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**APPENDIX 16**  
**Free-product recovery of petroleum hydrocarbon liquids**

# **FREE-PRODUCT RECOVERY OF PETROLEUM HYDROCARBON LIQUIDS**

**Health and Environmental Sciences Department**

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## SECTION 4 – FREE-PRODUCT RECOVERY TECHNOLOGY

This section provides an overview of free-product recovery (FPR) technology. The five different technologies discussed are the most widely used in practice. They include interceptor trenches, skimming wells, single pump wells, dual pump wells and vacuum-enhanced recovery wells. The attributes and limitations of the various methods are discussed.

Some of the FPR methods can be used in conjunction with other technologies for subsurface remediation. For example, FPR wells are often used in conjunction with soil vapor extraction. EPA (1996) suggests a method of vapor extraction and groundwater extraction (VE/GE or “veggie”) to decrease residual LNAPL mass.

The final section of the chapter provides a summary of the different FPR technologies and lists criteria useful for selecting a technology that may be appropriate for a given site.

### 4.1 Interceptor Trenches

Interceptor trenches are designed to control the migration of free product and dissolved hydrocarbons in groundwater by controlling and intercepting water table gradients (Avci *et al.*, 1992). Interceptor trenches act in much the same way as do extraction wells, except they tend to draw water toward a linear source, rather than radially toward a well. Trenches are normally placed hydraulically downgradient from the LNAPL release. While trenches can be installed to depths greater than 50 feet, they are usually installed to depths ranging from 20 to 30 feet.

Interceptor trenches create a linear region of very high permeability within an aquifer. This high-permeable zone connects to a sump or well. Because the trench has very high permeability, the trench tends to stay in close hydraulic communication with the sump, meaning that the trench quickly equilibrates as fluids are pumped from the sump. Manipulating fluid levels in the trench can

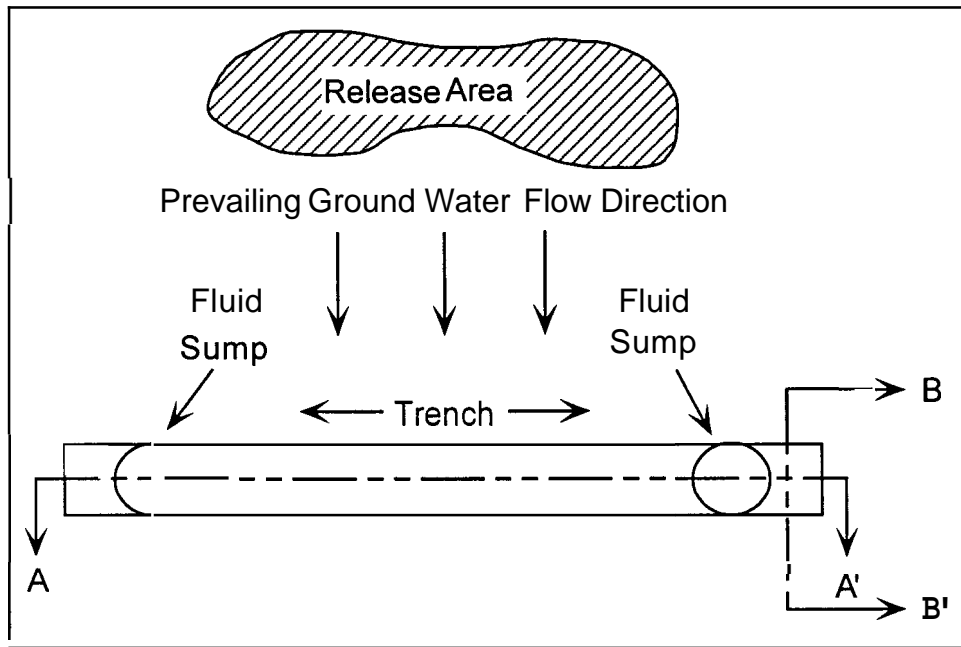
influence the water table in the aquifer so that the gradient points toward the interceptor trench.

A skimmer or single- or dual-phase recovery techniques can be used in trenches. Figure 4.1.1 shows a plan view of a dual-phase recovery interceptor trench. Also notice the two section lines that are used for following figures. Section A-A' from Figure 4.1.1 is shown in Figure 4.1.2, a vertical cross-section along the long axis of the well. Notice the dual LNAPL and water recovery pumps located in the sumps. Figure 4.1.3 depicts section B'-B in Figure 4.1.1, a vertical cross section through the short axis of the trench. Both water and free product tend to flow into the trench due to the pumping within the fluid sump.

Figure 4.1.1 portrays a trench where fluids can come from either side. Other possible configurations may use an impermeable barrier on the down stream face of the interceptor trench. A barrier would significantly reduce the amount of fluid that passes through the trench and downstream. This configuration is used when it is critical to contain the hydrocarbon transport (API, 1996). If this method is employed, it is important that fluids do not accumulate in the trench and eventually flow around the ends of the trench. This is accomplished by balancing the pumping in the sumps with the fluid flow into the trench.

#### **4.1.1 Advantages and Limitations**

The advantages of trench FPR systems include the following: (1) The recovery system consists of a continuous line of interception. LNAPL cannot migrate past the trench unless the trench production system fails. **(2)** Because it provides a continuous line of LNAPL-interception, a trench recovery system is very good for large new releases. Large releases will migrate along the capillary fringe for considerable distances before the free-phase becomes trapped and significant amounts of the release have dissolved into the water-phase. (3) Shallow trenches are easy to construct.

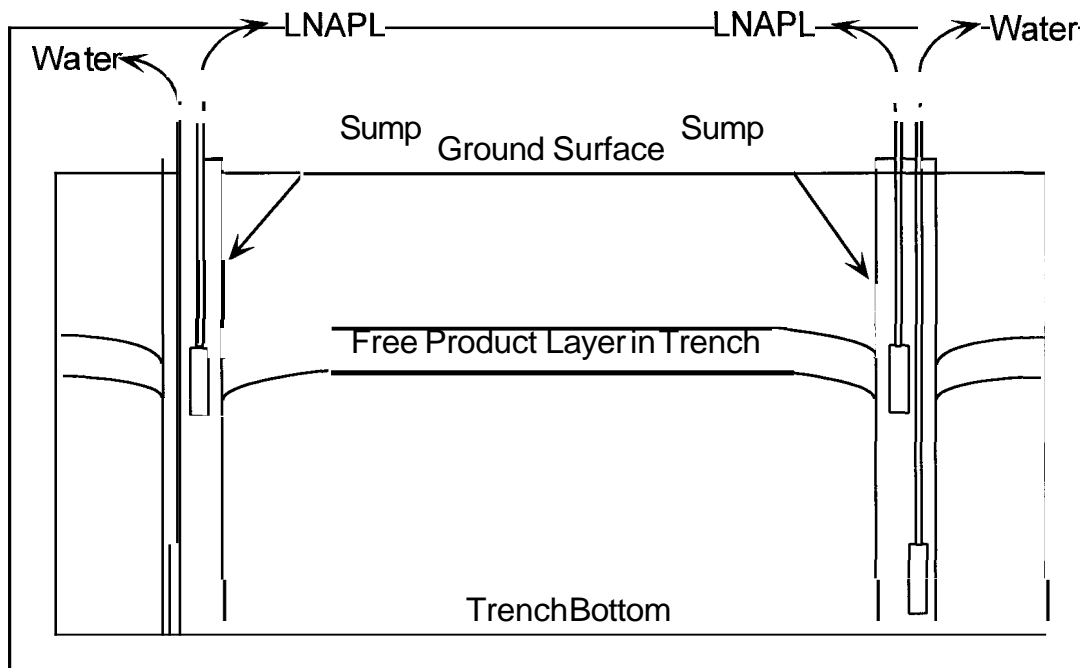


**Figure 4.1.1** Plan and Section View for Example Trench

There are a number of limitations to trench FPR systems. (1) Their effectiveness is limited in low permeability soils. (2) Trenches may be difficult to site around buildings and buried utilities. (3) It is increasingly more difficult to maintain the stability of the trench walls with depth. (4) Trench construction may provide the potential for worker exposure, and the excavated soil may present disposal problems. (5) Depending on their depth and length, trenches can be very expensive.

#### **4.1.2 Common Site Conditions for Use**

API (1996) suggests the following site conditions for use: (1) A heterogeneous earth material in which fluid migration is through randomly occurring zones such as discontinuous layers of sand. (2) Areas with a shallow water table (10 to 15 feet) and relatively low hydraulic conductivity where interception of LNAPL in trenches or horizontal wells is a more practical alternative than numerous closely spaced recovery wells. (3) Locations where the saturated thickness of the aquifer is small and wells would be ineffective. Examples include zones along rivers that may be dry during parts of the year.

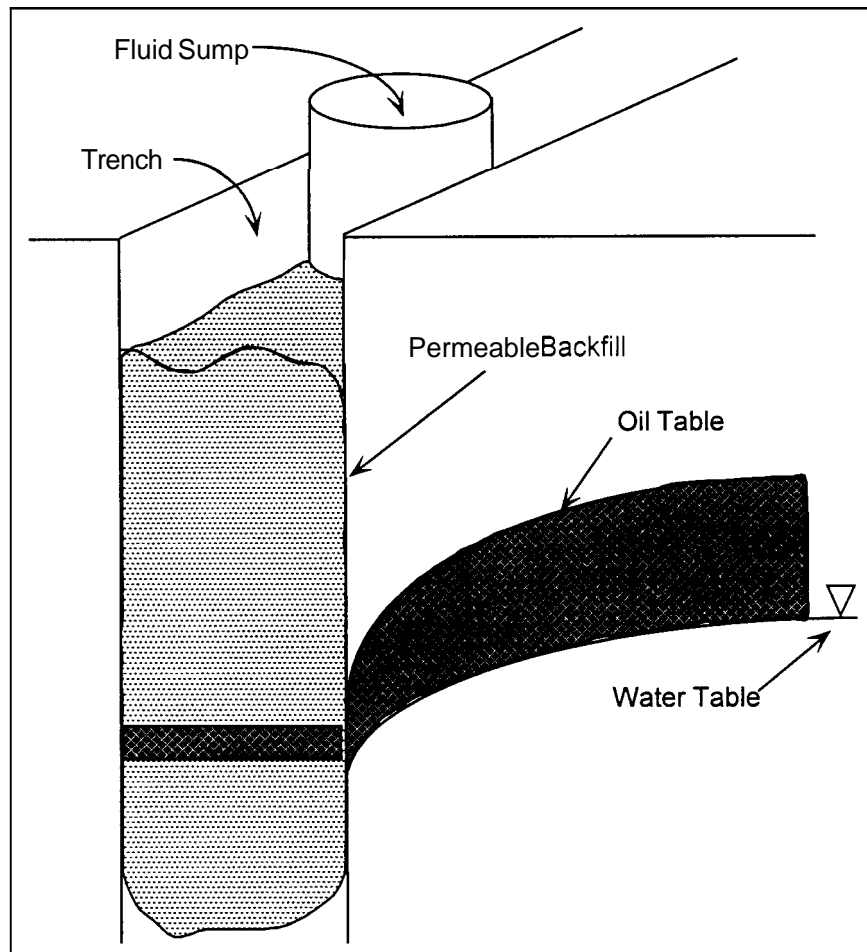


**Figure 4.1.2** Vertical Cross Section of Section A-A' of Figure 4.1.1

Noel and Ebbott (1991) suggest that large spills in the near subsurface that are quickly attended to may significantly benefit from trench type FPR. In their study nearly 70 % of the free LNAPL was recovered from the release site. O'Connor *et al.* (1984) described interceptor trenches that were used to stop the advance of free hydrocarbon offsite. Avci *et al.* (1992) described interceptor trenches that were used to stop the advance of free hydrocarbon into a lake.

#### **4.1.3 Operation and Maintenance**

Interceptor trenches are normally installed with either trenching machines or through a slurry trench method (API, 1996). Other methods of installation include braced excavations and driven sheet pile excavations (Navon, 1997). Trenching machines normally use a chain driven digging machine, which excavates a narrow (1 to 2 feet) trench. Trenching machines are normally limited to depths less than 15 to 20 feet (4 to 6 m), depending on soil stability and machinery (API, 1996).



**Figure 4.1.3** Vertical Cross Section of Section B'-B of Figure 4.1.1

The slurry trench method employs a conventional backhoe with an extended arm. Trenches can reach depths of 90 feet, but FPR trenches usually tend to be limited to a range of 15 to 20 ft. Use of special equipment such as a clamshell allows for deeper excavations. During excavation for high permeability trenches, a biodegradable slurry may be added to the trench to hold the excavation open by hydrostatic forces (Daniel, 1993).

After construction, the trench will be operated to optimize FPR. Most trench designs incorporate the pumping of both oil and water. Maintenance during this period will closely resemble the maintenance of the single- or dual-pump techniques that are discussed in Section 4.3.

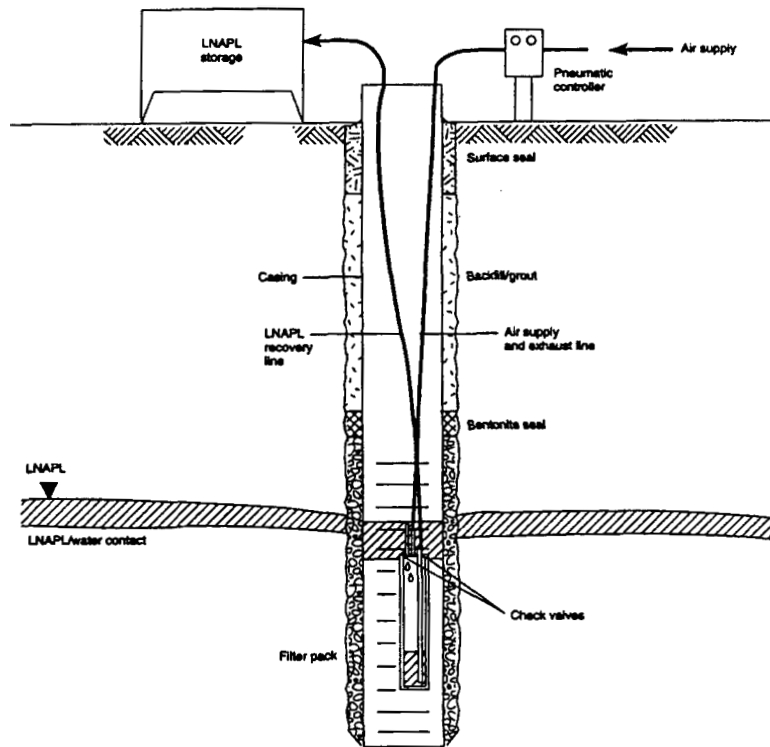
During construction, oil-impacted soil and possibly slurry may need to be treated or disposed. In some instances a biodegradable slurry has been accepted by publicly owned treatment works (POW) (Day, 1990). In another case the slurry was moved to a tank where it was degraded and then released to a storm sewer (Hanford and Day, 1988). The operator of the local POW should be consulted for further information. If oil-impacted soil is excavated, the cost for its appropriate treatment or disposal must be considered. Fluids pumped from the trench during operation should be handled in much the same manner as for the single- or dual-pump techniques discussed in Section 4.3.

## **4.2 Skimmer Well Free-Product Removal Systems**

Skimmer pump systems are useful when the remediation goal is to collect free product with essentially no water, and when the recovery rates are not expected to be large. Skimmer pumps may be used in wells or trenches. They are often used as an initial response action where free product has entered an open excavation.

A typical skimmer well system is shown in Figure 4.2.1. This figure shows a pneumatic skimming pump suspended in a well. An air supply forces the captured hydrocarbon from the pump up to the ground surface where it is stored for reclamation.

Skimming systems are available in a variety of forms. (1) Pneumatic skimming systems with a top intake that allows skimming of fluids from the LNAPL/water interface. This is the system shown in Figure 4.2.1. (2) Pneumatic skimming systems with a density-sensitive float valve that disallows passing of water before the valve seats. (3) Floating or depth-controlled skimming systems with conductivity sensors that activate the surface-mounted pump when LNAPL has accumulated to sufficient thickness in the well or trench. (4) Filter skimming systems with a filter material that preferentially passes hydrocarbon, including absorbent skimming systems that remove hydrocarbon via a recirculating belt. (API, 1996). Skimmer pumps are discussed in more detail below.



**Figure 4.2.1** Pneumatic Pump Skimming System (from API, 1996)

#### **4.2.1 Advantages and Limitations**

The primary advantage to skimmer well systems is that little water is produced. This becomes important when water discharge limitations exist. They also provide for simple operation and maintenance requirements, and they are inexpensive.

The main limitation to the use of skimmer pumps is that they have a small area of influence. They provide no hydraulic control to limit migration of either the dissolved plume or free-product plume, unless the wells are placed in a trench and have sufficient capacity to remove hydrocarbon liquids at their rate of entry to the trench.

#### **4.2.2 Common Site Conditions for Use**

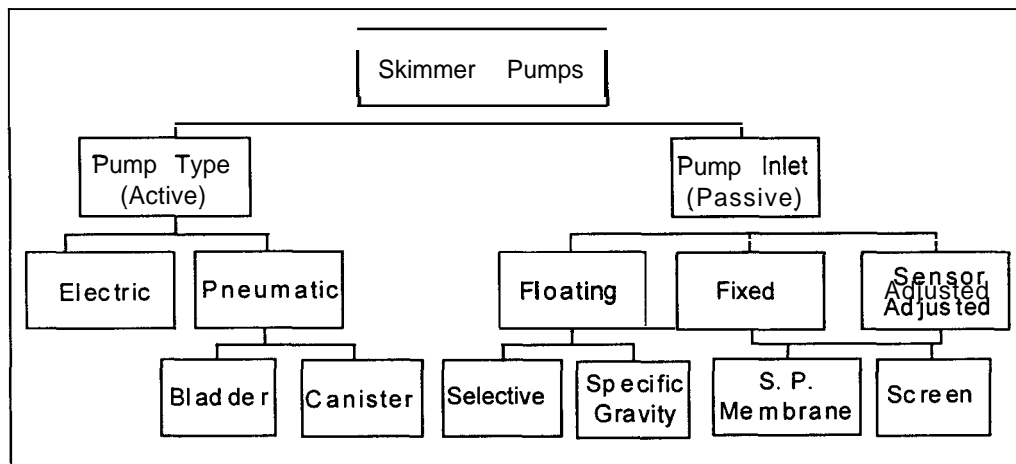
Skimmer well systems may be used in relatively permeable hydrogeologic environments. The hydraulic conductivity should be greater than  $10^{-4}$  cm/sec to

ensure a sufficient influx of LNAPL to the skimmer pump (EPA, 1996). Because of their low capacity, they are used when water table depression is not critical to control migration or enhance recovery. They are also used when produced-fluid handling, treatment and disposal capabilities are limited, such as in emergency response situations. Skimmer pumps may be attached to a float, so they are useful when water table fluctuations may interfere with discharge from a fixed pump intake.

### **.3 Operation and Maintenance**

Skimmer pumps come in many different sizes and configurations. They may be discussed from two different points of view. Figure 4.2.2 outlines the different skimmer-pump types for discussion. Pumps contain two basic parts. The first is the active fluid displacement mechanism of the pump, and second is the pump inlet or the passive portion of the pump. The active side of the pump is of two types: electric and pneumatic. Pneumatic pumps can be of two types: bladder and canister. There are three passive inlet systems: floating, fixed and sensor adjusted. Floating passive skimmers can be either selective or specific gravity driven. Fixed and sensor adjusted skimmers can be of two types: selectively permeable membrane and screened. Bladder pumps use compressed air to inflate a bladder and force liquid toward the surface. Canister pumps force air and oil toward the surface together. Floating intakes attached to vertical guide rods ride on top of the water or LNAPL in the well. Fixed intakes are used for non-fluctuating water tables. Sensor adjusted intakes use a piston to keep the inlet in the LNAPL layer as the oil and water table changes. Screened pump inlets are used where large volumes of oil are to be pumped. Selective (semi permeable membrane) inlets are selectively permeable for certain liquids. Specific gravity skimmers use a float that sinks in one phase but floats in the second phase. (Breslin, 1996).

Operation and maintenance requirements for skimmer well systems are fairly routine. Monitoring of product thickness and levels in the skimmer wells or a sump and in monitoring wells is necessary. Inspection of electrical and mechanical components should be scheduled on a regular basis. Intake screens or selective membranes may require periodic cleaning to eliminate biofouling.



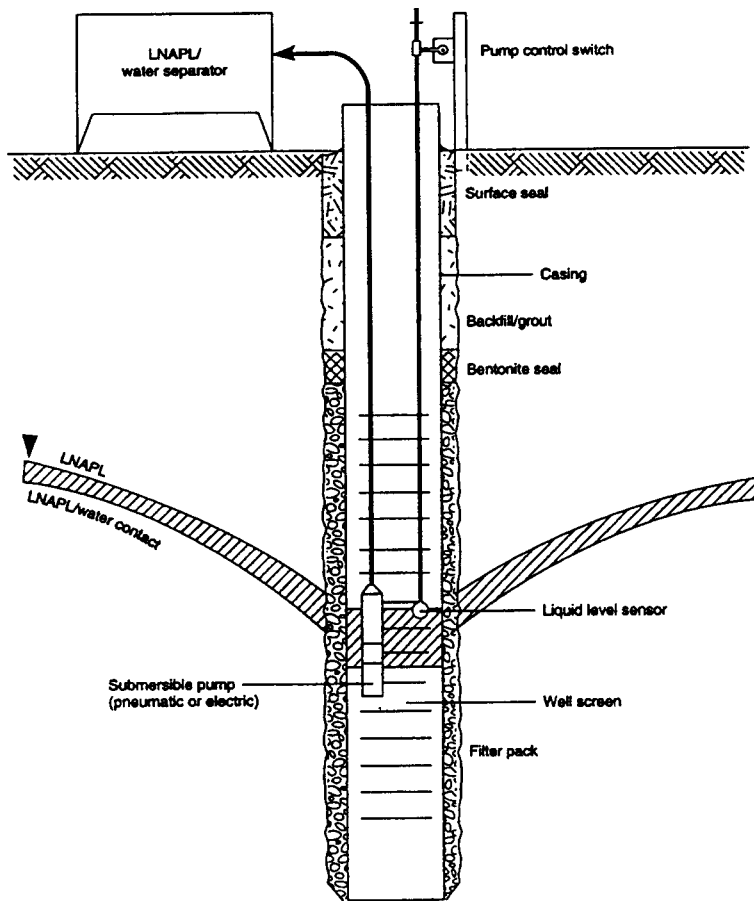
**Figure 4.2.2** Skimmer Well Pump Types (modified from Breslin, 1996)

### 4.3 Single- and Dual-Pump Recovery Systems

Single- and dual-pump recovery systems use water table depression to expand their area of influence. Both water and LNAPL may be produced at rates much greater than from skimmer wells. These larger production rates create a cone of depression that draws LNAPL towards the well, allowing an increased recovery rate compared to skimmer systems.

Single-pump recovery systems use a single-pump intake within a recovery well. The single pumps will, in some cases, pump both water and LNAPL, and, in other cases, just pump the free hydrocarbon that enters the well. A typical single pump system is shown in Figure 4.3.1.

Dual-pump recovery systems use two pumps in a common well. One pump draws groundwater creating a "bowl" or cone of depression. This drawdown sets the "floating" LNAPL in motion toward the well and ultimately the second pump intake. A typical dual-pump recovery system is shown in Figure 4.3.2. For both single- and dual-pump systems, as the drawdown cone deepens, the maximum LNAPL production increases. However, as the water table is drawn down, LNAPL is left behind, or "smeared" into previously non-impacted areas.



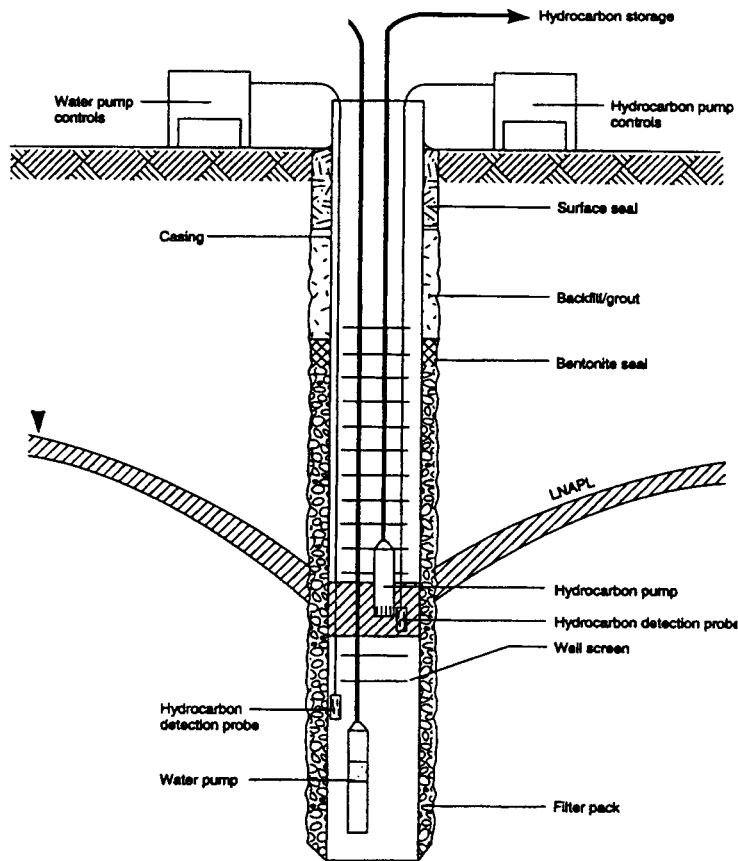
**Figure 4.3.1** Single-Pump Recovery System (from API, 1996)

One of the most important considerations when using pumping as the means for FPR is to have wells perforated or “screened” over the section of the aquifer where the oil is most likely to be during the entire recovery period. Water table drawdown and fluctuations complicate the process of choosing the correct screened interval.

#### **4.3.1 Advantages and Limitations**

Some of the primary advantages of single- and dual-pump recovery systems include the following: (1) Single- and dual-pump recovery systems installed in wells have relatively low cost compared with some other methods (e.g., vacuum-enhanced recovery). (2) They are versatile, being able to work within shallow formations or at depth. (3) They may cause fairly rapid removal of free product.

(4) Wells are easily adapted to variable water table elevations. (5) Unlike trenches, recovery wells work well in congested industrial sites. (6) Wells can be placed so they do not disturb adjacent operations. (7) Recovery wells occupy a small area at the ground surface. (8) Pumping wells can provide hydraulic control of offsite groundwater and LNAPL migration.



**Figure 4.3.2** Dual-Pump Recovery System (from API, 1996)

The limitations of single- and dual-pump recovery wells are as follows: (1) They may have maintenance problems including biofouling and failure of mechanical parts. (2) As the fluid elevations move up or down the well inlets must be moved in order to maximize LNAPL recovery. (3) For single-pump systems an API separator is usually required to separate oil and water for treatment and disposal. (4) Produced water may require treatment before disposal. (5) LNAPL must be recycled or disposed of properly. (6) A considerable amount of LNAPL may be

left within the formation as smeared residual. (7) Single-pump systems can increase dissolved hydrocarbon concentration in the recovered water and therefore increase the treatment costs.

#### **4.3.2 Common Site Conditions for Use**

Nearly all site conditions are adequate for application of single- and dual-pump recovery technologies. Aquifer hydraulic conductivities should generally be greater than about  $10^{-6}$  cm/sec for pumping to be applied. The approach presented in Section 5 will help evaluate the practical application of single- and dual-pump technologies. Though it is not a limitation, depth to the water table is normally greater than five feet.

Single-pump systems are normally limited to areas of low hydraulic conductivity where the total liquid production is small (API, 1996). API suggests that single-pump recovery methods should be used where water production rates are small to moderate (5 to 20 gpm or 960 to 3850 ft<sup>3</sup>/day).

Dual-pump systems are normally used under the following conditions. (1) When water table depression will increase recovery and achieve hydraulic control of the LNAPL plume. (2) When hydraulic conductivity and saturated thickness are moderate to large. (3) When oil/water separation facilities are impractical for treating large volumes of produced water. (API, 1996).

#### **4.3.3 Operation and Maintenance**

Hollow stem auger and direct mud rotary are the two current methods of choice for drilling FPR wells (Daniel, 1993). For wells less than 50 m (165 ft) deep Daniel recommends the use of a hollow stem auger to place a well. This method tends to have less impact on the aquifer and provides an easier way to deal with soil cuttings than does the mud rotary technique. The filter pack design is a key design variable when considering the placement of a FPR well (Daniels, 1996). Some authors suggest that the filter pack material is crucial to efficiently allow free product to flow into a well (see Hampton and Heluvelhorst, 1990).

Single-pump recovery systems can fit into wells as small as two inches in diameter. Dual-pump systems normally require a minimum of a four-inch diameter well. As newer systems are developed it is not impossible to imagine that dual-phase recovery will be available for two-inch diameter wells (Clean Environment Equipment, 1996). Normal pump operation requires a power source. The two most common are either electricity or compressed air.

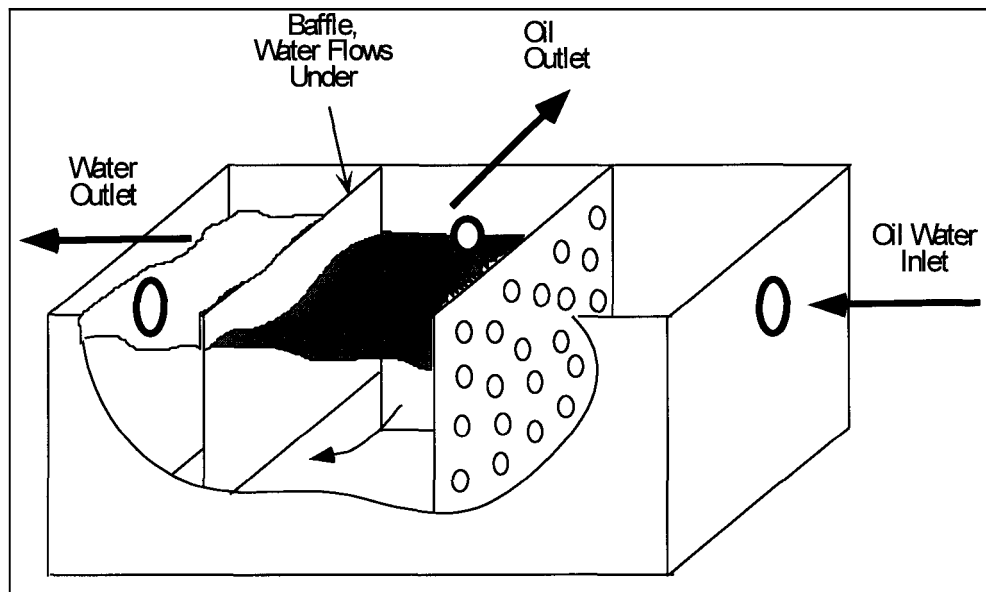
Maintenance for pump systems generally revolves around adjusting the pump inlet heights and to a lesser extent keeping the pump inlet free of debris, precipitates and biomass. Single-pump systems that skim oil are made to float on top of the water table. Single-pump systems that pump both water and oil commonly set the pump inlet at a specific distance below the original LNAPL table. This distance corresponds to a specific water table gradient that will allow the LNAPL to flow more readily toward the well. Until the LNAPL and water table have been drawn down to the pump inlet, only water will be the produced fluid. After the LNAPL and water level have been lowered to the elevation of the pump intake, both water and oil will be produced. If the natural water table drops below the pump inlet, possibly because of seasonal groundwater variation, no production will occur.

Dual-pump systems normally place the water extraction pump intake toward the bottom of the well, and this intake elevation remains constant over the period of FPR operation. Because the water pump is commonly set to a specific flow rate and not a specific head, the LNAPL and water water table will move up or down, primarily because of infiltration. Therefore the LNAPL pump may require an inlet that moves along with the LNAPL and water interface. This is accomplished through constant maintenance or with a pump inlet that can “float.” API (1996) suggests that water-pumping rates should be carefully monitored to allow a constant LNAPL and water table surface in the well.

Typical maintenance problems for single- and dual-pump systems include fouling of the removal system, variable water levels in the wells requiring frequent resetting of the skimmer pump intake, pumping of water rather than hydrocarbon because of misplacement of the pump intake, and biodegradation of hydrocarbon causing clogging of the floating pump intake (Brown and Pollara, 1994).

#### 4.3.4 Separation and Treatment of Extracted Water

Three different fluid streams can be generated by single- and dual-pump systems. In the single-pump system water and hydrocarbon liquids are normally produced at the same time as an emulsion or as a two-phase mixture. This emulsion requires an additional treatment step to separate the water and hydrocarbon liquids. This treatment step is generally provided through use of an API separator (oil/water separator), such as shown in Figure 4.3.3. Oil from the API separator is normally placed in a storage unit for reclamation, or if the reclamation site is close (e.g., at a refinery), the oil can be directly pumped for reclamation. Water from the separator normally requires treatment before disposal. Depending on the extent of dissolved hydrocarbons in the water, treatment can range from simple discharge to a waste water treatment plant (WWTP), or publicly owned treatment works (POTW) facility, to an advanced hydrocarbon removal system.



**Figure 4.3.3** An API Oil/Water Separator

Dual-pump systems will produce two different fluid streams. This type of system may be set-up to skip the API separator step. The oil phase is separated in the well by top-filling pneumatic pumps or selective oil skimming pumps. These specialized pumps have fluid sensors that allow them to exclude nearly all water.

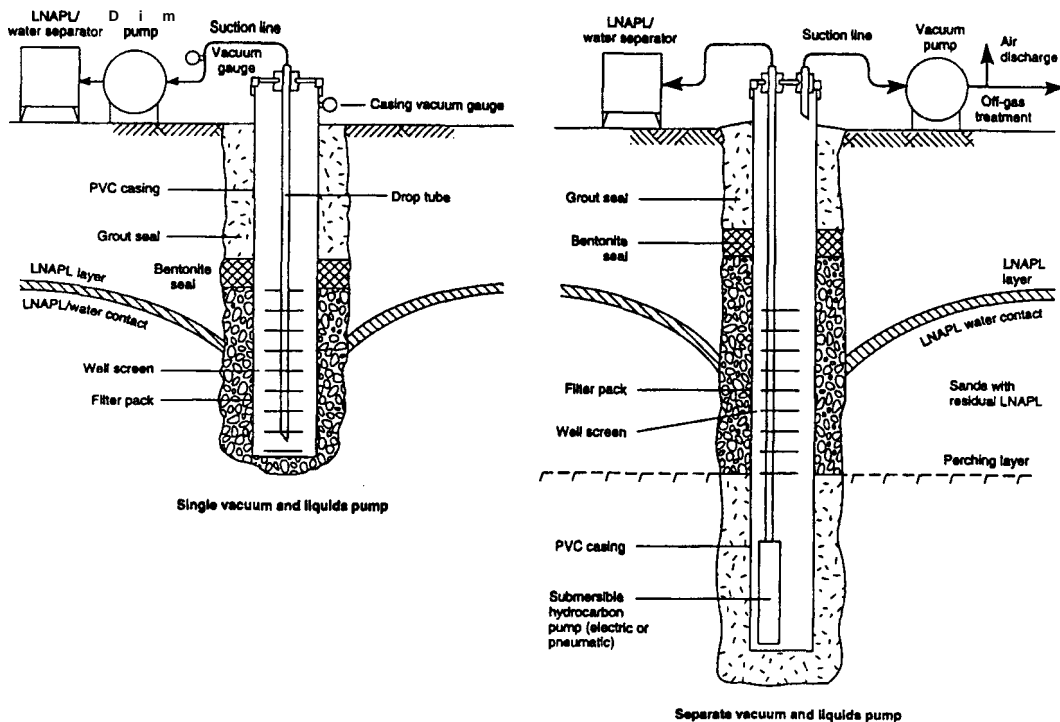
The oil is then sent to storage or directly, via a pipeline, to recycling or reclamation facilities. Water from a dual recovery well is normally pumped from the bottom of the well. Pumping water from the base of the aquifer does two things: (1) It decreases the likelihood of oil being emulsified in the water stream. (2) Water from the base of the aquifer also tends to contain less dissolved hydrocarbon contaminants. Water pumped from the base of the aquifer rarely must go through an API separator and in many cases, requires minimal treatment.

#### **4.4 Vacuum-Enhanced Recovery**

Vacuum-enhanced recovery (VER) can be used to increase the performance of a single- or dual-pump FPR system. A vacuum is applied to a sealed well, where the FPR system resides. VER increases the driving force toward a recovery well by using both gravity and a pressure difference (Nyer *et al.*, 1996). This increased driving force in turn increases the fluid flow toward the well. VER can be used in conjunction with nearly any FPR pumping configuration; however, VER is normally used in conjunction with single-pump techniques (API, 1996). Figure 4.4.1 shows two possible VER configurations. The version on the left uses a suction pump to produce water and oil while applying a vacuum to the well. This type of configuration is normally limited to within 15 feet (Nyer *et al.*, 1996) of the ground surface. The VER system shown on the right of Figure 4.4.1 uses a separate pump to produce fluids while also using a vacuum pump that can be used at greater depths.

##### **4.4.1 Advantages and Limitations**

There are several advantages to vacuum-enhanced recovery systems: (1) They are easy to install. (2) They remain effective when the LNAPL layer thickness is small. (3) They are effective in low permeability formations. (4) When skimmer wells are used, little wastewater is produced. (5) Application of the vacuum to the well can increase the hydraulic gradient, and thus, the capture zone. (6) Finally, VER systems can treat some of the residual LNAPL in the vadose zone.



**Figure 4.4.1** Vacuum-Enhanced Recovery Systems (from API, 1996)

There are limitations to use of VER systems: (1) If water is produced, the wastewater may have very high concentrations of dissolved hydrocarbons. (2) An API separator is generally required. (3) Finally, because of the limited suction that is normally applied, required remediation times can be long unless water production is also used to increase the gradient towards the recovery well.

#### 4.4.2 Common Site Conditions for Use

VER systems are most commonly used where other conventional pumping and trench systems are inappropriate. API (1996) notes VER has been used in situations where low permeability formations are present, where a deep water table has a small LNAPL thickness, and where surface obstacles limit the potential for trench installation. VER systems may be used where perched zones of hydrocarbon exist with interbedded sands and clays (Nyer *et al.*, 1996, Blake *et al.*, 1990). Nyer *et al.* (1996) note that low transmissivity formations are necessary to develop a vacuum of sufficient magnitude to have an effect at reasonable flow rates. Nyer *et al.* (1996) and Blake *et al.* (1990) suggest that

VER systems are most effective where hydraulic conductivity ranges from  $10^{-3}$  to  $10^{-5}$  cm/sec. If the permeability is too high or too low the system will likely become ineffective.

Trowbridge and Malot (1990) reviewed three case studies, each at a different Superfund site. This study found that VER was used to remove liquid hydrocarbon residual, liquid free product via slurping, hydrocarbon vapors, dissolved hydrocarbons in the ground water and hydrocarbon that was adsorbed on the soil particles/organic carbon in the soil matrix. At one study site the VER apparently performed much better than the previously installed FPR system. Prince-Larson and Markley (1994) found VER to be effective at a site with a low permeability and a shallow water table. For this application the volume of liquids that were produced was a serious concern, so a hydrocarbon belt skimmer was used along with a vacuum pump to recover solely hydrocarbon. Bruce *et al.* (1992) note that VER helps to stimulate petroleum-degrading microorganisms in the subsurface, leading to increased rates of decay.

#### **4.4.3 Operation and Maintenance**

Vacuum and liquid pumping rates are the most important operational variables. The optimal vacuum pressure is the lowest suction pressure that accomplishes the goals of remediation. For single-pump systems, such as shown on the left in Figure 4.4.1, this vacuum is that suction pressure required to pull liquids to the surface. For dual-pump systems the vacuum is a variable that depends on the remediation goals. Airflow rates and liquid flow rates can be estimated by a number of methods. For example, see Section 5.

General maintenance for SVE systems would likely apply to VER. Single vacuum pumping methods tend to have problems trying to balance the vacuum when multiple wells are used. Nyer *et al.* (1996) note that two-pump systems tend to be easier to operate and allow for increased design flexibility. Lindhult *et al.* (1995) found that using VER at relatively clayey sites tended to fill the knock-out drum with sediments that required periodic cleaning. Granskog *et al.* (1995) found problems associated with fouling of the piping and pumps. Their investigation found that fouling was most probably related to bacterial growth at

the well screen. One of the most important recommendations was to design systems that can be easily maintained.

Separation and treatment requirements will be much the same as for other vapor extraction and FPR technologies. Depending on local regulations, off-gas treatment units may be needed for air processing and oil/water separators for liquids. **VER** systems will tend not to produce as much water or air from low conductivity soils, so fluid treatment units will likely be smaller than those required for **SVE** and high-volume oil/water separation.

#### **4.5 Selection of Free-Product Recovery Systems**

The preceding sections have described trenches, skimming wells, single- and dual-pump systems, and vacuum-enhanced systems for application in free-product recovery. Each system has a range of conditions for which it is the preferred technology. For some conditions two or more technologies may be technically feasible and selection should be made on the basis of cost and operation/maintenance requirements.

Selection of the most appropriate technology for a given site depends upon the criteria that must be evaluated and the priorities and weights used by different site managers. The most important criteria include:

- 1) the established remediation goals,
- 2) depth to groundwater and the LNAPL layer,
- 3) formation permeability,
- 4) thickness of the saturated zone,**
- 5) whether or not onsite containment is required,
- 6) magnitude of typical groundwater fluctuations,
- 7) capabilities for treatment of the produced fluids including an oil/water separator,
- 8) installation costs and difficulty, and
- 9) operation and maintenance requirements.

The attributes of the various systems based on these factors are summarized in Table 4.5.1. Site conditions can be compared with this table as a guide to selection of an appropriate FPR method.

Depth to groundwater is important for trenches and for skimmer wells using certain types of pumps. Trenches and dual-pump systems work best in formations having high permeability ( $10^{-3}$  to  $10^{-2}$  cm/sec), while vacuum-enhanced systems work best in low to moderate permeability formations ( $10^{-6}$  to  $10^{-4}$  cm/s) so that the applied vacuum will effect LNAPL and water table drawdown. Use of production wells requires moderate to thick aquifers since a drawdown cone will be created. On the other hand, vacuum-enhanced systems can be very effective in thin or perched aquifers since the LNAPL flow is driven by air movement rather than water table drawdown. If hydraulic containment is required to prevent offsite LNAPL or dissolved plume migration then production wells must generally be used. An alternative is to produce water from a trench; however, the depth of the trench will limit drawdown.

**Table 4.5.1** Summary Characteristics of Free-Product Recovery Technologies

Technology	Depth	Permeability	Saturated Zone Thickness	Containment	Surface Treatment	Relative cost	Operation and Maintenance
Trenches	Shallow	High	Any	With Water Production	None to Limited	Low to High	Low
Skimming Wells	Shallow to Moderate	Moderate to High	Any	None	None to Limited	Low to Medium	Low
Single-Pump Wells	Any	Moderate	Moderate to Thick	Yes	Significant	Low to Medium	Low to High
Dual-Pump Wells	Any	High	Thick	Yes	Limited to Moderate	Low to High	Low to High
Vacuum-Enhanced Wells	Any	Low to Moderate	Any	Limited	Limited	Medium to High	Medium to High