths of 8 and 10 feet below ground surface have benzene concentrations at 0.05 and 0.08 mg/kg, which exceed the Method A level of 0.03 mg/kg. (The Method A cleanup level for benzene is based on protection of groundwater). Adequate monitoring has been performed to document that none of the Method A groundwater cleanup levels for those contaminants likely to be present and listed in WAC 173-340-900, Table 720-1 have been exceeded anywhere on the property[2], including the 5 µg/l standard for benzene. If information can be provided to document that the remaining soil impacts will not result in groundwater exceedances in the future, then the existing soil benzene concentrations can be considered empirically-derived Method B soil cleanup levels that are protective of the soil to groundwater pathway.

While the soil to groundwater pathway has been adequately addressed in this example, other pathways of concern would still need to be assessed since benzene in soil exceeds the Method A soil cleanup standards:

- **Direct Contact:** Since the measured soil concentrations at the site are well below the Method B benzene direct contact level of 18.2 mg/kg for unrestricted use, the direct contact pathway has been addressed.

- **Vapor Intrusion:** WAC 173-340-740(3)(b)(iii)(C)(III) requires that the soil to vapor pathway must be evaluated….“for other volatile organic compounds, including petroleum compounds, whenever the concentration is significantly higher than a concentration derived for the protection of groundwater.” The measured concentrations of benzene in soil (0.05 and 0.08 mg/kg) are not significantly higher than the concentration that is protective of groundwater (i.e., the Method A value of 0.03 mg/kg) and therefore the vapor pathway has been adequately addressed.

  Note: Ecology generally considers that benzene concentrations less than three times (3x) the Method A cleanup level are not significant, provided that limited contaminant mass remains in the soil. This would need to be assessed on a site-specific basis.

- **Terrestrial Ecological Evaluation (TEE):** The first step in evaluating this pathway for a typical gas station is to determine if any of the factors that would allow the site to be excluded have been met. Frequently, petroleum contamination at gas stations or other small commercial operations can be excluded because there is insufficient contiguous undeveloped land. For purposes of this example, the site does not meet the exclusion for undeveloped land and the

---

[2] In this example the relevant TPH standards would be 800 µg/l NWTPH-Gx, since benzene is present, and 500 µg/l NWTPH-Dx (total of diesel and heavy oil).

> property owner does not want an environmental covenant placed on the property. If the site does not qualify for an exclusion, the next step is to determine if a site-specific TEE is required. In this case, site conditions are such that a site-specific TEE is not required and therefore a simplified TEE can be pursued.
>
> For the simplified TEE procedure, the measured GRO and DRO soil concentrations are below the ecological standards contained in WAC 173-340-900, Table 749-2 (200 mg/kg and 460 mg/kg respectively) and benzene does not have a promulgated ecological standard. Therefore the TEE can end and an environmental covenant is not required.

Based on this discussion, all pathways of concern in Example 1 have been addressed and therefore the site is eligible for a no further action letter. No environmental covenant would be necessary.

Example 2 – Mixing cleanup methods for total petroleum hydrocarbons (TPH). As part of routine maintenance work, a historical release of gasoline from the piping system under a pump island at an active gas station was discovered. The property is approximately one acre in size. Over half of this area is paved with the rest covered by the convenience store. There is no undeveloped land within 1/8 of a mile in all directions. The selected remedial action resulted in a majority of the soil contamination being removed. Confirmation sampling results show that no compound specific Method A soil cleanup levels were exceeded (e.g. BTEXN). Comprehensive groundwater monitoring documented that none of the relevant Method A TPH groundwater cleanup levels in WAC 173-340-900, Table 720-1 were exceeded. Multiple groundwater samples taken over time show that the groundwater concentrations are decreasing. However, three confirmation samples revealed GRO in soil at concentrations ranging between 75 and 90 mg/kg, which exceeds the Method A soil cleanup level of 30 mg/kg. The Method A soil cleanup level is based on protection of groundwater if any benzene was present in the soil.

In general, when establishing a Method B soil TPH cleanup level under MTCA, an Extractable Petroleum Hydrocarbons/Volatile Petroleum Hydrocarbons (EPH/VPH) analysis must be conducted and used to calculate a site-specific soil cleanup level. However, in situations where low residual soil concentrations of TPH are present, EPH/VPH testing will often result in non-detectable levels for many of the fractions. This can skew the composition ratios and subsequently affect the calculated soil and groundwater TPH cleanup levels. This typically occurs when TPH concentrations are less than several hundred ppm in soil. In Example 2, the residual soil concentrations (75 mg/kg to 90 mg/kg) are low enough that it is unlikely fractionated soil testing using the EPH/VPH methods would provide meaningful results.

Due to the potential complications associated with developing Method B soil cleanup levels using EPH/VPH analysis when low levels of TPH are present in the soil, Ecology has determined there are limited circumstances when it would be acceptable to use NWTPH soil and groundwater sampling data in conjunction with Method A groundwater TPH cleanup levels for making an empirical demonstration. Specifically, the Method A groundwater cleanup levels in Table 720-1 can be used to assess whether the remaining concentrations of TPH in soil are protective of the soil to groundwater pathway, as long as the following criteria are met:

1. **Source Removal.** A remedial action is selected and implemented that removes the majority of contaminant mass in the soil. To document compliance with this criteria, an estimate of the mass of contamination removed from the site must be provided. The estimate should be based on a comparison of data from the initial site characterization with the results from post-remediation sampling.

2. **Groundwater Monitoring.** A groundwater monitoring program is implemented that meets the provisions contained in Chapter 10.3 of Ecology's *Guidance for Remediation of Petroleum Contaminated Sites* and documents that:

    a) All compound specific contaminants of concern (e.g. benzene) are below the Table 720-1 Method A Groundwater Cleanup Levels, and

    b) The applicable Method A TPH cleanup levels set out in Table 720-1 have been meet.

3. **Assessment of Groundwater Quality**. Groundwater monitoring data must document that the plume is stable or receding. For situations where monitoring shows the plume is stable, an assessment of whether the concentrations of TPH will likely decrease over time should also be provided[3].

If all three criteria cannot be met, then soil or groundwater samples must be obtained and analyzed for TPH fractions using the EPH/VPH Methods as appropriate. Additionally, Method B must be used to establish both soil and groundwater TPH cleanup levels.

For the purposes of Example 2, it is assumed that the above criteria have been met. If sufficient time has elapsed for contamination to have migrated to the groundwater table, then the measured GRO soil concentrations can be considered Method B soil cleanup levels that are protective of the soil to groundwater pathway. Since GRO concentrations

---

[3] Options for evaluating plume stability and assessing the mass flux of contamination in groundwater are found in the Ecology publication *Guidance on Remediation of Petroleum-Contaminated Groundwater by Natural Attenuation* (Ecology 2005).

exceed the Method A soil cleanup level for unrestricted use, other pathways of concern would need to be assessed.

- **Direct Contact:** Confirmation testing documents that total TPH does not exceed the level Ecology considers to be a conservative direct contact cleanup level (1500 mg/kg) at all sampling locations and therefore the direct contact pathway has been addressed[4]. As the document in Footnote 4 discusses, the 1500 mg/kg value does not replace or modify the existing Method A soil cleanup levels for diesel, heavy oil, or mineral oil.

- **Vapor Intrusion:** WAC 173-340-740(3)(b)(iii)(C)(I) requires that the soil to vapor pathway must be evaluated…"for gasoline range organics, whenever the total petroleum hydrocarbon (TPH) concentration is significantly higher than a concentration derived for the protection of groundwater." The measured concentrations of GRO in soil (between 75 and 90 mg/kg) are not significantly higher than the concentration that is protective of groundwater (i.e., the Method A value of 30 mg/kg) and therefore the vapor pathway has been adequately addressed.

  Note: Ecology generally considers that TPH-Gx concentrations less than three times (3x) the Method A cleanup levels are not significant, provided that limited contaminant mass remains in the soil. This would need to be assessed on a site-specific basis.

- **Terrestrial Ecological Evaluation:** Since there is no contiguous undeveloped land on the site or within 500 feet in any direction, the site is eligible for a TEE exclusion under WAC 173-340-7491.

Based on the discussion in Example 2, all pathways of concern have been addressed and therefore the site is eligible for a no further action letter. An environmental covenant would be necessary because the impacted soil is beneath a cap/cover, which is not necessarily representative of future site conditions as required by WAC 173-340-747(9)(b)ii.

---

[4] For more information on how this level was determined, see *Model Remedies for Sites with Contaminated Soils* (Ecology 2015).

6.0 FAQs about Environmental Covenants

Question No. 10:

Under what circumstances does an empirical demonstration require an environmental covenant to ensure that remaining soil concentrations are protective of the other pathways of concern?

Answer:

Three specific examples are provided to illustrate when an environmental covenant would be required. This discussion is specific to empirical demonstrations and as a result, the environmental covenant may also need to address other restrictions such as limiting the site to industrial land use:

> ***Example 1.*** If measured soil concentrations are above direct contact cleanup levels in the top 15 feet of soil.
>
> ***Example 2.*** If measured soil concentrations are above cleanup levels for another pathway of concern (e.g., terrestrial ecosystems or vapor migration).
>
> ***Example 3.*** If soil contamination is located above the water table and a cap or cover such as a parking lot, building, or roadway are present above the contaminated soil. In this case, the characteristics of the site are not necessarily representative of future site conditions because if the structure was later removed, leaching of contaminants could increase and ultimately cause the applicable groundwater cleanup levels to be exceeded.

Question No. 11:

Under what circumstances is an environmental covenant not necessary when using an empirical demonstration?

Answer:

Two examples are provided to show when a covenant is not necessary. As with **Question 10**, this discussion is limited to empirical demonstrations, and the environmental covenant may also need to address other restrictions such as limiting the site to industrial land use. These two examples assume that a) sufficient time has elapsed for hazardous substances to migrate from soil to groundwater, and b) it was determined that the remaining soil contamination does not threaten any other pathways, including direct contact, terrestrial ecosystems, and vapor migration.

> ***Example 1***. The soil contamination is located below the water table but groundwater monitoring data from immediately down-gradient of the soil contamination shows that groundwater concentrations are less than the applicable cleanup levels.
>
> ***Example 2.*** The soil contamination is located above the water table, is fully open to leaching (i.e., no overlying structures or intact pavement) and groundwater monitoring data immediately down-gradient of the soil contamination shows that groundwater concentrations are below the applicable cleanup levels.

7.0 References

Ecology. (2005). *Guidance on remediation of petroleum-contaminated ground water by natural attenuation*. (Publication No. 05-09-091). Lacey, WA: Washington State Department of Ecology, Toxics Cleanup Program. Retrieved from: https://fortress.wa.gov/ecy/publications/SummaryPages/0509091.html.

Ecology. (2011). *Guidance for the remediation of petroleum contaminated sites.* (Ecology Publication No. 10-09-057). Lacey, WA: Washington State Department of Ecology, Toxics Cleanup Program. Retrieved from: https://fortress.wa.gov/ecy/publications/SummaryPages/1009057.html

Ecology. (2013). *Model Toxics Control Act regulation and statute: MTCA Cleanup Regulation Chapter 173-340 WAC, Model Toxics Control Act Chapter 70.105D RCW, Uniform Environmental Covenants Act Chapter 64.70 RCW*. (Ecology Publication No. 94-06). Lacey, WA: Washington State Department of Ecology, Toxics Cleanup Program. Retrieved from: https://fortress.wa.gov/ecy/publications/summarypages/9406.html and http://apps.leg.wa.gov/wac/default.aspx?cite=173-340

Ecology. (2015). *Model Remedies for sites with petroleum contaminated soils* (Ecology Publication No. 15-09-043). Lacey, WA: Washington State Department of Ecology, Toxics Cleanup Program. Retrieved from: https://fortress.wa.gov/ecy/publications/SummaryPages/1509043.html.

Attachment A:

Technical Considerations When Evaluating Whether Measured Soil Concentrations Are Protective of Groundwater

This page left intentionally blank.

Introduction

The Model Toxics Control Act (MTCA) provides a number of methods to establish soil cleanup levels protective of groundwater quality. One of these options is set forth in WAC 173-340-747(9) and termed an "empirical demonstration." This method requires a demonstration that groundwater concentrations are less than or equal to the applicable groundwater cleanup level established under WAC 173-340-720 and that the measured soil concentrations will not cause an exceedance of the applicable groundwater cleanup level at any time in the future.

There are two scenarios where an empirical demonstration may be possible. The first is when monitoring data show that all contaminants of concern were either not detected or were below the applicable groundwater cleanup levels. In this situation, documentation must be provided that sufficient time has elapsed for contamination to have migrated from soil to groundwater. This scenario can include contamination in the unsaturated zone, as well as when contaminated soil is located below the water table. Appendices 1 and 2 of this Attachment provide options for completing this evaluation.

The other scenario is when groundwater concentrations are initially above cleanup levels but after remedial actions are completed, monitoring data indicates that contaminant concentrations meet the applicable cleanup levels. In this situation, calculating contaminant travel time is not necessary. Once a sufficient number of sampling rounds are completed to document compliance with the cleanup level, the empirical demonstration has been made. The approaches set forth in this Attachment can be used at any site where an empirical demonstration is being pursued.

General Considerations

The options described in this Attachment assume that groundwater characterization and monitoring will be necessary to provide the data to make an empirical demonstration (Ecology's *Frequently Asked Questions (FAQ's) Regarding Empirical Demonstrations and Related Issues, Implementation Memorandum No. 15*, publication no. 16-09-047 (Ecology 2016), discusses when groundwater monitoring may not be needed.) The site characterization must include enough monitoring points so that groundwater flow directions can be determined. Water level measurements should take place over several seasons, with results plotted on one or more plan sheets so that potential changes in flow directions can be assessed.

The well(s) to be used in determining whether the empirical demonstration has been made should be located as close as practicable to the source area. If sampling cannot confirm the exact location of the source, assumptions based on available site-specific information should be used to estimate contaminant travel times. The proximity of these wells to the source area should be included on one or more cross sections.

Contamination in the Unsaturated Zone

The MTCA regulations do not provide specific equations for calculating the time for contaminants to migrate through the unsaturated zone. There are a number of publicly available unsaturated zone models, but most of them are complex and typically require a significant amount of site information. While any of those models provide a potential option for estimating travel times through the unsaturated zone, Ecology recommends using the process set out in Appendix 1. This is a straightforward approach for estimating contaminant migration to the water table, with limited site-specific information needed.

> **Note:** When contaminated soil is located in the unsaturated zone and overlain by a cap/cover (e.g. pavement, buildings, etc.) it is not necessary to estimate contaminant migration times since the site will require an environmental covenant.

In some circumstances, it may be possible to provide a qualitative assessment of whether sufficient time has elapsed for contamination to have migrated to the groundwater. When considering a qualitative assessment, the following factors should be evaluated:

- The amount of time that has passed since the release took place;
- Information on the quantity of contaminants released;
- The soil types in the area of contamination;
- Depth to groundwater;
- The migration potential of the contaminants released; and
- Remedial actions implemented at the site.

Situations that would be most conducive to a qualitative approach would be at sites where there are highly permeable soils, shallow depth to groundwater, and a long period of time since the release was first documented. The Ecology Cleanup Project Manager should be consulted if this approach is being considered.

Contamination in the Saturated Zone

When contaminants are present at or below the water table, the empirical demonstration will typically be straightforward, assuming that the monitoring well(s) are installed down-gradient and in close proximity to the source of contamination. If monitoring shows that groundwater concentrations do not exceed the applicable groundwater cleanup levels, the last remaining requirement would be to provide information that cleanup levels would not be exceeded in the future. This would require evaluating whether sufficient time has elapsed for groundwater contamination to have migrated from the source area to the applicable monitoring points. Appendix 2 of this Attachment provides an example of how this evaluation could be completed.

Water table elevations near the source area should be collected to help determine whether groundwater fluctuations are significant enough so that contaminants are “smeared” across the unsaturated zone. In such situations, it is generally acceptable to estimate travel times using contaminant migration through just the saturated zone.

Appendix 1:

Procedures for Calculating Infiltration / Percolation Rates through the Unsaturated Zone

Introduction

The contaminant migration rate to a down-gradient groundwater monitoring well can be determined if the flow velocity and migration distance are known. Migration can occur in an unsaturated media, a saturated media, or both. In a steady-state, uniformly saturated porous media, the flow velocity is constant since saturation does not change. For a steady-state, uniformly unsaturated porous media, the flow velocity depends on the soil texture and the water content of the soil. Consequently, deriving the flow velocity for unsaturated soil is more involved than for saturated soil.

Infiltration / Percolation

Infiltration is the rate at which soil absorbs water entering the soil through precipitation, snow melt, or surface water. *Percolation* is the rate at which water flows through the soil (FEMA 2010). Infiltration rate is typically rapid initially and slows down with time to reach a steady-state flow. Percolation rate occurs at approximately the point where infiltration rate reaches steady flow. For the purpose of this Appendix, the contaminated soils are assumed to have achieved steady-state conditions, and therefore have achieved a uniform flow rate in the soil.

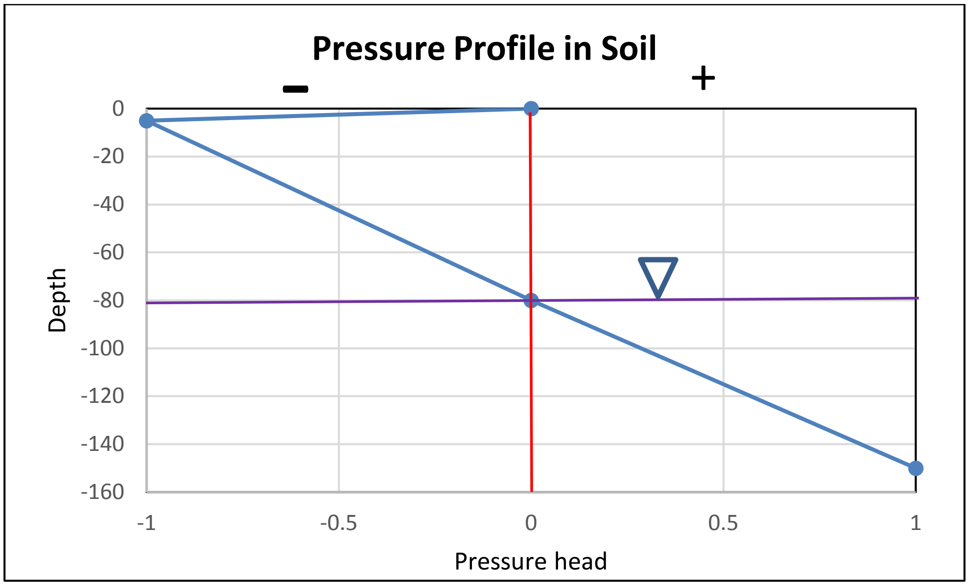


Figure 1: Generic pressure profile through a soil column.

Figure 1 illustrates infiltration and percolation through the soil column. The pressure head and depth values are somewhat arbitrary and only represent the general construct of the model.

- The **blue (nearly horizontal) line** in top left corner of graph represents the pressure head change with depth through the profile.
- Negative pressure is to the left of the **red (vertical) line** and positive pressure is to the right.
- The water table is represented by the **purple (horizontal) line in center of graph**.

In this range, negative pressure, or suction, increases rapidly. From -2 to the water table, the negative pressure head declines steadily as percolation occurs, until the water table is reached and pressure head is back to 0. Below the water table, hydraulic pressures become positive to reflect the weight of the water column at some distance below the water table.

Soil Physics Concepts

The hydraulic properties of soils can be derived from physical properties of the soil, such as particle size distribution, bulk density, and particle density. They can also be derived from direct measurement of hydraulic properties, such as water content, pressure head, and flow rate. Collection of the physical properties data is often easier and more cost effective than direct measurement of the hydrologic properties. The objective of this section is to derive the site-specific flow rate through an unsaturated soil by using an easy, low cost approach.

The first step is to collect multiple soil samples that represent the textural variability through the vertical column of a soil boring. The physical properties that need to be obtained from the sample are sieve data, soil dry bulk density, and soil particle density. Soil water content is also needed to determine flow rate through the soil:

- The **soil water content** is derived by weighing a soil sample collected at the site, drying the sample in an oven, and re-weighing the sample.
- The measured difference is the **water mass**.
- The **gravimetric water content** is then simply the water mass divided by the total dry soil sample mass.
- The **volumetric water content** is the gravimetric water content, times the soil dry bulk density.

With these data, the flow rate can be determined for the specific soil at the measured water content.

The soil porosity represents the available total pore space in the soil. The total soil sample consists of solid, water, and air. Total porosity assumes that all the available void space (water and air) is water filled. Total porosity (φ) can be calculated using the following equation,

$$\varphi = 1 - \frac{\rho_b}{\rho_s} \qquad (1)$$

Where ρ_b is soil dry bulk density and ρ_s is soil particle density. Porosity can be equated to saturated water content (θ_s).

- The **dry bulk density** is simply the mass of the soil fraction divided by the volume total.
- The **particle density** is the mass of the solid divided by the volume occupied by the soil fraction (volume total minus the volume of the void space).

The flow rate for specific soil textures through unsaturated soil is calculated using hydrologic and physical parameters as input to standard equations from which to derive soil hydraulic characteristic curves. Effective saturation is a representation of the relative saturation in a soil. Effective saturation (S_e) ranges from 0 at residual saturation (θ_r) to 1 for fully saturated (θ_s). The value θ_v, represents the volumetric water content (volume water divided by volume total) that is derived from the site specific soil sample.

$$S_e = \frac{(\theta_v - \theta_r)}{(\theta_s - \theta_r)} \qquad (2)$$

Effective saturation can also be calculated using the van Genuchten equation listed below. The input parameters are derived from either a curve fit through measured data, or derived from generic parameters reported in soil physics literature for specific textural types. The inputs include h, which is the pressure head (suction pressure); α and n are empirically derived parameters; and m is calculated from n, as shown below.

$$S_e = \frac{1}{[1+(\propto h)^n]^m} \qquad (3)$$

$$m = 1 - \frac{1}{n} \qquad (4)$$

The hydraulic conductivity for a specific effective saturation [K(S$_e$)] is then calculated by the Mualem equation below. Inputs to the Mualem equation include l = 0.5; saturated hydraulic conductivity (K_s); m defined above; and effective saturation (S_e).

$$K(S_e) = K_s {S_e}^l \left[1 - \left(1 - {S_e}^{1/m}\right)^m\right]^2 \qquad (5)$$

For the purpose of deriving hydraulic properties of the soils, standard hydraulic tables for various textural types will be used from which to derive the input parameters for the hydraulic curves that express S_e and $K(S_e)$ above. The input parameters are derived from the publication of Carsel and Parrish (1988). The discussion of the calculation methods are in van Genuchten (et al.) (1991).

Once S_e and $K(S_e)$ are derived, the steady-state flow is calculated using the Darcy Equation as follows:

$$q = -K(S_e)\left(\frac{dh}{dz} + 1\right) \qquad (6)$$

For gravity drainage only, $\frac{dh}{dz} = 0$ and the negative sign indicates downward flow.

$$q = |k(S_e)| \qquad (7)$$

Therefore, the flow rate through the soil is equated to the hydraulic conductivity at the measured saturation in the soil.

The travel time (t_z) through the unsaturated zone is then calculated as the distance from the source in the unsaturated zone to groundwater (z; L) divided by the velocity (q; L/t), where L is units of length and t is units of time.

$$t_z = \frac{z}{q} \qquad (8)$$

The X-axis values of the characteristic curves is derived using Equation 2 and the corresponding Y-axis values are derived using Equation 5. Hydraulic parameters in Table 1 are used to calculate the characteristic curves (Figures 4 through 15) for each of the textural types. The site-specific volumetric water content, θ_v, is derived from the measured gravimetric water content, θ_g.

Approach for Estimating Contaminant Travel Time

Inputs for this method are derived from the collection of soil samples and include a) sieve analysis data, b) weight of the unaltered (moist) soil sample, and c) weight of the dry soil sample. Data can be processed by a geotechnical engineering firm or using in-house equipment. The particle size distribution data is collected using a set of sieve screens and a particle size distribution is developed. A scale is used to weigh the soil samples. An oven or stove is used to dry the samples. The sample volume must also be determined prior to sieving to assess the density of the sample (sample mass divided by sample volume).

Multiple samples should be collected along the vertical profile. This is done to collect a representative sample of the textural variability through the profile. Ideally, the textural type that exhibits the lowest hydraulic conductivity for the moisture content present in the soil will determine the flow rate through the column. The steps to conduct this follow:

1. Weigh the soil sample in the container in which it was collected. The container is assumed full (100% of the volume is filled with the soil sample).
2. Remove the soil sample and weigh the container (**wet weight**).
3. Oven dry the soil sample and weigh the dry soil (**dry weight**).

4. **Gravimetric water content** (θ_g) = mass of water/mass of dry soil[5]

5. **Dry bulk density** (ρ_b) is the weight of the dry soil divided by the sample container volume.

6. **Volumetric water content** = θ_g x ρ_b. This value is θ_0 in the equation to calculate S_e above.

7. Place the soil sample in the largest sieve screen and shake the soil so that soil fractions are collected in the respective sieve screens, fining downward. Weigh the soil in each screen interval to get a weight. The fraction of the total weight in each screen interval is the weight percent passing for the respective particle size.

8. Using the textural triangle in Figure 2, select the textural type derived from Step 7 and determine the texture of the soil sample.

9. Select the characteristic curve from Figures 4 through 15 that corresponds to the textural type.

10. Using the values of θ_s and θ_r from Table 1 (Carsel and Parrish) for the appropriate textural type, solve the equation for S_e. This is the effective saturation of the site sample relative to full saturation = 1 and residual saturation = 0.

11. Using the characteristic curve figure, project a vertical line from the calculated S_e on the X-Axis to the curve and then project horizontally to the Y-Axis to get the $K(S_e)$ value. This value is the flow rate within the site soil at partial saturation in the field. This is the value q above.

12. Determine the distance from the contaminant source in the unsaturated zone to the water table (z).

13. Calculate the travel time for contamination to migrate from the unsaturated zone to groundwater.

---

[5] M1 = mass of can and moist soil
M2 = mass of can and dry soil
M3 = mass of empty can

$$\theta_g = \frac{M1-M2}{M2-M3}$$

Example Calculation 1:

The scenario for this example: a soil sample has been collected from a single soil sample at three meters depth.

Sieve results: 30% sand, 55% silt, 15% clay. Using textural triangle in Figure 2, the soil texture is silt loam.

Weight of moist soil and can = 130 g

Weight of dry soil and can = 120 g

Weight of can = 20 g

$$\theta_g = \frac{130 - 120}{120 - 20}$$

θ_g = 0.10 g/g, the gravimetric water content

If container volume is 60.6 cm^3

P_b = 100 g/60.6 cm^3 = 1.65 g/cm^3

The density of water is 1 g/cm^3, divide dry bulk density by water density to cancel mass. Using the gavimetric water content and dry bulk density, the volumetric water content is,

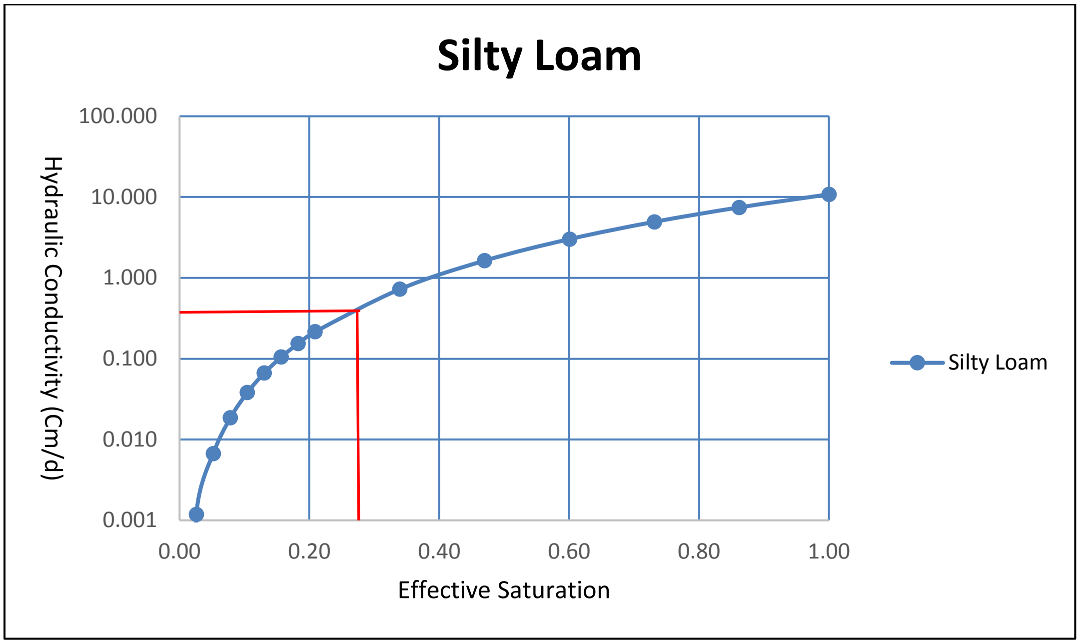
θ_v = (0.10 g/g * 1.65) = 0.165 cm^3/cm^3

Use Table 1, derived from Carsel and Parrish (1988), to provide θ_r and θ_s for a sandy textured soil. With the site-specifc water content (θ_v) calculated above, the effective saturation is calculated as follows.

$$S_e = \frac{0.165 - 0.067}{0.45 - 0.067} = 0.26$$

Projecting S_e = 0.26 on the plot for silty loam, the flow through the soil is about 0.5 cm/d or 0.005 meters per day.

Plot for Example Calculation 1: Silty loam characteristic curve.



If the depth to the aquifer is 10 meters, then the time for the contamination to reach the water table is,

t_z = (10 m)/(0.005 m/d) <u>= 2000 days or 5.5 years</u>

Example Calculation 2:

Now also assume that a second soil sample is collected from the same borehole at a depth of six (6) meters.

Sieve results: 70% sand, 20% silt, 10% clay. Using textural triangle in Figure 2, the soil texture is sandy loam.

Weight of moist soil and can = 125 g

Weight of dry soil and can = 120 g

Weight of can = 20 g

$$\theta_g = \frac{125 - 120}{120 - 20}$$

θ_g = 0.05 g/g, the gravimetric water content

If container volume is 60.6 cm^3

P_b = 100 g/60.6 cm^3 = 1.65 g/cm^3

The density of water is 1 g/cm^3, divide dry bulk density by water density to cancel mass. Using the gavimetric water content and dry bulk density, the volumetric water content is,

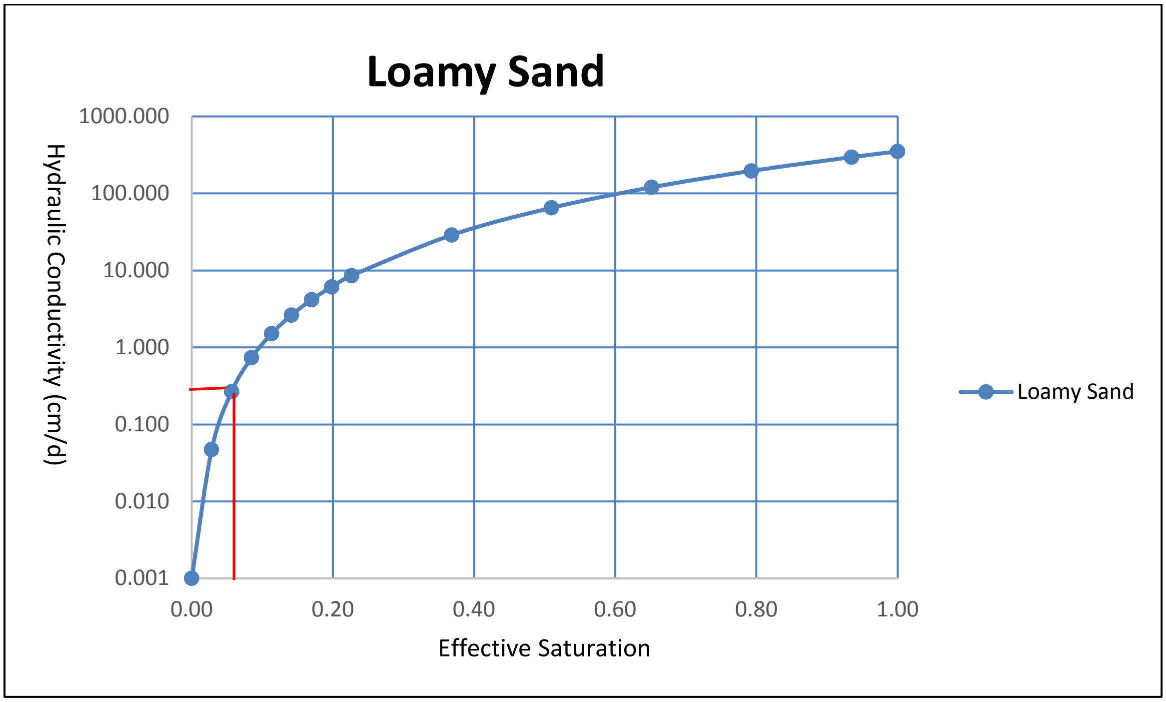
θ_v = (0.05 g/g * 1.65) = 0.08 cm^3/cm^3

Use Table 1, derived from Carsel and Parrish (1988), to provide θ_r and θ_s for a sandy textured soil. With the site-specifc water content (θ_v) calculated above, the effective saturation is calculated as follows.

$$S_e = \frac{0.08-0.065}{0.41-0.065} = 0.04$$

Projecting S_e = 0.04 on the plot below, the flow through the sand is about 0.3 cm/d or 0.003 meters per day.

Plot for Example Calculation 2: Loamy sand characteristic curve.



If the depth to the aquifer is 10 meters, then the time for the contamination to reach the water table is,

t_z = (10 m)/(0.003 m/d) = <u>3333 days or 9 years</u>

Since travel time is a function of the most impermeable material, the migration time of the contamination will be represented by the 3333 day migration time.

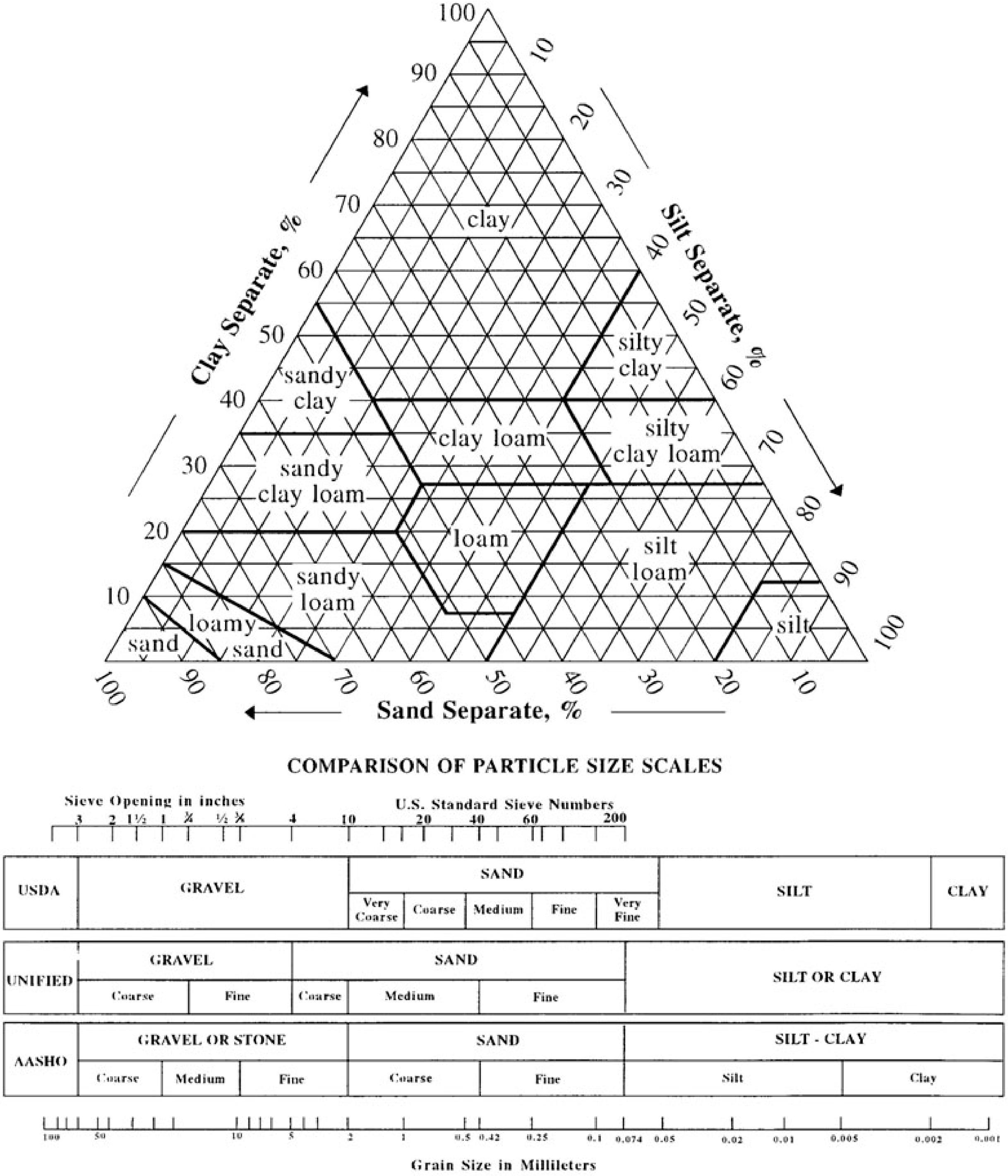
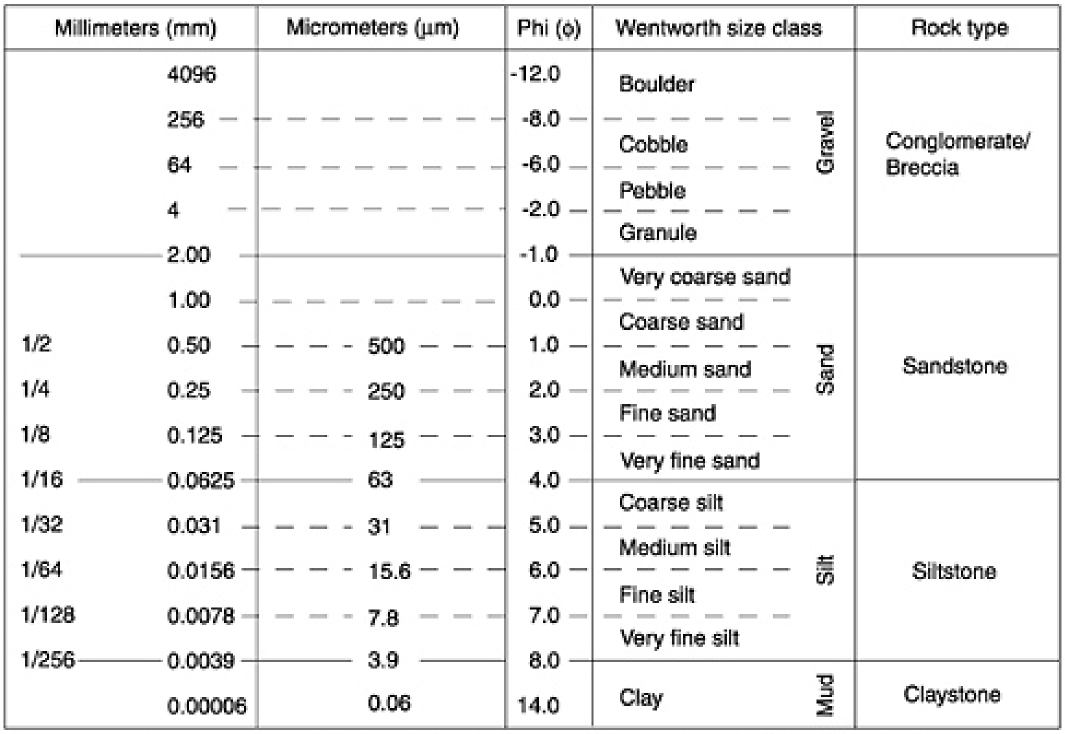


Figure 2: Textural triangle.



Millimeters (mm)		Micrometers (µm)	Phi (ϕ)	Wentworth size class		Rock type
	4096		-12.0	Boulder	Gravel	Conglomerate/ Breccia
	256		-8.0	Cobble		
	64		-6.0	Pebble		
	4		-2.0	Granule		
	2.00		-1.0	Very coarse sand	Sand	Sandstone
	1.00		0.0	Coarse sand		
1/2	0.50	500	1.0	Medium sand		
1/4	0.25	250	2.0	Fine sand		
1/8	0.125	125	3.0	Very fine sand		
1/16	0.0625	63	4.0	Coarse silt	Silt	Siltstone
1/32	0.031	31	5.0	Medium silt		
1/64	0.0156	15.6	6.0	Fine silt		
1/128	0.0078	7.8	7.0	Very fine silt		
1/256	0.0039	3.9	8.0	Clay	Mud	Claystone
	0.00006	0.06	14.0			

Udden-Wentworth grain-size classification. (source: Wentworth, 1922)

Figure 3: Particle size distribution and texture.

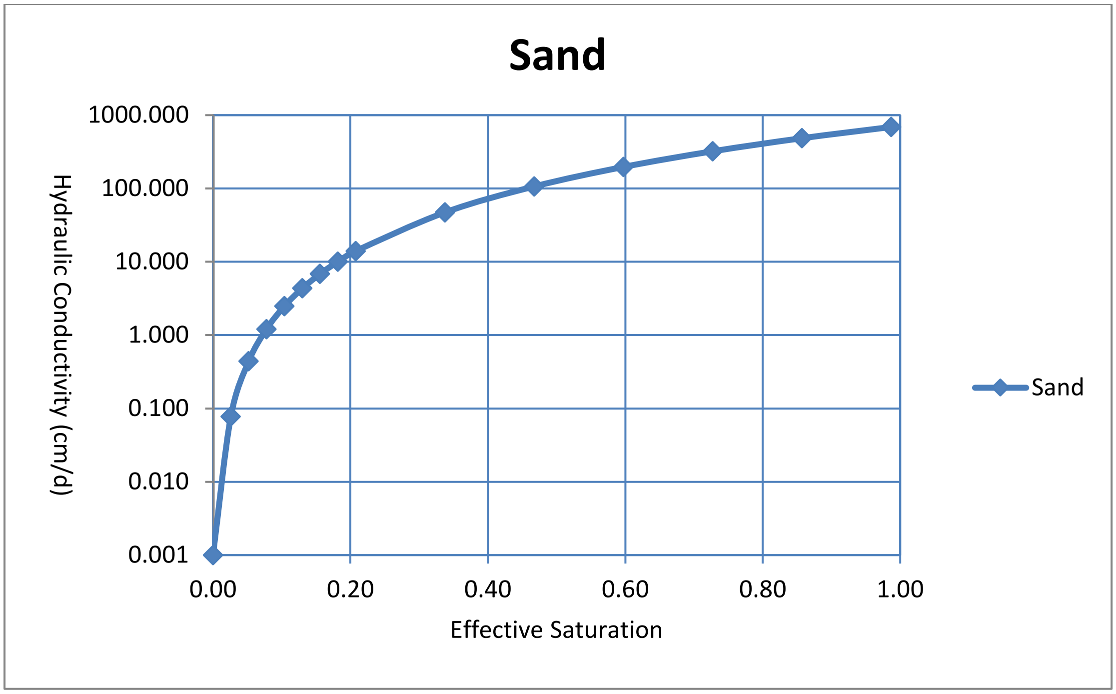


Figure 4: Sand characteristic curve.

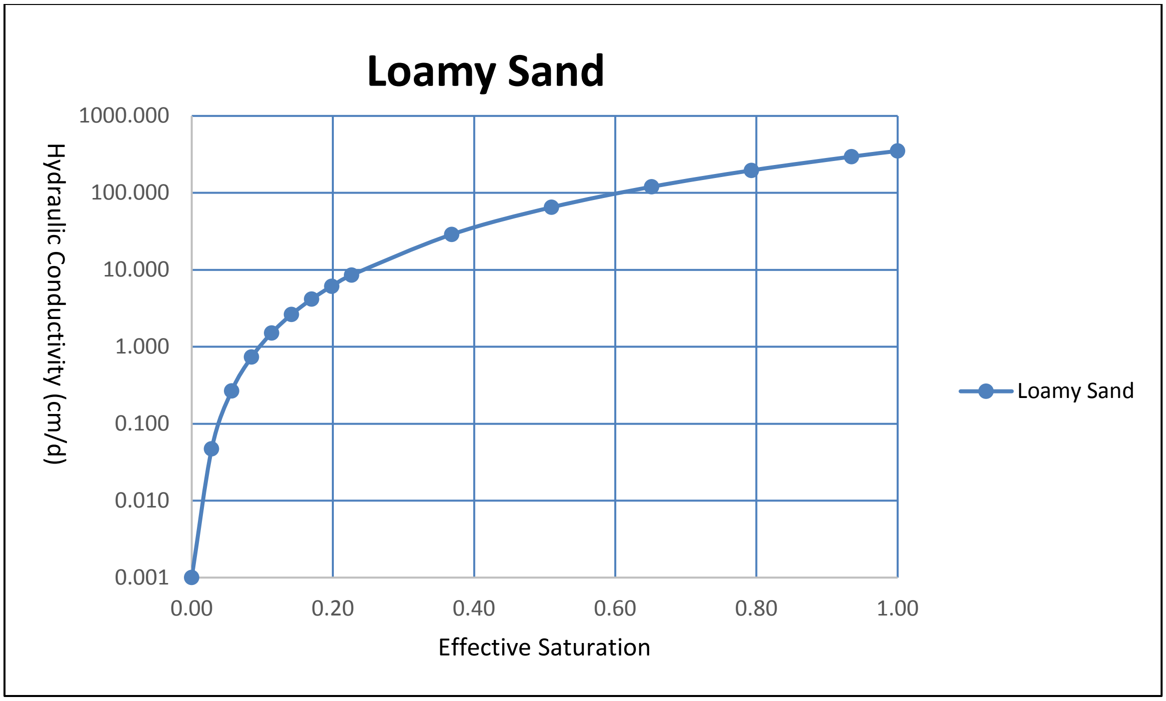


Figure 5: Loamy sand characteristic curve.

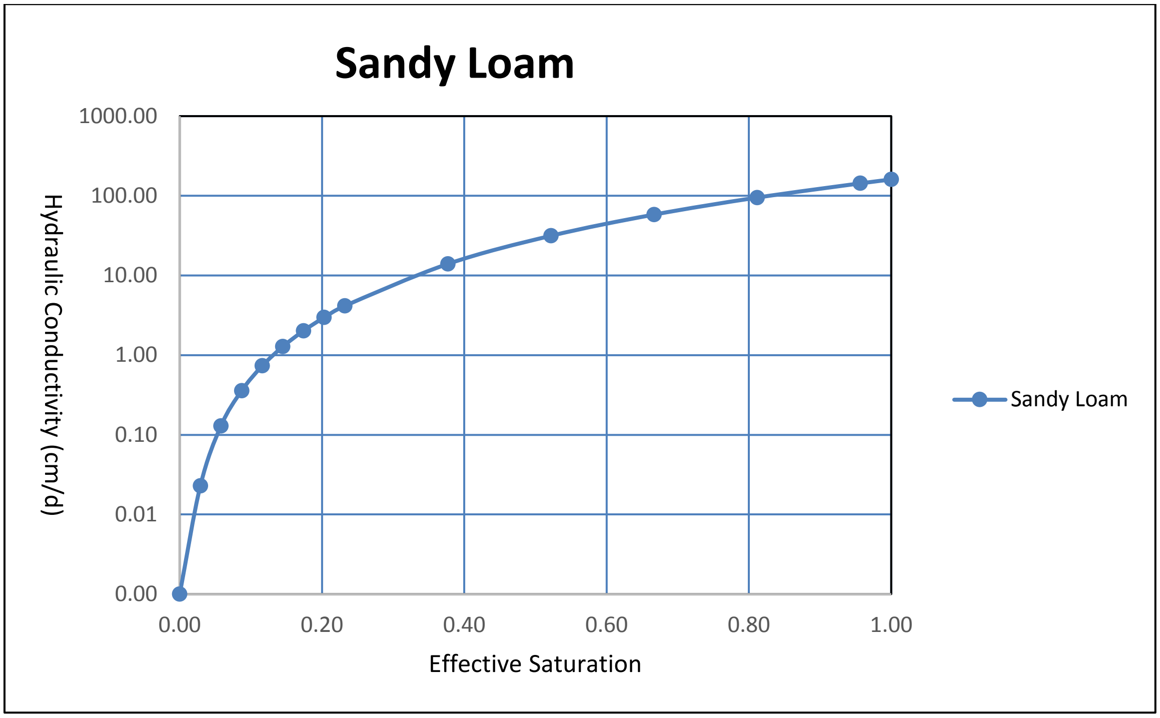


Figure 6: Sandy loam characteristic curve.

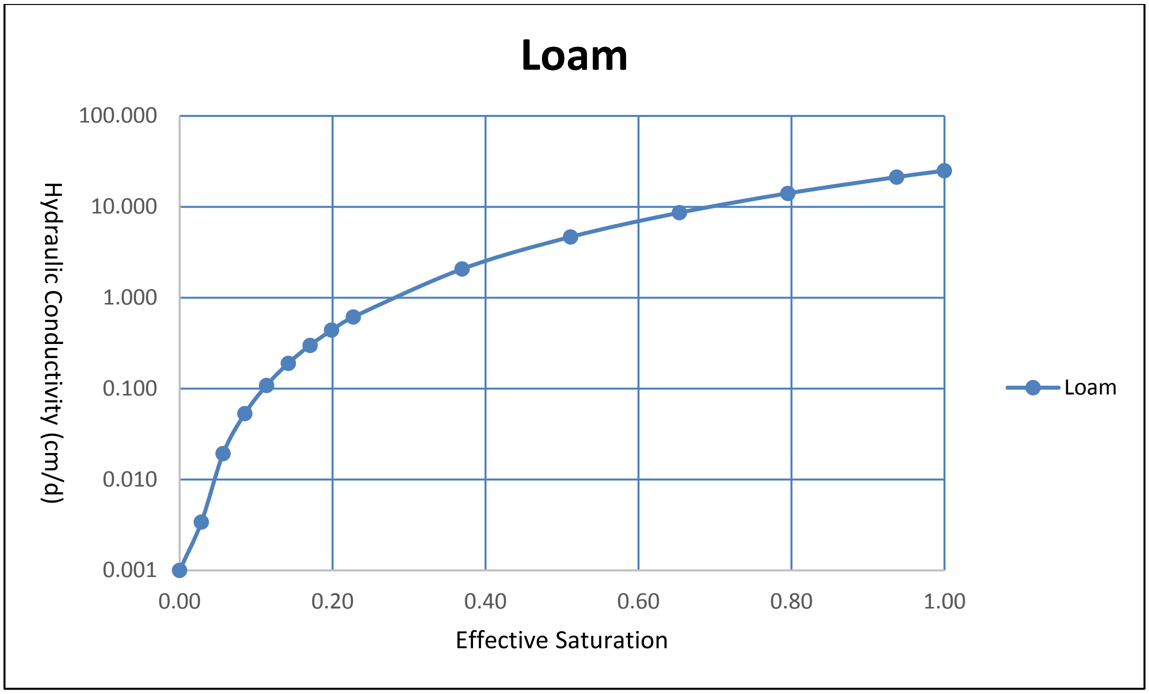


Figure 7: Loam characteristic curve.

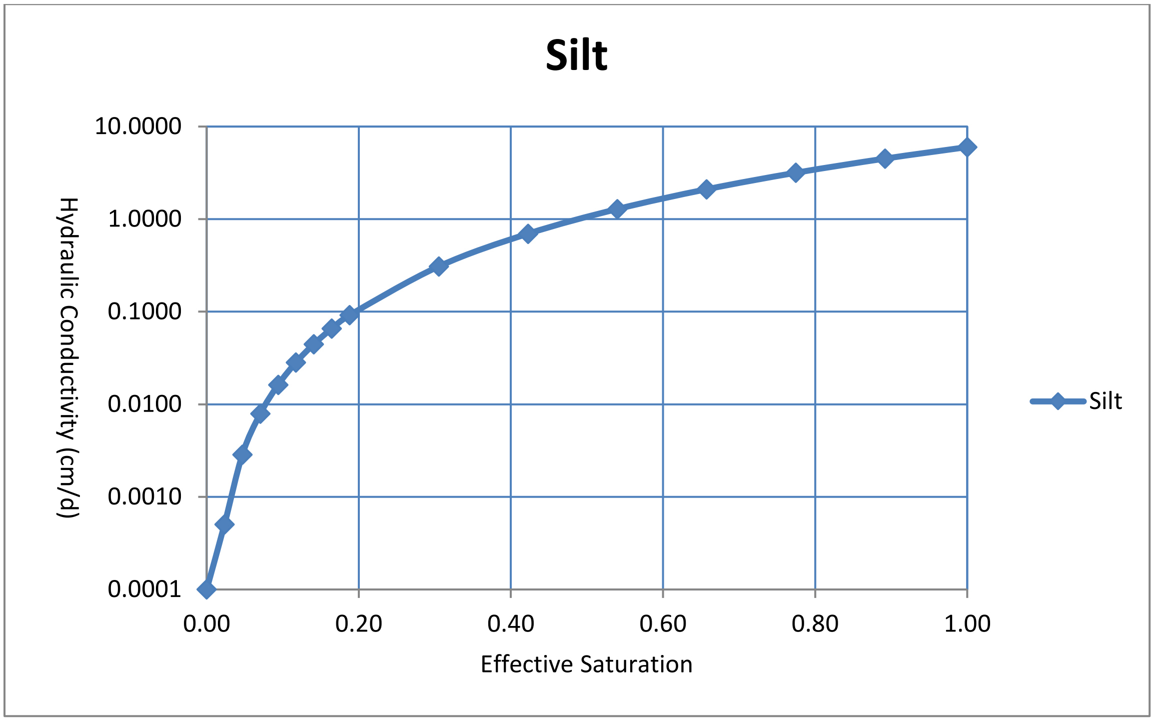


Figure 8: Silt characteristic curve.

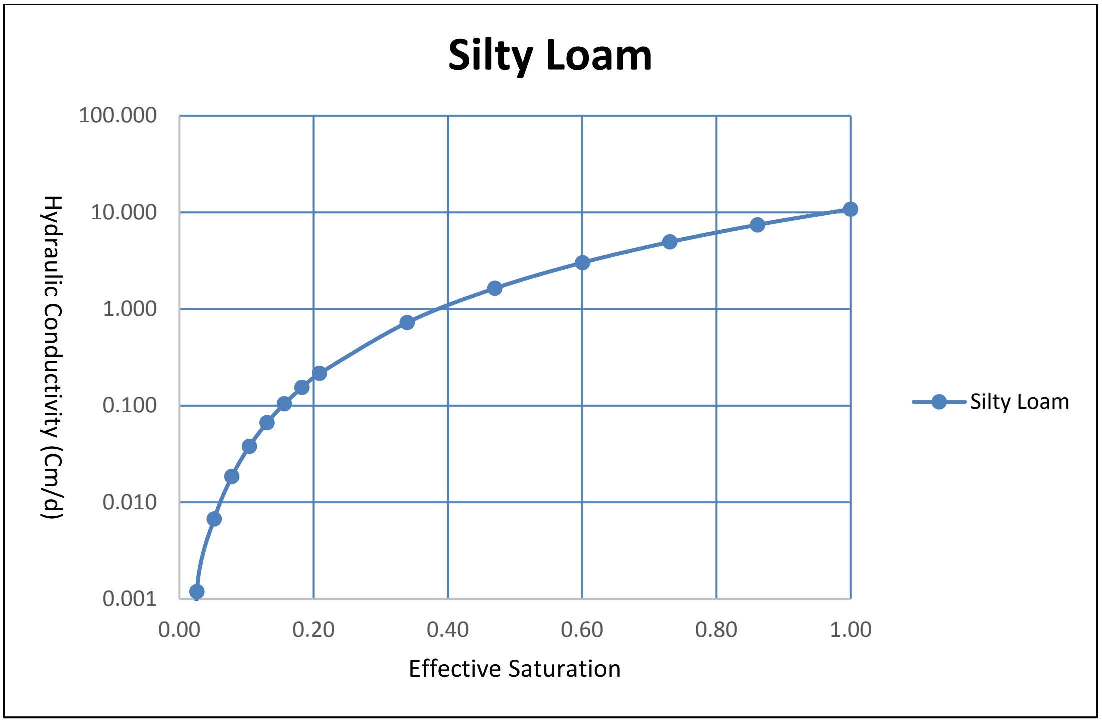


Figure 9: Silty loam characteristic curve.

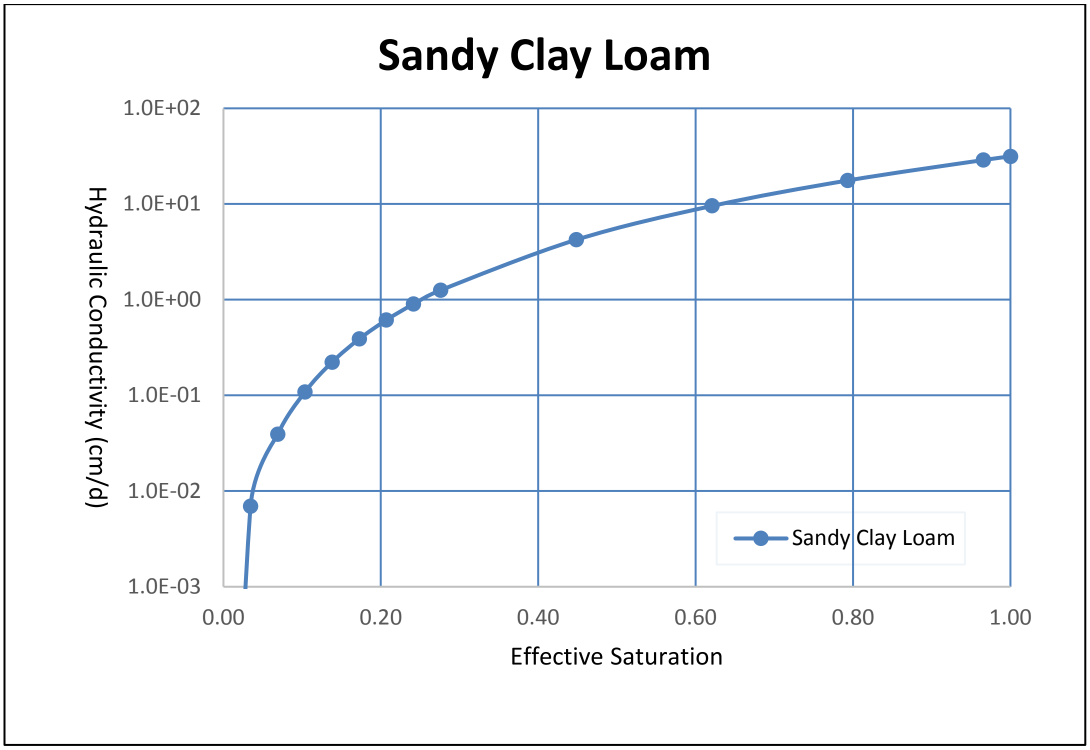


Figure 10: Sandy clay loam characteristic curve.

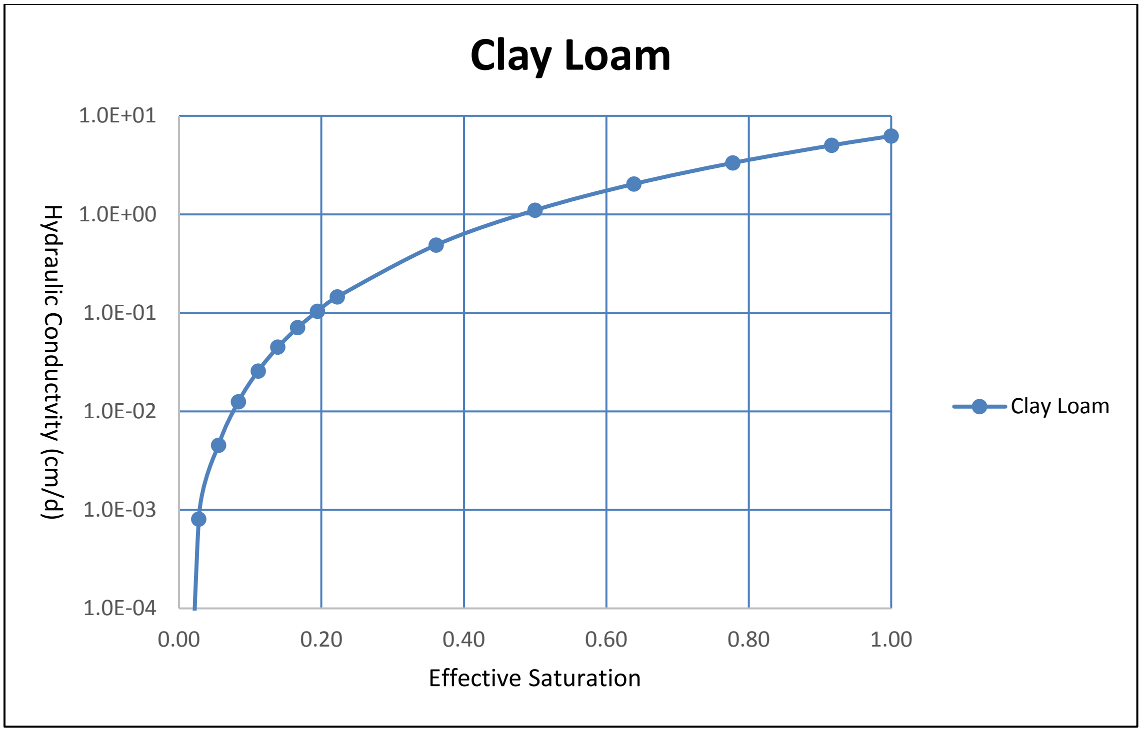


Figure 11: Clay loam characteristic curve.

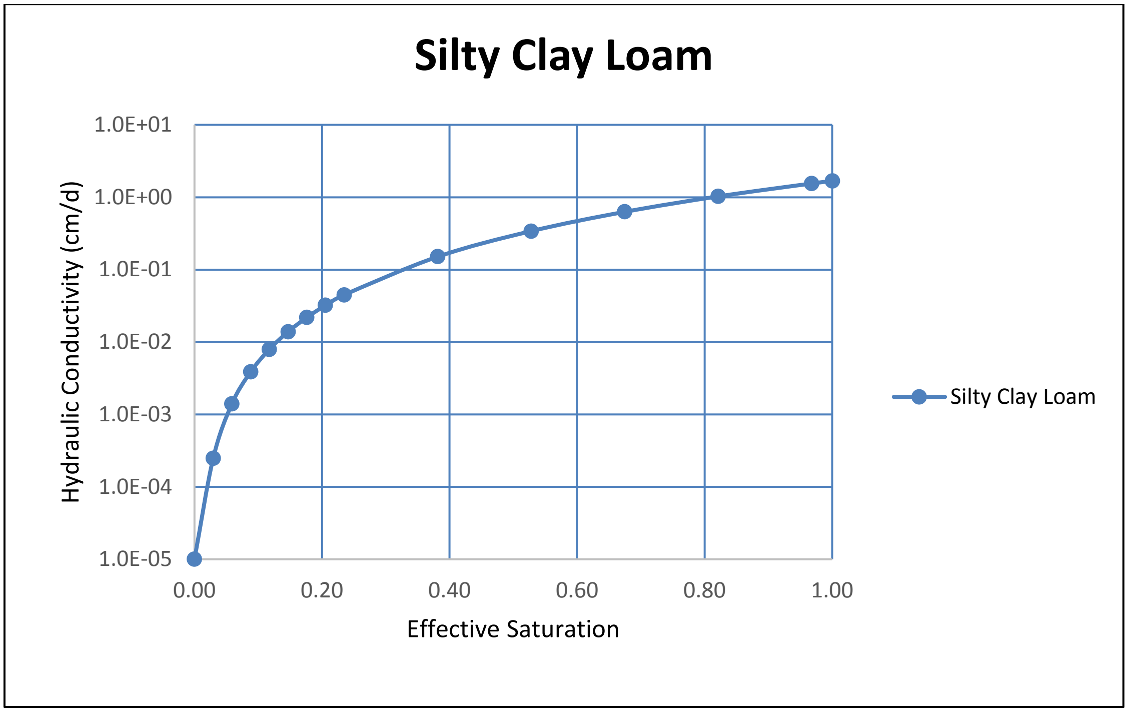


Figure 12: Silty clay loam characteristic curve.

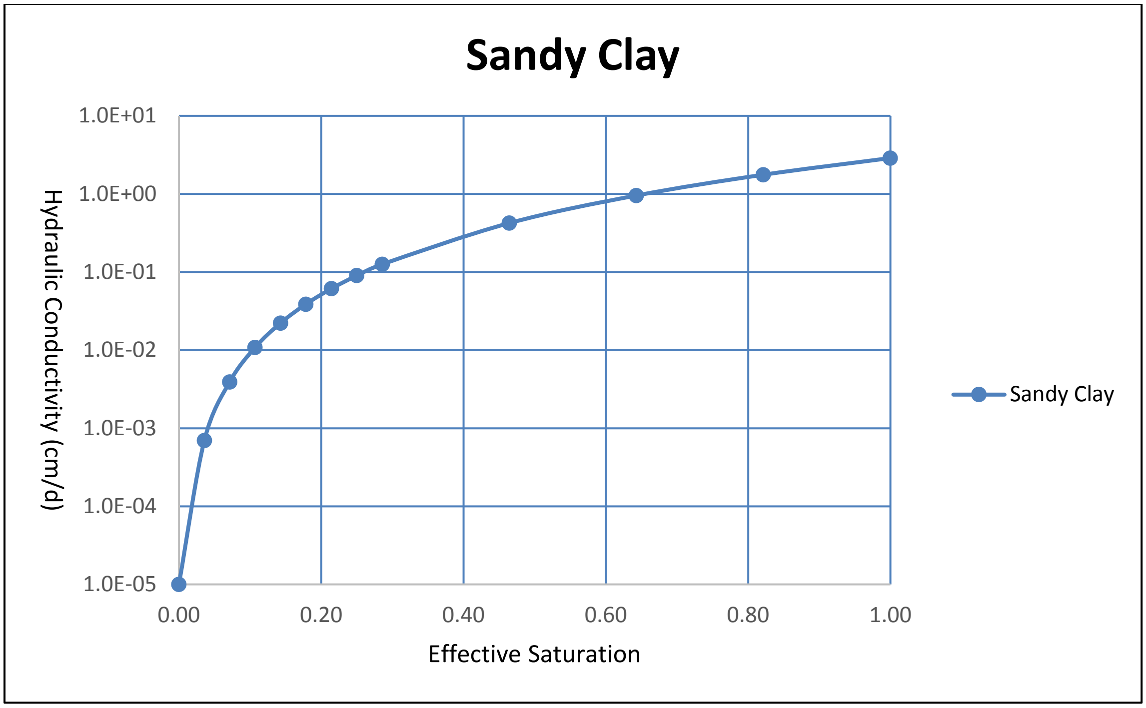


Figure 13: Sandy clay characteristic curve.

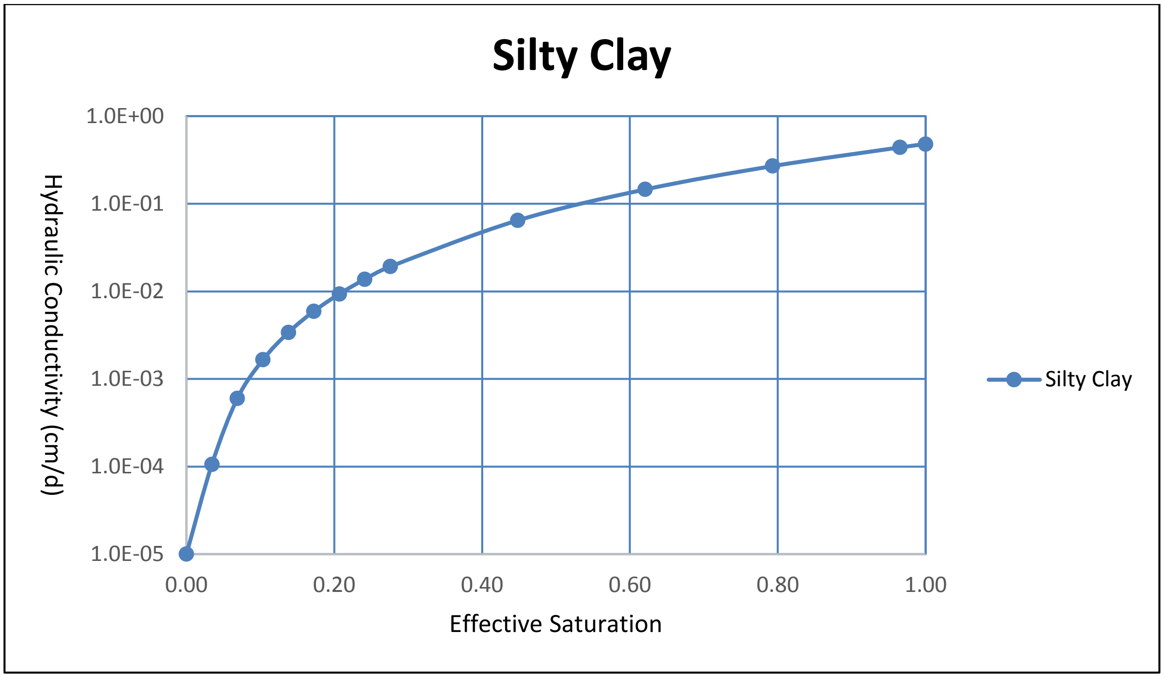


Figure 14: Silty clay characteristic curve.

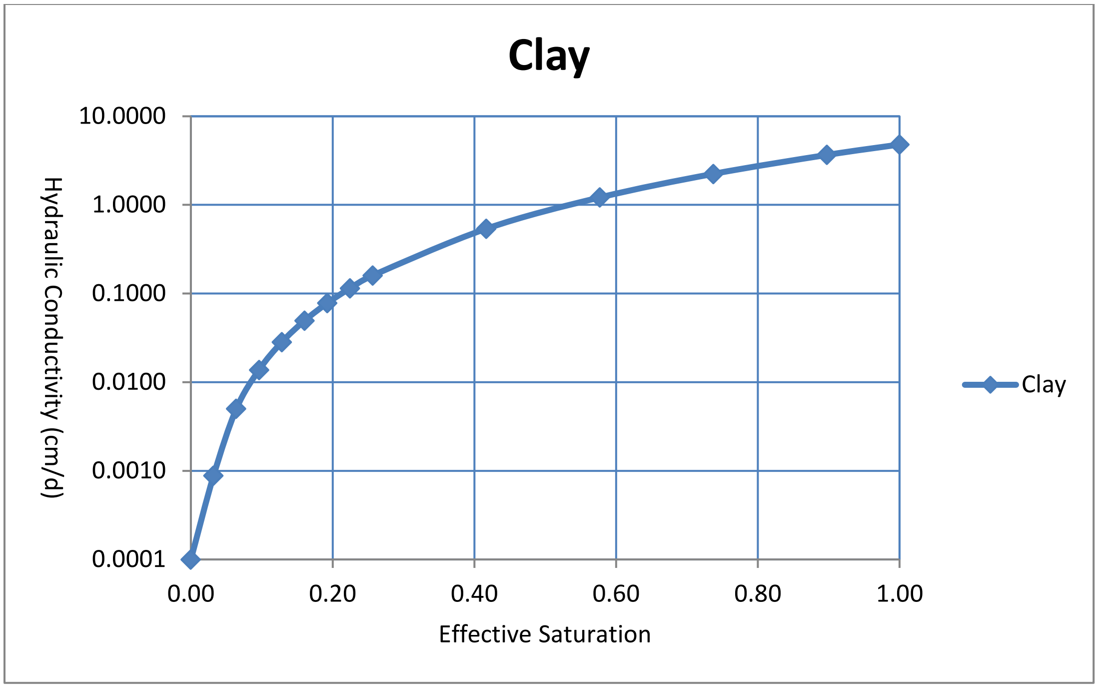


Figure 15: Clay characteristic curve**.**

Table 1: Soil water retention and hydraulic conductivity parameters (Carsel and Parrish, 1988)

Texture	**θr**	**θs**	**α (1/cm)**	**n**	**Ks (cm/d)**
Sand	0.045	0.43	0.145	2.68	712.8
Loamy Sand	0.057	0.41	0.124	2.28	350.2
Sandy Loam	0.065	0.41	0.075	1.89	160.1
Loam	0.078	0.43	0.036	1.56	24.96
Silt	0.034	0.46	0.016	1.37	6
Silty Loam	0.067	0.45	0.02	1.41	10.8
Sand Clay Loam	0.1	0.39	0.059	1.48	31.44
Clay Loam	0.05	0.41	0.019	1.31	6.24
Silty Clay Loam	0.089	0.43	0.01	1.23	1.68
Sandy Clay	0.1	0.38	0.027	1.23	2.88
Silty Clay	0.07	0.36	0.005	1.09	0.48
Clay	0.068	0.38	0.008	1.09	4.8

References

Carsel R.F. and R.S. Parrish. (1988). Developing joint probability distributions of soil water retention characteristics. *Water Resources Research, 24*, 755-769.

van Genuchten M. Th., Leij, F.J., and Yates, S.R. (1991). *The RETC code for quantifying the hydraulic functions of unsaturated soils* (EPA/600/2-91/065). Ada, OK: United States Environmental Protection Agency. Retrieved from: http://www.pc-progress.com/Documents/programs/retc.pdf

FEMA. (2010). *Guidelines for estimation of percolation loss for NFIP studies*. Department of Homeland Security: Federal Emergency Management Agency. Retrieved from: www.fema.gov/media-library/assets/documents/18299

Jury, W.A. and Horton, R. (2004). *Soil physics* (Sixth Ed.). New Jersey: John Wiley and Sons Inc,

This page left intentionally blank.

Appendix 2:
Example Groundwater Travel Time Calculation

Approach

Estimating the travel time from the source to a down-gradient well should generally be based on site-specific data that includes hydraulic conductivity tests and measured groundwater gradients. These estimates will usually be made at sites where the wells are very close to the source. Therefore, a simplified analysis that does not incorporate chemical retardation is typically appropriate for this purpose.

When an evaluation of chemical retardation is <u>not</u> necessary, groundwater velocity can be determined using the following equation:

$$V_{gw} = \frac{(K)(i)(U)}{n}$$

Where:

V_{gw}= seepage velocity (*ft/day*)
K = hydraulic conductivity (*cm/sec*)
i = hydraulic gradient (unitless)
U = unit conversion factor = $2834.646 \ \frac{ft/_{day}}{cm/_{sec}}$
n = porosity

<u>Example:</u>

In this example, the average hydraulic conductivity is 1x10^{-5} cm/sec and the measured hydraulic gradient is 0.05. A porosity value of 0.43 is used to be consistent with the provisions contained in WAC 173-340-747(4)(e)(ii) for contaminated soil located in the saturated zone. These input parameters result in a groundwater velocity of 0.0033 feet/day or 1.2 feet/year as shown below.

$$V_{gw} = \frac{(10^{-5}\ {cm}/_{s})(0.05)\left(2834.646\ \frac{ft/_{day}}{cm/_{sec}}\right)}{(0.43)} = 0.0033\ {ft}/_{day}$$

The travel time from the source of the contamination in the saturated zone to the closest down gradient monitoring well is:

$$t = \frac{d}{V_{gw}}$$

Where:

$t =$ travel time in days
$d =$ distance in feet from source to well
V_{gw}= seepage velocity (*ft/day*)

If the well is located 15 feet from the source, the estimated travel time would be approximately 12.5 years.

$$t = \frac{(15\, ft)}{\left(0.0033\ {}^{ft}/_{day}\right)} = 4551\ days\ or\ 12.5\ years$$

If the groundwater became impacted more than 12.5 years ago, and if sufficient sampling has been completed, then the empirical demonstration has been made.