Evaluation of Buried Secondary Containment Liners

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Abstract

Buried secondary containment liners at several pump station tank farms along the Trans Alaska Pipeline System (TAPS) were evaluated in 2000 to determine if they complied with the Alaska Department of Environmental Conservation oil pollution prevention regulations under the Alaska Administrative Code, Title 18, Chapter 75 (18 AAC 75). These secondary containment systems (SCSs), which were constructed in the mid to late 1970’s, are diked areas composed of a flexible membrane liner covered by an average of about 0.61 m of soil that surround the pump station tank farms.

Golder Associates Inc. performed a comprehensive assessment of the tank farm liner systems at five pump stations that included a qualitative examination of project records, the development of a visual inspection checklist, and select test pits at each pump station tank farm to confirm that the liners met regulatory requirements. The field investigation also included using geophysical techniques, such as ground penetrating radar and electric leak detection surveys, to identify potential liner damage locations. Based on the liner damage identified at each pump station tank farm SCS, leakage rates were calculated and compared to leakage rates through a soil liner with a permeability of $1x10^{-6}$ cm/sec.

Introduction

Under the Alaska Administrative Code, Title 18, Chapter 75 (18 AAC 75), the Alaska Department of Environmental Conservation (ADEC) requires that secondary containment systems (SCSs) at existing facilities be “sufficiently impermeable…to protect groundwater from contamination and to contain a discharge until it can be detected and cleaned up.”

During meetings with the Alyeska Pipeline Service Company (Alyeska) in 1999, the ADEC requested a comprehensive assessment of the tank farm liner systems at Pump Stations 3, 5, 7, 9, and 12 to approve Alyeska’s “Oil Discharge

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Prevention and Contingency Plan." These SCSs, which were constructed in the mid to late 1970's, are diked areas composed of a flexible membrane liner, typically reinforced chlorinated polyethylene (CPER), covered by an average of about 0.61 m of soil that surround the pump station tank farms. The comprehensive assessment was to include a qualitative examination of project records and select test pits to confirm the tank farm liners condition.

Qualitative Examination of Records

The qualitative examination of records included interviewing people familiar with the historical pump station tank farm operations and an investigation of construction archives, engineering reports, and spill records. Based on the interviews and qualitative historical document review, the liner installation had been monitored for quality control and the installation met the intent of the plans and specifications.

Golder Associates Inc. (Golder) generated a report that summarized the findings of the historical document review and recommended test pit locations in areas where the liner integrity may be suspect. In addition, a visual inspection checklist was developed to inspect the surface condition of the cover soils for gross problems that increase the likelihood or indicate the presence of leaks.

Field Investigation

The field investigation at Pump Stations 3, 5, 7, 9, and 12 was performed to directly observe and evaluate the tank farm secondary containment liner at these facilities. The field investigation included a visual inspection of the SCSs, selection of test pit locations based on the visual inspection and qualitative record review, excavation of test pits, and documentation of the exposed liners condition. In addition, work at Pump Station 5 included a geophysical survey using ground penetrating radar (GPR) and electric leak detection (ELD) methods, selection of three 15 m by 15 m trench areas to perform the ELD survey, and exposing the liner at up to 16 significant anomaly locations identified during the ELD survey. These tasks are summarized in the following sections.

Visual Inspection. Visual inspection of the protective cover soils was performed to identify gross problems that increase the likelihood or indicate the presence of leaks. A visual inspection checklist developed during the qualitative examination of records was used. Some of the suspect areas included deep ruts, animal burrows, surficial cracks and depressions, and areas where evidence of structural movement was apparent.

Test Pits and Trenches. The location selection and excavation methods used for the test pits and trenches are described below.

Location Selection. With the exception of two pump stations, the results of the visual inspection and the qualitative record review were generally used to identify test pit locations at the tank farms. When potential leak locations could not be identified by visual inspection, test pits were located randomly in an area where there was no record of previous test pits.

At Pump Station 5, the majority of test pits were located based on results from the ELD survey, except for one test pit, which was positioned at a penetration boot that had no record of being repaired. Two of the three trenched areas at Pump Station 5 were located based on anomalies identified during the GPR survey performed as part of this investigation and a 1992 GPR survey. The third trench was selected based on the visual inspection of the cover soils.

Additional test pits were also excavated along the east slope of the east cell at Pump Station 7 to further define the extent of large liner damage that was observed earlier in the investigation. Cover soils along the east slope in this area were observed to have grading marks from what appeared to be a front loader bucket. Test pits were initially located about every 3 m along the east slope. If large liner damage was uncovered in the test pits, then the test pits were expanded about 1.5 m on either side or to the next adjacent test pit where no liner damage had been found.

Excavation. Excavation of the protective cover soils to expose the liner was done using air knives, a vacuum truck, and metal and plastic shovels according to prepared instructions. A small backhoe was also used at Pump Station 5 to remove the first foot of cover soils for the test pits. The protective cover soils were typically excavated with extreme care so as not to damage the liner. However, some liner damage did occur occasionally as a result of the excavation.

Geophysical Survey. A geophysical survey that included GPR and ELD was performed by Golder at Pump Station 5. This geophysical survey was performed in addition to the visual inspection of the cover soils to identify potential leak locations.

Ground Penetrating Radar. GPR is a geophysical technique that transmits electromagnetic waves into the ground that are reflected at subsurface interfaces and subsequently detected by a receiving antenna. A subsurface profile is acquired by moving the transmitter and receiver antennas along a traverse and continuously recording a series of soundings. The resulting reflection data are displayed on a graphic recorder as a continuous profile depicting the subsurface strata.

Reflections arise due to contrasts in the electrical properties (conductivity and dielectric properties) of subsurface materials. These properties are a function of water content, grain size, mineralogy and the presence of petroleum products. The best subsurface penetration is obtained through hard material such as rock or concrete and in medium to coarse-grained sediment. The poorest penetration is in fine-grained sediment (silt and clay) or conductive material such as salt water.

The GPR survey was conducted with a GSSI System 8 with a 400-MHz antenna. The 400-MHz antenna produces a high-resolution image of the subsurface with a maximum penetration depth on the order of 6 m to 9 m. Field procedures included laying out a grid system on the ground surface, calibrating the instrument, profiling along the alignment, interpreting the data, and marking the location of GPR anomalies on the ground with spray paint. The results of the GPR survey are discussed in more detail below.

Electric Leak Detection Survey. The ELD system is an electrical technique that is closely related to the direct current electrical resistivity method. To locate the leaks, an electrical current is applied to the ground between electrodes. One electrode is located inside of the cell above the liner and the other is located outside of the cell in the soils surrounding the liner. A second set of moving electrodes is then used to measure the electrical potential at closely spaced points throughout the area of concern. If the liner is intact, very little electrical current will flow through the highly resistive plastic liner. However, if a hole exists in the liner there will be an increase in the current flow through the point of leakage that will create an electrical potential value. Careful mapping of these electrical potentials indicates the location of perforations in the liner. These perforations can range in size from less than a millimeter to very large tears in the liner.

Results of Geophysical Survey. The GPR anomalies were categorized as either an undulation of the liner or a low amplitude reflection of the liner. The undulating anomaly of the liner is related to the subsurface elevation change of the underlying material. The low amplitude signal, in some areas, may be related to a change in the material overlying the liner.

An example of the contour plan of current potential data developed during the ELD survey and the approximate location of the test pits is shown in Figure 1. The anomalies were identified as those with readings larger than 950 mV at Trench 1, larger than 150 mV at Trench 2, and larger than 80 mV and lower than –400 mV at Trench 3. The majority of anomalies were confirmed with test pits.

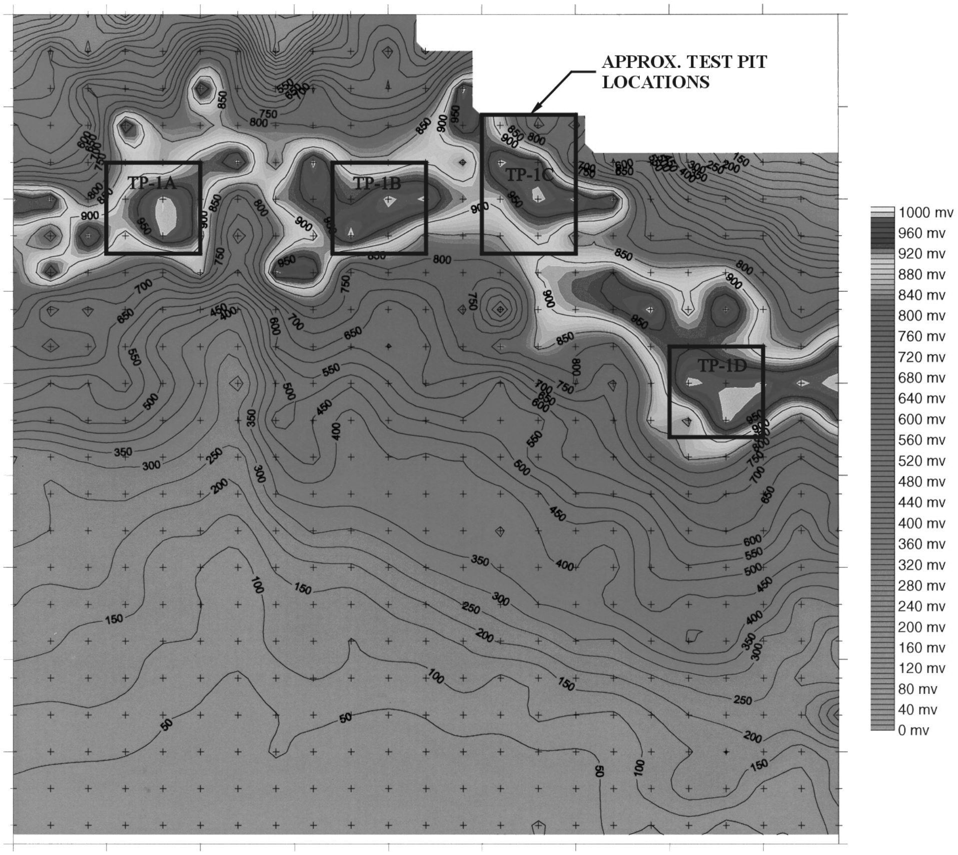


Figure 1. ELD Survey Results for Trench 1 at Pump Station 5

Based on the results of the excavation program, the ELD was precise and effective at locating leaks in the liner. However, results from the GPR survey were ambiguous and undefined.

Liner Inspection. The liner was visually inspected for damage after the cover soils had been removed and the liner had been swept clean and washed off. The liner inspection was done according to developed procedures, which included a geomembrane liner inspection checklist. The geomembrane liner inspection checklist included a description of the protective cover soils, the location and size of the exposed liner, the condition of the liner, and photographs and sketches of the test pits. The geomembrane liner inspection checklists for the test pits at Pump Station 5 are summarized in Table 1.

The liner was typically inspected using visual methods only. However, pinholes and other small liner damage that could not be visually verified to perforate the liner were tested using a vacuum box. The condition of the liner seams was observed for fishmouths and/or unbonded lengths with less than 5.1 cm overlap. Unbonded seams with greater than 5.1 cm overlap and at least 61 cm of protective cover were considered to be passable based on previous work by Golder.

Observations made during the visual inspection of the trenches and test pits are summarized below.

Protective Cover Soils. The protective cover soils were inspected for thickness, aggregate particle size, and aggregate angularity. The protective cover soils were typically composed of a sandy gravel surface course overlying a sand cushion layer that averaged about 7.6 cm thick. At Pump Station 5, the sand cushion layer was not discernable from the surface course materials. However, sandy soil was typically observed above the geomembrane liner.

Table 1. Summary of Liner Evaluation Checklist for Pump Station 5

TEST PIT OR TRENCH NUMBER	LOCATION (SLOPE OR FLOOR)	PROTECTIVE COVER THICKNESS (MIN. - MAX., cm)	SAND CUSHION THICKNESS (MIN. - MAX., cm)	LINER COLOR	LINER DAMAGE (YES OR NO)	SEAM BONDING AND CONDITION		
						HEAT FUSION	ADHESION	UNBONDED
TRENCH 1	FLOOR	- - -	- - -	GRAY	YES	OKAY	OKAY	FISHMOUTH
TP-1A	FLOOR	81 - 86	0	GRAY	YES	OKAY	FISHMOUTH	- - -
TP-1B	FLOOR	76 - 81	0	GRAY	YES	- - -	OKAY	- - -
TP-1C	FLOOR	76 - 79	0	GRAY	YES	OKAY	- - -	OKAY
TP-1D	FLOOR	74 - 76	0	GRAY	YES	OKAY	- - -	- - -
TRENCH 2	FLOOR	- - -	- - -	GRAY	YES	OKAY	OKAY	FISHMOUTH
TP-2A	FLOOR	61 - 81	0	GRAY	YES	OKAY	OKAY	- - -
TRENCH 3	BOTH	- - -	- - -	GRAY	YES	OKAY	- - -	- - -
TP-3A	BOTH	46 - 76	0	GRAY	YES	OKAY	- - -	- - -
TP-3B	FLOOR	76	0	GRAY	YES	OKAY	- - -	- - -
TP-4	FLOOR	124	0	GRAY	YES	- - -	- - -	< 5.1 cm OVERLAP

NOTES: 1. ALL LINER EXPOSED WAS REINFORCED.

2. LINER AND SEAMS WERE INSPECTED VISUALLY. VACUUM BOX USED OCCASIONALLY TO DETERMINE WHETHER DAMAGE PENETRATED LINER.

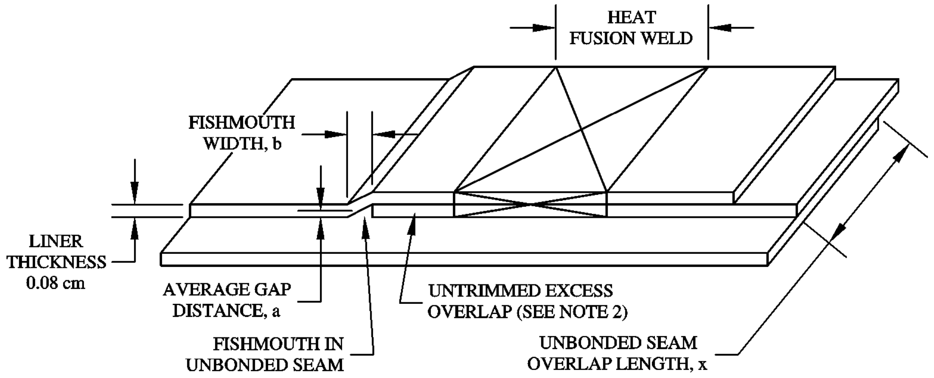
3. SEAM BONDING AND CONDITION INDICATES WHAT TYPE OF SEAM(S) WAS EXPOSED AND ITS CONDITION. UNBONDED SEAM GENERALLY CONSIDERED TO BE OKAY WITH > 5.1 CM OVERLAP AND AT LEAST 61 CM OF PROTECTIVE COVER SOILS.

4. - - - = NOT APPLICABLE

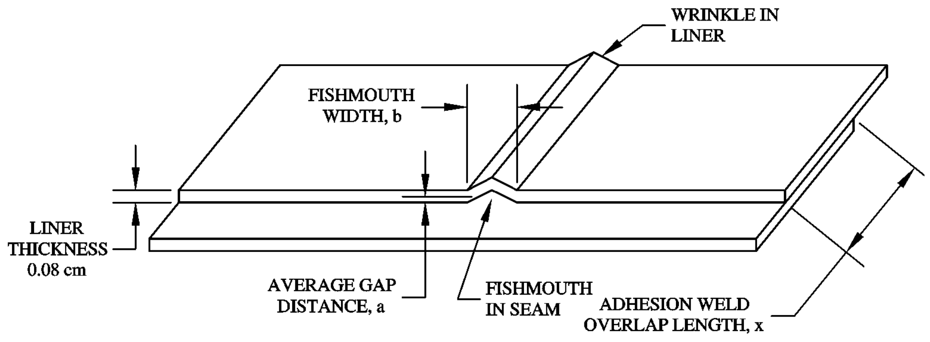
Liner Damage. The following types of liner damage, and their definitions, were observed at the pump station tank farms:

- Perforation (holes and tears): damage that perforates or penetrates the liner
- Abrasion: damage that marks or scores the layer of geomembrane liner above the reinforcing scrim, but does not perforate the entire liner
- Delamination: damage when a laminated geomembrane layer separates from the reinforcing scrim, but does not necessarily perforate the entire liner
- Fishmouth: irregular contact surface between the top liner and the bottom liner in a seam
- Unbonded seam with less than 5.1 cm overlap

The majority of damage observed was caused by perforations that ranged in size from a pinhole (defined in this study as a perforation having a diameter less than or equal to 0.32 cm) to tears up to 2.1 m wide. Seam damage in the form of fishmouths and unbonded seams with less than 5.1 cm overlap were also observed. Sketches of the two types of fishmouths observed are shown in Figure 2.



INTERSECTION OF HEAT FUSION WELD AND UNBONDED SEAM



WRINKLE ALONG ADHESION WELD

NOTES: 1. DIMENSIONS USED TO CALCULATE FLOW RATE THROUGH FISHMOUTH AS FLOW BETWEEN TWO FIXED PLATES.

2. NO FLOW ASSUMED THROUGH UNTRIMMED EXCESS OVERLAP WITH AT LEAST 61 CM OF SOIL COVER.

Figure 2. Examples of Liner Seam Fishmouths

Liner Evaluation

The secondary containment systems were evaluated based on the condition of the liner observed in the test pits and trenches excavated at the pump station tank farms. The liner evaluation included a review of literature and past reports, estimation of leakage rates through observed liner damage, and comparison of an overall leakage rate to the flow rate through a clay liner with a permeability of $1\text{x}10^{-6}$ cm/sec.

Literature and Report Review. Literature and past reports were reviewed to determine what has been done previously to estimate the leakage rate through geomembrane liner defects (Giroud, et al., 1997; Texas Agricultural Experiment Station, 1987). Of all the literature reviewed, tests performed by Golder in 1999 were the only work done that simulated conditions such as exist at the pump station tank farms secondary containment systems, i.e. thickness and permeability of cover soils, head of liquid on top of geomembrane, and type of geomembrane. Therefore, information from this 1999 report was used.

Leakage Rate Estimation. Leakage rates were estimated for liner perforations and for fishmouths in the liner seams. A hydraulic head of 1.2 m was typically used, which was based on 95% of the largest tank volume over the lined area of the smallest tank farm cell. The methods used to estimate these leakage rates are described below.

Leakage Rate Through a Perforation. The leakage rate through a perforation, either a hole or tear, was estimated using the equation for flow through a submerged weir:

$$q = Ca\sqrt{2gh} \qquad \text{(Daugherty, et. al., 1985)}$$

where: q is the leakage rate through the perforation (m^3/sec converted to lpd); C is a coefficient that is a function of the inlet geometry and is between 0 and 1 (dimensionless); a is the area of the perforation (m^2); g is the acceleration due to gravity (m/sec^2); and, h is the total hydraulic head (m).

A coefficient of 0.6, which is the coefficient for free flow through an orifice (Giroud, et al., 1997), was used in the 1999 Golder study to estimate flow through a geomembrane liner perforation overlain by 61 cm of cover soils that had a permeability of $1\text{x}10^{-3}$ cm/sec. However, calculations using this coefficient overestimated the measured flow rate through a soil cover overlying a geomembrane perforation by four orders of magnitude. Therefore, data from the 1999 Golder study were used to back-calculate a new coefficient value of $8\text{x}10^{-6}$. This coefficient was then used to calculate the leakage rates for a variety of perforations as shown in Figure 3.

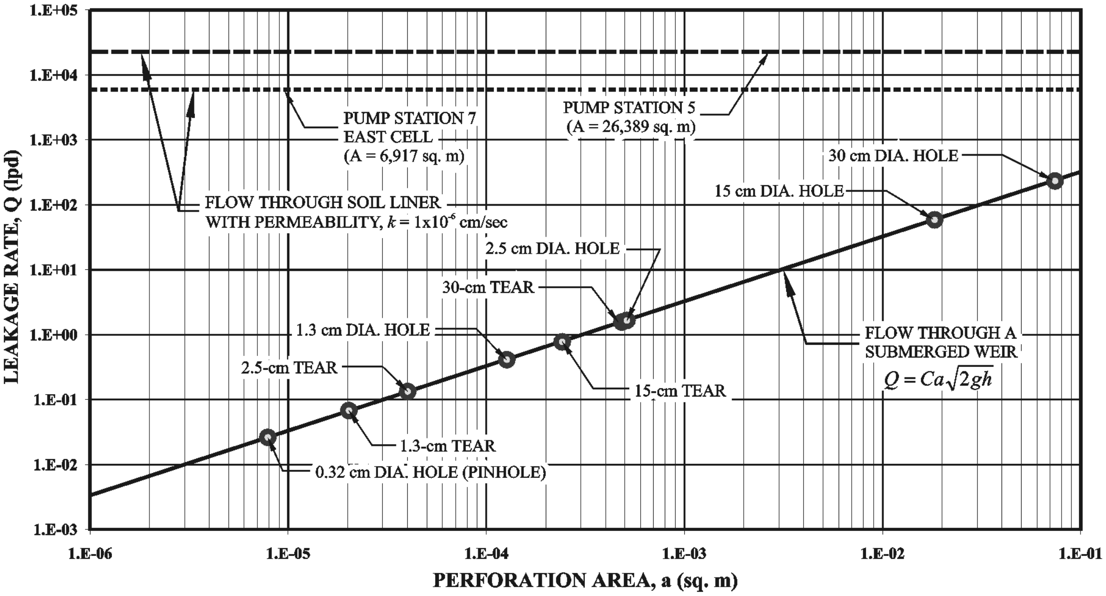
Leakage Rate Through a Fishmouth. The leakage rate through a fishmouth was estimated using the equation for flow between two fixed plates:

$$Q = \frac{ba^3}{12\mu}\Delta P \qquad \text{(White, 1979)}$$

where: Q is the leakage rate through the fishmouth (m^3/sec converted to lpd); b is the width of the fishmouth (m); a is the average gap distance between the geomembranes (m); μ is absolute viscosity of the fluid (10^{-3} N-sec/m^2 at room temperature for water); ΔP is the pressure differential $[-d(P+\rho gz)/dx]$ or $(P_1-P_2)/x$; P_1 is the pressure head at the top of the seam (water head (m) converted to N/m^2); P_2 is the pressure head at the bottom of the seam (assumed to be zero); x is the distance along the flow path between the seam (seam overlap length) (m); ρ is the mass density of the fluid; and, z is the elevation between the top and bottom of the seam (assumed negligible).

Figure 2 shows two types of seam fishmouths and the dimensions used to estimate the leakage rate. The average gap distance was estimated from field observations to be equal to the thickness of the liner at a maximum, about 0.08 cm. The fishmouth widths were measured in the field or calculated assuming a 2 horizontal to 1 vertical slope. The seam overlap lengths were measured in the field.

The calculated leakage rates for the seam fishmouths observed at Pump Stations 3 and 5 are shown in Figure 4. However, since these calculated leakage rates do not consider the reduction of flow due to the cover soils, they are likely to be overly conservative. In addition, based on the previous tests performed by Golder in 1999, the calculated fishmouth leakage rates are also likely to be overly conservative by one to several orders of magnitude.



NOTES:
1. **FLOW THROUGH A SUBMERGED WEIR CALCULATED ASSUMING A COEFFICIENT (C) OF 8X10-6 AND A HYDRAULIC HEAD (h) OF 1.2 m.**
2. **FLOW THROUGH A SOIL LINER BASED ON DARCY'S LAW, $q = kiA$, ASSUMING A HYDRAULIC GRADIENT (i) OF UNITY.**
3. **AREA OF TEAR IN LINER ASSUMES WIDTH OF 0.16 cm.**

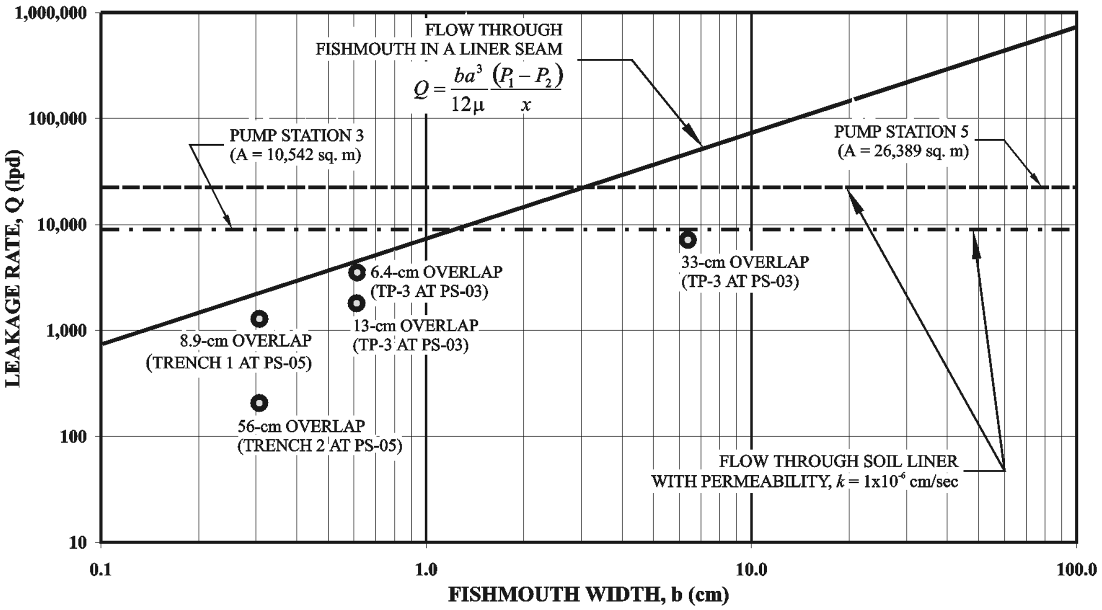
Figure 3. Comparison of Liner Perforation Leakage Rates

Acceptable Leakage Rates. Under the current ADEC 18 AAC 75.990(124) regulation for "sufficiently impermeable," compiled October 1999, a soil liner with a permeability of $1\text{x}10^{-6}$ cm/sec would be acceptable for use as newly installed secondary containment. Darcy's Law was used to determine the flow rate through a soil liner and is defined as:

$$q = kiA \qquad \text{(Sowers, 1979)}$$

where: q is the flow rate (m^3/sec converted to lpd); k is the coefficient of permeability ($1\text{x}10^{-6}$ cm/sec as defined by ADEC regulation 18 AAC 75.990(124) converted to m/sec); i is the hydraulic gradient or head loss over the flow path, $\Delta h/l$, assumed to be equal to 1; Δh is the head loss (m); l is the flow length (m); and, A is the lined area of the pump station tank farm (m^2).

The hydraulic gradient, or head loss over the flow path, of unity assumes that the depth of saturated soil liner thickness is equal to the hydraulic head that is forcing water downward into the subbase soil below the soil liner. Low permeability soil liners are generally 0.3 m to 0.9 m thick. Therefore, since we are typically assuming a hydraulic head of 1.2 m for calculating the leakage rates through a damaged liner, using a hydraulic gradient of unity to calculate the flow rate through a low permeability soil liner is rather conservative. In other words, using a larger hydraulic gradient would yield higher "acceptable" flow rates through the soil liner.



NOTES:
1. **FLOW THROUGH FISHMOUTH IN A LINER SEAM ANALYZED AS FLOW BETWEEN TWO FIXED PLATES, ASSUMING A 0.08-cm GAP (a), AN ABSOLUTE VISCOSITY (μ) OF 0.001 N-SEC/M^2, A PRESSURE HEAD AT THE TOP OF THE FISHMOUTH (P_1) OF 1.2 cm, AND A SEAM OVERLAP (x) OF 5.1 cm. CALCULATION DOES NOT CONSIDER REDUCTION OF FLOW DUE TO COVER SOILS.**
2. **FLOW THROUGH A SOIL LINER BASED ON DARCY'S LAW, $q = kiA$, ASSUMING A HYDRAULIC GRADIENT (i) OF UNITY.**

Figure 4. Comparison of Liner Seam Fishmouth Leakage Rates

The approximate lined area for each pump station tank farm was estimated from scale drawings of each facility. The soil liner leakage rates for select pump stations are shown for comparison to estimated leakage rates for perforations and fishmouths in Figures 3 and 4, respectively.

The number and type of observed liner defects were used to predict the number of defects that could exist at each facility by extrapolating the liner area exposed in the test pits and trenches over the total lined area. Defects of concern were identified as holes, ranging in size from 0.32 cm diameter (pinholes) to 2.5 cm diameter, and 15-cm tears because of their frequency. Other damage such as fishmouths, defects larger than 15 cm, and unbonded seams with less than 5.1-cm overlap were discounted for the following reasons:

Fishmouths. Fishmouths were discounted because they were observed to be uncommon and have an estimated leakage rate that is very low.

Large Defects. The only large defects that were larger than 15 cm were observed along the east slope of the east cell at one pump station, which was considered an isolated event.

Unbonded Seams With Less Than 5.1 cm Overlap. This type of defect was only observed at one pump station where the older liner boot had been cut. The liner boot has since been repaired.

Calculation of Total Leakage Rates. The total leakage rate at each facility was determined by summing the product of the number of predicted defects and their estimated leakage rate. The total leakage rate at each pump station tank farm was much less than the acceptable leakage rate as calculated under the ADEC regulation.

Conclusions

Golder preformed a comprehensive assessment of the tank farm secondary containment liners at Pump Stations 3, 5, 7, 9, and 12 that included a qualitative examination of project records and a field investigation to confirm the tank farm liners condition. The following conclusions were developed as part of the comprehensive assessment:

- The historic inspection records indicated that the liner installation was monitored for quality control and that the installation met the intent of the plans and specifications. There was no record of collateral damage.
- The SCSs at the pump station tank farms appeared to be “sufficiently impermeable” because the leakage rate through the predicted number of defects at each pump station was many times lower than the flow rate through a system with a $1x10^{-6}$ cm/sec soil liner.
- Liner damage that perforated the liner was only found at three pump stations.
- The majority of liner damage at each pump station tank farm was due to pinholes with a diameter that was less than or equal to 0.32 cm. With one exception, no liner damage was observed that was larger than 15 cm.
- The large liner damage observed along the east slope of the east cell at one pump station was considered an isolated event.

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