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title: INFLUENCE OF OVERLAND TRANSFER HOSE SIZE/NUMBER AND PUMP SET CHOICES ON MARCORPS AMPHIBIOUS ASSAULT FUEL SYSTEM

author: J. R. Moreland and C. K. Smith, Ph D

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The bulk fuel needs of a Marine Amphibious Force (MAF) require that the overland transfer capability of the Amphibious Assault Fuel System (AAFS) be increased from 600 gpm (0.0379 m^3/sec) to 800 gpm (0.0505 m^3/sec). Different pump and hose line combinations are assessed in terms of technical and operational considerations, logistic burden, procurement costs, reliability and life cycle costs.

CONTENTS

INTRODUCTION

To meet the projected future needs of amphibious assault operations for fuel ashore, it is necessary to increase the flow rate capability of the overland transfer portion of the Marine Corps amphibious assault fuel system (AAFS) from 600 gpm (0.0379 m^3/sec) to 800 gpm (0.0505 m^3/sec). There are several ways in which this could be achieved. This document reports the results of an investigation to determine which of these ways should be chosen.

This work is a part of an RDT&E program of much larger scope (Ref 1) to provide the Marine Corps with expeditionary bulk fuel equipment capable of meeting projected fuel requirements ashore in support of Marine Amphibious Force (MAF) and smaller sized amphibious operations. That program is, in turn, part of a total system RDT&E program at the Civil Engineering Laboratory (CEL) directed toward development of an improved Navy/Marine Corps amphibious bulk fuel system for delivery of fuel from tankers offshore to users ashore, capable of meeting projected needs through the 1980's and beyond.

BACKGROUND

Present System

In an amphibious assault operation, the present Navy offshore fuel delivery system supplies fuel (JP-5, diesel, and MOGAS) to the beach at 600 gpm (0.0379 m^3/sec) through a single 6-inch (15-cm) line that extends up to one mile (1.6 km) offshore. The existing Marine Corps AAFS, shown in Figure 1, is designed to interface with the Navy offshore system at the beach and provide the network necessary for onshore transfer, storage and distribution of the fuel (Ref 2)*.

To receive the fuel and transfer it overland into the tank farms of the AAFS, each AAFS includes one beach unloading station (Figure 2) and two high capacity booster pumping stations (Figure 3) with over 2.0 miles (3.2 km) of 6-inch (15-cm) discharge hose to connect these three stations in series. Additional hoses are provided to connect this series of pumping stations to the manifold and then to the tank farms, as shown in Figure 1.

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*Since this work was originated, a new edition of Reference 2 has been promulgated (U.S. Marine Corps Technical Manual TM-3835-15/1: Installation, Operation, and Maintenance, Amphibious Assault Fuel System (AAFS) and Tactical Airfield Fuel Dispensing System (TAFDS), Oct 1978). However, comparison of these manuals indicates that the use of the new edition rather than Reference 2 would not change the results presented in this document.

The pump sets now in the AAFS, including those of the beach unloading station and the booster pumping stations, are trailer-mounted and have diesel-engine-driven centrifugal pumps rated to deliver 600 gpm (0.0379 m^3/sec) at about 125 psi (862 kPa) discharge pressure, which is the rated pressure of the fuel hose. These same pumps can deliver 800 gpm (0.0505 m^3/sec) at about 95 psi (655 kPa) discharge pressure (Ref 2).

Presently, the 6-inch (15-cm) fuel discharge hose is in 50-foot (15-m) sections provided with quick-disconnect fittings for coupling the sections together. These sections are coiled individually and packaged in wooden boxes. The uncrated weight of each hose section is 118 lb (53.5 kg). The weight of one section is about the maximum that two men can reasonably handle without materials handling equipment.

Preparation for laying the hose requires breakout of the sections from their wooden boxes, coupling the sections together and faking the coupled hose in a stake-bed trailer. All of these preparations may have to be done on the beach. Once the hose is faked on the trailer, it is hauled to the location at which it is needed and then deployed manually by pulling it from the trailer. Retrieval and retrograde follow the reverse of this procedure.

The 20,000-gal (75.7-m^3) tanks provided throughout the AAFS are collapsible and are packaged individually in lightweight aluminum chests. Before installation, a berm is constructed for each tank by scraping up soil from an area about 28-feet (8.5-m) long and 25-feet (7.6-m) wide. To contain the fuel in case a tank ruptures and cannot be repaired, the walls of the berm are made at least 5-feet (1.5-m) high and about 6-feet (1.8-m) thick at the base. The bottom of the surface inside the berm must be reasonably level so that the tank will not roll when it is filled. Berm construction requires a dozer; in addition, a front-end loader and a scraper are often used.

To support an amphibious assault operation the size of a Marine Amphibious Force (MAF), the Force Service Support Group (FSSG) would rate (Ref 3) two bulk fuel companies. Each of these companies would have six AAFS's. In these 12 AAFS's, there would be a total of 48 pump sets, 72 collapsible tanks, and more than 24 miles (39 km) of 6-inch (15-m) hose available for beach unloading and overland transfer. A transfer system composed of a booster pumping station feeding a set of series-connected booster pumping stations can serve several AAFS's. Therefore, only 2 (and in certain cases 3) of the 12 beach unloading stations would ordinarily be needed. That leaves the components of the remaining 9 or 10 available for other purposes (such as spares, and additional booster pumping stations in the main or branch lines).

Need for Change

The Navy is developing the capability to deliver fuel ashore at the rate of 800 gpm (0.0505 m^3/sec) through each of two 8-inch (20-cm) pipelines to meet the projected future demands of a MAF-sized amphibious operation and to permit employment of modern tanker ships. It is presently envisioned to dedicate one of these lines to JP-5, and the other to diesel and MOGAS on a timesharing basis. Therefore, it is necessary to determine what changes in AAFS components should be made to best handle these increases in flow rate and line size.

Further, laying and retrieval of the long runs of hoseline between pump sets of the beach unloading station and the booster pumping stations for overland transfer is tedious, time consuming, and labor intensive. Development of a better method would be very beneficial.

ACCOMPLISHMENTS

An analysis was performed to determine the influence of hose size/number and of upgrading the pump sets on the required spacing and number of booster pumping stations and quantity of hose required for overland transfer. Procurement costs and logistic burden data were established for each pump/hose combination analyzed. Reliability and life cycle cost analyses were performed on the pump/hose combinations that remained favorable alternatives after other analyses had been performed.

DISCUSSION

Pump Set Choices Considered

Two possibilities were considered for the pump sets used in the beach unloading station and booster pumping stations.

The existing pump sets will deliver 800 gpm (0.0505 m^3/sec) at a discharge pressure of 95 psi (655 kPa). Therefore, the first possibility is to decrease to 95 psi (655 kPa) the pressure drop between the pump sets of the beach unloading station and the booster pumping stations so that the existing pump sets can be used.

The second possibility is to modify the pump sets of the beach unloading station and the booster pumping stations to upgrade them so that each pump set will deliver 800 gpm (0.0505 m^3/sec) at a discharge pressure of 125 psi (862 kPa). This would require (Ref 4) only the removal of the Detroit Diesel 3-53 series diesel engines from those pump sets and the installation of a new turbocharged version of the same engine (designated the Model 3-53T).

Hose Choices Considered

Three choices were considered for the discharge hoses connecting in series the pump sets of the beach unloading station and the booster pumping stations used for overland transfer. These are single 6-inch 15-cm) hose, dual 6-inch (15-cm) hoses, and single 8-inch (20-cm) hose. In the 6-inch (15-cm) size, quick disconnect fittings and hose lengths up to 400 feet (122 m) are known to be commercially available. Commercial availability of 8-inch (20-cm) fittings and discharge hose has also been confirmed (Ref 5 and 6).

Pump Spacing Analysis

The pressure loss in hose connecting two pump sets is the sum of the friction loss and static head loss. The distance between pump sets for any given case can be compared to that for a selected reference case using the equation:

$$\frac{L_n}{L_r} = \left(\frac{\Delta P_n}{\Delta P_r}\right)\left(\frac{N_n}{N_r}\right)^2\left(\frac{D_n}{D_r}\right)^5\left(\frac{Kf_r\,Q_r^{\,2} + Z\,N_r^{\,2}\,D_r^{\,5}}{Kf_n\,Q_n^2 + Z\,N_n^{\,2}\,D_n^{\,5}}\right)$$

where the symbols and units are defined in Table 1.

Section 1-8 in Chapter 2 of Reference 2 provides information for calculating the static head and friction losses in a single 6-inch (15-cm) hose line flowing 600 gpm (0.0379 m^3/sec) between booster pumping stations of the AAFS. This information is based on pumping of diesel fuel since it has the highest density of the fuels to be pumped. Because of its high density, diesel fuel has the greatest pressure losses due to static head and friction. Figure 1-15 of that section provides a graphical means for determining the allowable spacing of booster pumping stations as a function of the total pressure drop in the hose and of the static head (elevation difference) between stations, citing the friction loss as 30 psi per 1,000 feet of hose (678 kPa/km of hose) for a 6-inch (15-cm) hose flowing 600 gpm (0.0379 m^3/sec) of diesel fuel. This corresponds (Ref 5) to a friction factor of 0.057 at a Reynolds Number of about 1.5 x 10^5 and relative roughness of 0.029.

The cases to be analyzed involve flow at 800 gpm (0.0505 m^3/sec) through single and dual 6-inch (15-cm) hose and single 8-inch (20-cm) hose, for which the Reynolds Numbers would be between 10^5 and 2 x 10^5. For Reynolds Numbers in that range and a relative roughness of 0.029, the friction factor has a constant value of 0.057 (Ref 7). Therefore,

$$f_r = f_n = 0.057$$

can be used as the friction factor throughout the analysis.

Six cases were analyzed relative to a reference case that represents the present AAFS components. Case identification remains the same throughout this report and is summarized in Table 2. The reference case and these six cases have input values to the equation for L_n/L_r as follows:

Reference: Q_r = 600 gpm (0.0379 m^3/sec), D_r = 6 in. (15 cm), N_r = 1, ΔP_r = 125 psi (862 kPa), f_r = 0.057

Case 1 (n = 1): Q_1 = 800 gpm (0.0505 m^3/sec), D_1 = 6 in. (15 cm), N_1 = 1, ΔP_1 = 95 psi (655 kPa), f_1 = 0.057

Case 2 (n = 2): Q_2 = 800 gpm (0.0505 m^3/sec), D_2 = 6 in. (15 cm), N_2 = 2, ΔP_2 = 95 psi (655 kPa), f_2 = 0.057

Case 3 (n = 3): Q_3 = 800 gpm (0.0505 m^3/sec), D_3 = 8 in. (20 cm), N_3 = 1, ΔP_3 = 95 psi (655 kPa), f_3 = 0.057

Case 4 (n = 4): $Q_4 = 800$ gpm ($0.0505\ m^3/sec$), $D_4 = 6$ in. (15 cm), $N_4 = 1$, $\Delta P_4 = 125$ psi (862 kPa), $f_4 = 0.057$

Case 5 (n = 5): $Q_5 = 800$ gpm ($0.0505\ m^3/sec$), $D_5 = 6$ in. (15 cm), $N_5 = 2$, $\Delta P_5 = 125$ psi (862 kPa), $f_5 = 0.057$

Case 6 (n = 6): $Q_6 = 800$ gpm ($0.0505\ m^3/sec$), $D_6 = 8$ in. (20 cm), $N_6 = 1$, $\Delta P_6 = 125$ psi (862 kPa), $f_6 = 0.057$

The results of the pump spacing analysis are tabulated in Table 3 and shown graphically in Figure 4. If desired, these may be converted into actual values of L_n using values of L_r (based on Figure 1-15 of Reference 2) as follows:

Z		L_r	
ft/mi	m/km	ft	km
0	0.0	4,160	1.27
50	9.5	3,730	1.14
100	18.9	3,380	1.03
150	28.4	3,090	0.942
200	37.9	2,840	0.866
250	47.4	2,640	0.805
300	56.8	2,460	0.750
350	66.3	2,300	0.701
400	75.8	2,160	0.658
450	85.2	2,040	0.622
500	94.7	1,920	0.585

Logistic Burden Analysis

The six cases under investigation plus the reference case (see Table 2) were analyzed in terms of weight and volume of equipment for each mile (1.609 km) of fuel transfer distance. Hoselines, pumps, and 20,000-gallon ($75.7\ m^3$) collapsible tanks (including storage chests) are the equipment that comprise the logistic burden. The uncrated volumes for these items listed in Reference 2 were checked against actual measurements. Where discrepancies were noted, measured values were used. The differences in weight and volume for the existing and upgraded pump sets are considered negligible since the hardware is nearly identical. The following are values used:

Item	Dimension	Volume	Weight
Coiled 6-in. (15-cm) hose, 50-ft (15.2-m) long, with couplings	46 x 28 x 12 in. (117 x 71 x 30 cm)	9 ft^3 (0.25 m^3)	118 lb (53.5 kg)
Existing or upgraded pump set	156 x 74 x 67 in. (396 x 188 x 170 cm)	448 ft^3 (12.7 m^3)	1,385 lb (628 kg)
Collapsible tank in storage chest	165 x 30 x 26 in. (419 x 76 x 66 cm)	75 ft^3 (2.1 m^3)	2,858 lb (1,296 kg)

As discussed earlier, the present method for deploying 6-in. (15-cm) hose requires manual handling of the hose lengths. A single length of 8-in. (20-cm) hose should, therefore, be made equally conducive to manhandling. Stress calculations show that an 8-in. (20-cm) hose without couplings weighs 78% more than an equal length of 6-in. (15-cm) hose without couplings. This weight difference is due to the additional material necessary to resist the added burst force at a given pressure. If the weights of single sections of the two hose sizes are to be the same, then the 8-in. (20-cm) hose must necessarily be shorter. Also, weights for aluminum cam-locking hose couplings, obtained from the Evertite Coupling Company (Ref 8), are as follows:

6-in. (15-cm) coupling set	14.4 lb (6.53 kg)
8-in. (20-cm) coupling set	36.8 lb (16.69 kg)

These factors lead to the conclusion that a 22-ft (7-m) length of 8-in. (20-cm) hose with couplings has the same weight, 118 lb (53.5 kg), as a 50-ft (15-m) length of 6-in. (15-cm) hose with couplings. The logistic volume, 9 ft^3 (0.25 m^3) per 118-lb (53.5-kg) section, is about the same in either case.

Logistic burdens in terms of weights and volumes for each case are listed in Table 4. Table 5 shows the same values in metric form.

Equipment Procurement Cost Comparisons

Equipment cost data were accumulated in order to compare funds required to procure new equipment for each of the pump/hose cases under consideration. Costs used for collapsible tanks and existing pump sets were taken from current MARCORPS contracts:

Existing pump set	$15,500
20,000-gallon (75.7 m^3) collapsible tank	$4,000

Based on pump set manufacturers data, the procurement cost for an upgraded pump set is estimated at $17,000. Costs for hoses without couplings were adapted from dollar value figures for current Navy inventory:

6 in. (15 cm) hose	$9.18/ft ($30.12/m)
8 in. (20 cm) hose	$18.50/ft ($60.70/m)

Costs of couplings were obtained from Reference 8:

6 in. (15 cm) aluminum coupling set	$96.45
8 in. (20 cm) aluminum coupling set	$481.00

These figures were combined for 50 ft (15 m) and 22 ft (7 m) lengths of 6 in. (15 cm) and 8 in. (20 cm) hose, respectively. The resultant costs per foot (0.3048 m) were increased by 5% to account for coupling installation. The final figures are:

6 in. (15 cm) hose, 50 ft (15 m) long, with couplings	$11.67/ft ($38.29/m)
8 in. (20 cm) hose, 22 ft (7 m) long, with couplings	$42.38/ft ($139.05/m)

Procurement cost data for one mile (1.6 km) of fuel transfer equipment for each case is shown in Table 6.

Reliability and Life Cycle Cost Analyses

The analyses just described demonstrated that cases 3 and 6 considering 8-in. (20-cm) hose are not favorable alternatives. This is principally due to the disproportionate procurement costs (see Table 6). On the other hand, the previous analyses do not point to an obvious favorable alternative between cases 4 and 5. Because of this, it was decided to perform reliability and life cycle cost analyses on cases 1, 2, 4, and 5. This was accomplished by contract with the VSE Corporation. Their final report is included as the Appendix of this Technical Note.

Reliability models were developed according to guidance in MIL-HDBK-217. Reliability calculations for cases 1, 2, 4, and 5 were performed for systems 5 miles (8.0 km) in length having an elevation gradient of 50 ft/mi (9.5 m/km).

The life cycle cost analysis in the Appendix compares maintenance and replacement costs for cases 1, 2, 4, and 5 using the same 5-mile (8.0-km) systems considered in the reliability analysis. A ten-year cycle was assumed with 5,000 hours of operating time evenly distributed over the ten years.

Reliability and life cycle cost data for cases 1, 2, 4, and 5 have been extracted from the Appendix and tabulated in Table 7.

Results and Operational Considerations

The analytical results are tabulated in Tables 3, 4, 5, 6, and 7. The results in Table 3 show that the increased discharge head from the upgraded 800-gpm (0.0505-m^3/sec), 125-psi (862-kPa) pump set (cases 4, 5, and 6) provides significant improvements in increasing pump set spacing. Increased pump set spacing translates into less personnel required for operation of a cross-country fuel transfer system. At least one man is required at each booster pumping station due to the manual operating requirements for each pump set. Table 3 also shows substantial increases in pump set spacing due to parallel 6-inch (15-cm) hoses and 8-inch (20-cm) hose, cases 2, 5, and 3, 6, respectively. This too means less operating personnel; however, results of other analyses, discussed below, show drawbacks for the parallel 6-inch (15-cm) and 8-inch (20-cm) hose configurations.

Table 4 and Table 5 (metric version of Table 4) show the logistic burden for each case in terms of weight and volume. Volume is by far the most significant parameter since space aboard ships is almost always the limiting factor for equipment type stowage. The upgraded pump set (cases 4, 5, and 6) offers an obvious logistic advantage over the present pump set (cases 1, 2, and 3).

The upgraded pump set shows a similar advantage in Table 6, which lists estimated procurement costs for each case. The relatively high cost plus operational drawbacks of the 8-inch (20-cm) hose eliminates it from serious consideration. The operational drawbacks include its inefficient use in tank farms or for fuel transfer where quantities of 600 gpm (0.0379 m^3/sec) or less are required. The second drawback is that since 800-gpm (0.0505-m^3/sec) transfer flows are only required for a MAF-size operation, the addition of 8-inch (20-cm) hose to Marine Corps inventory would be cumbersome and inefficient for smaller amphibious operations. Having 8-inch (20-cm) hose in the AAFS also requires an equipment increase of special adapter fittings for interfacing existing 6-inch (15-cm) hardware.

The analyses to this point show cases 4 and 5 emerging as favorable solutions. However, questions regarding life cycle costs and reliability need to be addressed. The Appendix provides answers by comparing life cycle costs and reliability for cases utilizing 6-inch (15-cm) hose (i.e., cases 1, 2, 4, and 5). Table 7 shows comparative data extracted from the Appendix.

When Table 7 is consolidated with data from the other analyses above, case 4 emerges as an apparent most favorable system. However, as Table 3 implies, berm construction and operation for case 4 are more labor intensive, due to closer pump set spacing, when compared to case 5. This is offset to some degree by the increased labor to lay twice as much hose in case 5 as compared to case 4. CEL is currently investigating hose laying and retrieval methods that might be adapted for MARCORPS use. This work is being driven by advances in hose technology that may permit development of innovative hose laying and retrieval equipment. Fruition of this effort might cause the system (case 5) with parallel 6-inch (15-cm) hoselines to emerge more favorable than case 4 with the single 6-inch (15-cm) hoseline system.

As mentioned earlier, each reference case AAFS (i.e., the existing 600-gpm (0.0379-m^3/sec) system) has four of the existing model pump sets for beach unloading and overland transfer of fuel. Two of these pump sets are part of the beach unloading station. Of these two, one is intended for use in offloading fuel from shuttle craft and is connected in such a way (Figure 2) that it cannot receive fuel from the Navy offshore pipeline. The remaining three are series-connected (Figure 1) to form the overland transfer portion of the system. For the case 4 800-gpm (0.0505-m^3/sec) system to have about the same overland transfer distance capability as the existing 600-gpm (0.0379-m^3/sec) AAFS, hardware changes to each AAFS would be required as follows:

1. Modify the two existing pump sets in the booster pumping stations and at least one of the two existing pump sets in the beach unloading station so that each pump set will deliver 800 gpm (0.0505 m^3/sec) at a discharge pressure of 125 psi (862 kPa).

2. Add two complete booster pumping stations having the 800-gpm (0.0505-m^3/sec), 125-psi (862-kPa) pump sets.

Use of Table 3 with Figure 1-15 of Reference 2 shows that implementing the case 4 system in this way will result in an 800-gpm (0.0505-m^3/sec) overland transfer distance capability as follows:

Overland Transfer Distance Capability of One AAFS

Z		Existing 600-gpm (0.0379-m^3/sec) AAFS, Distance = $3L_r$		Case 4 800-gpm (0.0505-m^3/sec) AAFS, Distance = $5L_4$	
ft/mile	m/km	ft	km	ft	km
0	0.0	12,480	3.80	11,710	3.57
50	9.5	11,190	3.41	10,610	3.23
100	18.9	10,140	3.09	10,360	3.16
150	28.4	9,270	2.82	9,800	2.98
200	37.9	8,520	2.60	9,270	2.83
250	47.4	7,920	2.41	8,840	2.70
300	56.8	7,380	2.25	8,430	2.57
350	66.3	6,900	2.10	8,040	2.45
400	75.8	6,480	1.97	7,690	2.34
450	85.2	6,120	1.86	7,380	2.25
500	94.7	5,760	1.76	7,060	2.15

CONCLUSIONS

The conclusions developed as a result of this study can be summarized as follows:

1. To accomplish overland transfer at 800 gpm (0.0505 m^3/sec), a total of three pump sets from the beach unloading station and booster pumping stations in the AAFS should be upgraded to make them capable of delivering 800 gpm (0.0505 m^3/sec) at 125 psi (862 kPa). Also, two additional booster pumping stations having the upgraded pump sets should be added to each AAFS.

2. A single 6-inch (15-cm) hoseline should continue to be used to connect booster pump stations in the overland portion of the AAFS.

3. The use of dual 6-inch (15-cm) hoselines to connect booster pump stations should be reassessed if current work yields a labor-saving method for laying and retrieving hose.

4. Increasing the hose section length from the present 50 feet (15 m) would produce a significant increase in system reliablity.

FUTURE WORK

The RDT&E effort in the immediate future is directed toward (1) development of the upgraded pump set, (2) development of concepts for better transport and handling of the 6-inch (15-cm) hose, and (3) investigations of the feasibility of using hose lengths significantly longer than 50 feet (15 m).

Under a separate Work Unit, CEL is already developing for the AAFS pump sets an add-on control kit that monitors pump suction and discharge pressures and automatically regulates engine speed for maximum delivery. This development will increase the overall efficiency of fuel transfer by the pump sets. It may also eliminate the need for installation of one and perhaps both of the collapsible tanks at each booster pumping station. Therefore, it is planned that this control kit will be evaluated on development models of the upgraded pump sets, as well as on the existing sets.

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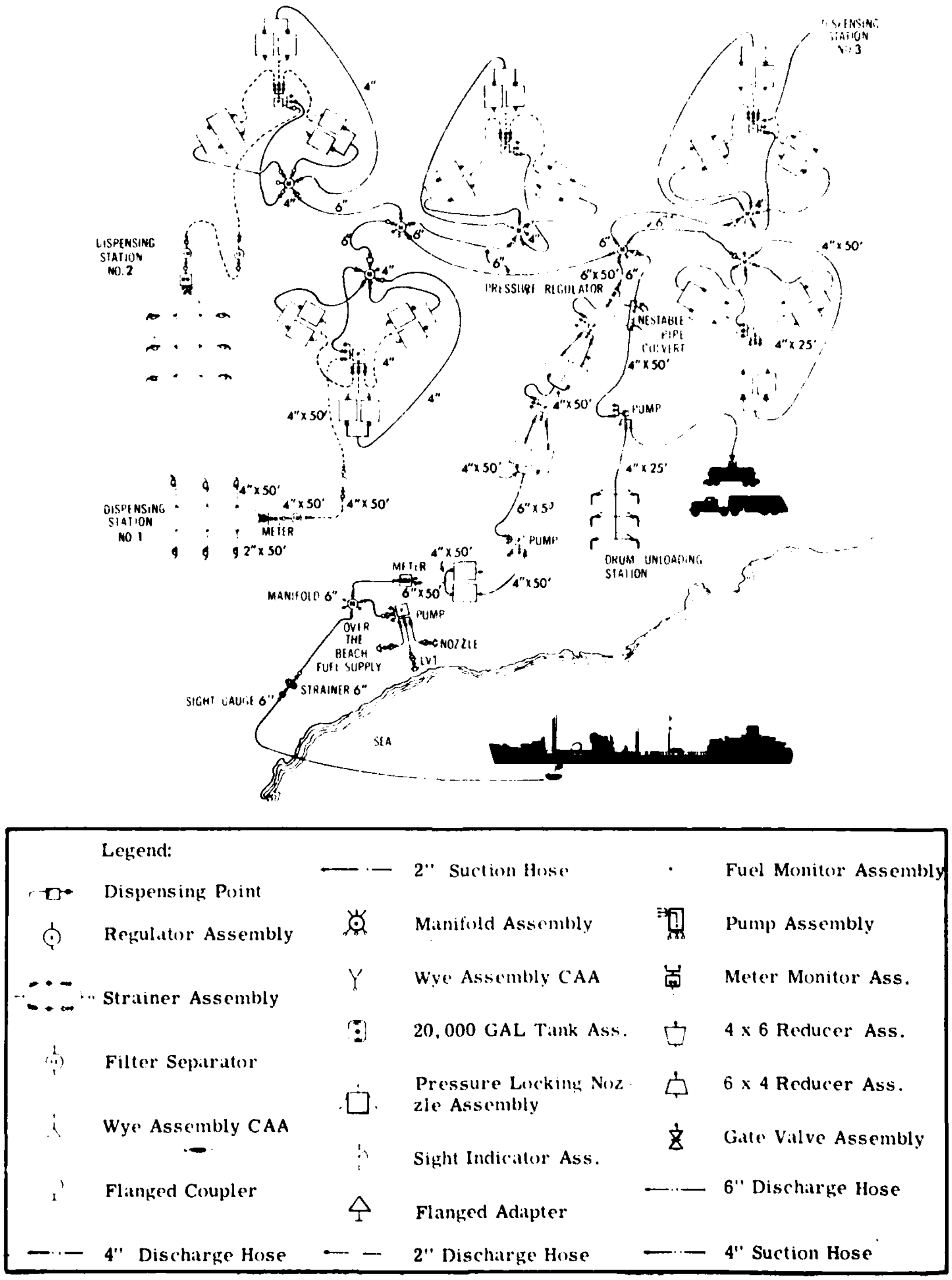


Figure 1. Amphibious assault fuel system (high capacity).

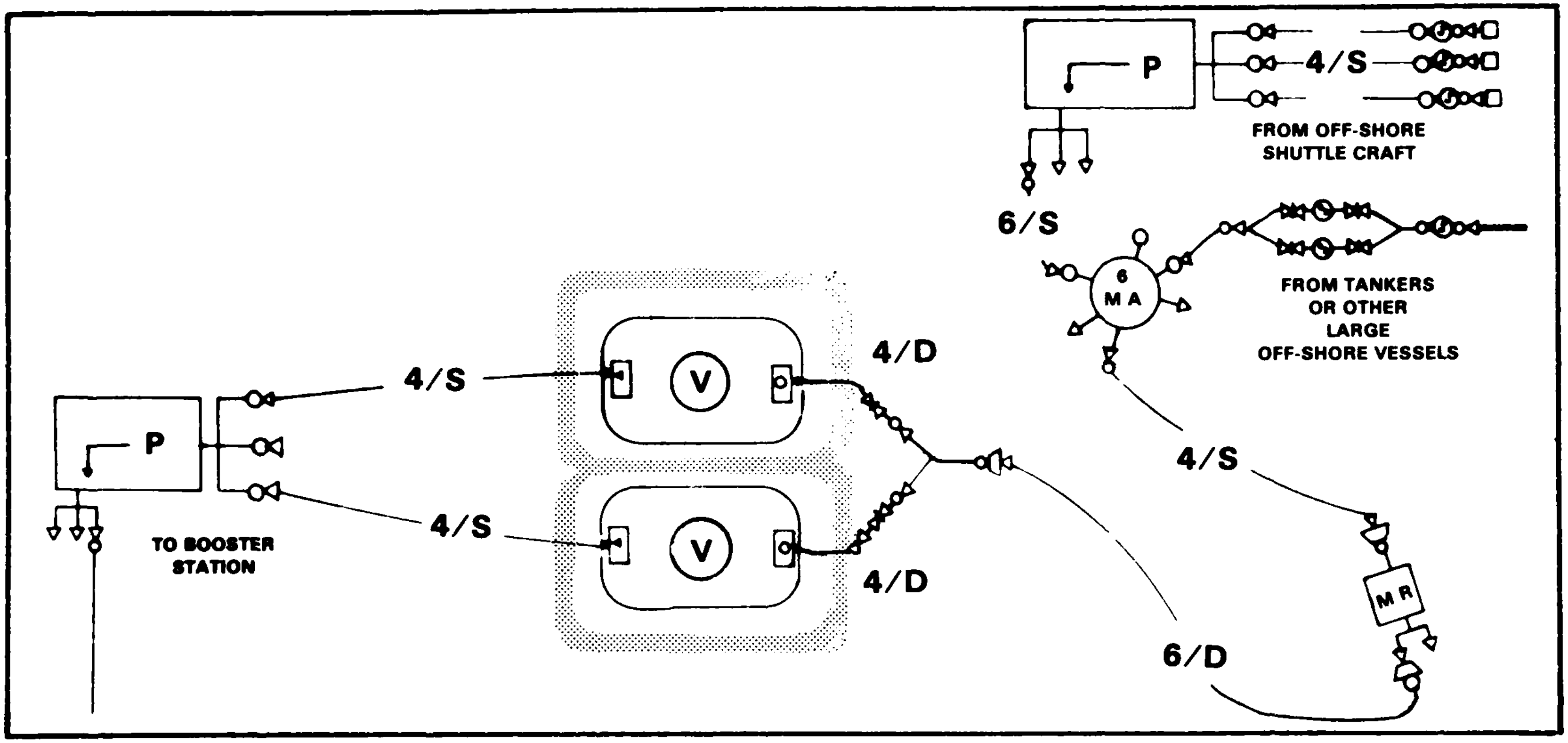
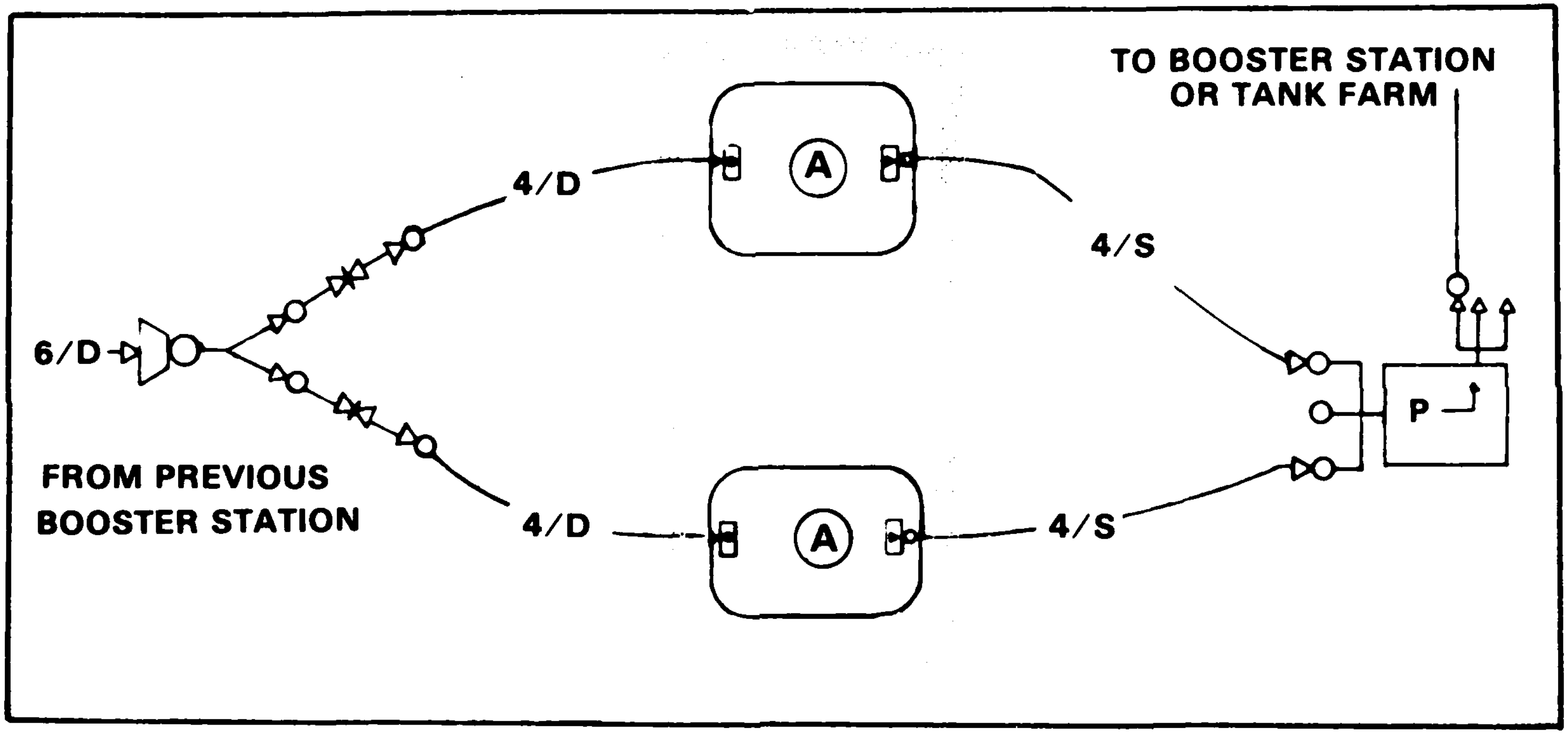


Figure 2. **BEACH UNLOADING STATION**



BOOSTER PUMP STATION

Figure 3. High capacity booster pumping station.

Figure 4. Influence of hose size/number and upgrading pump set on AAFS booster pumping station spacing.

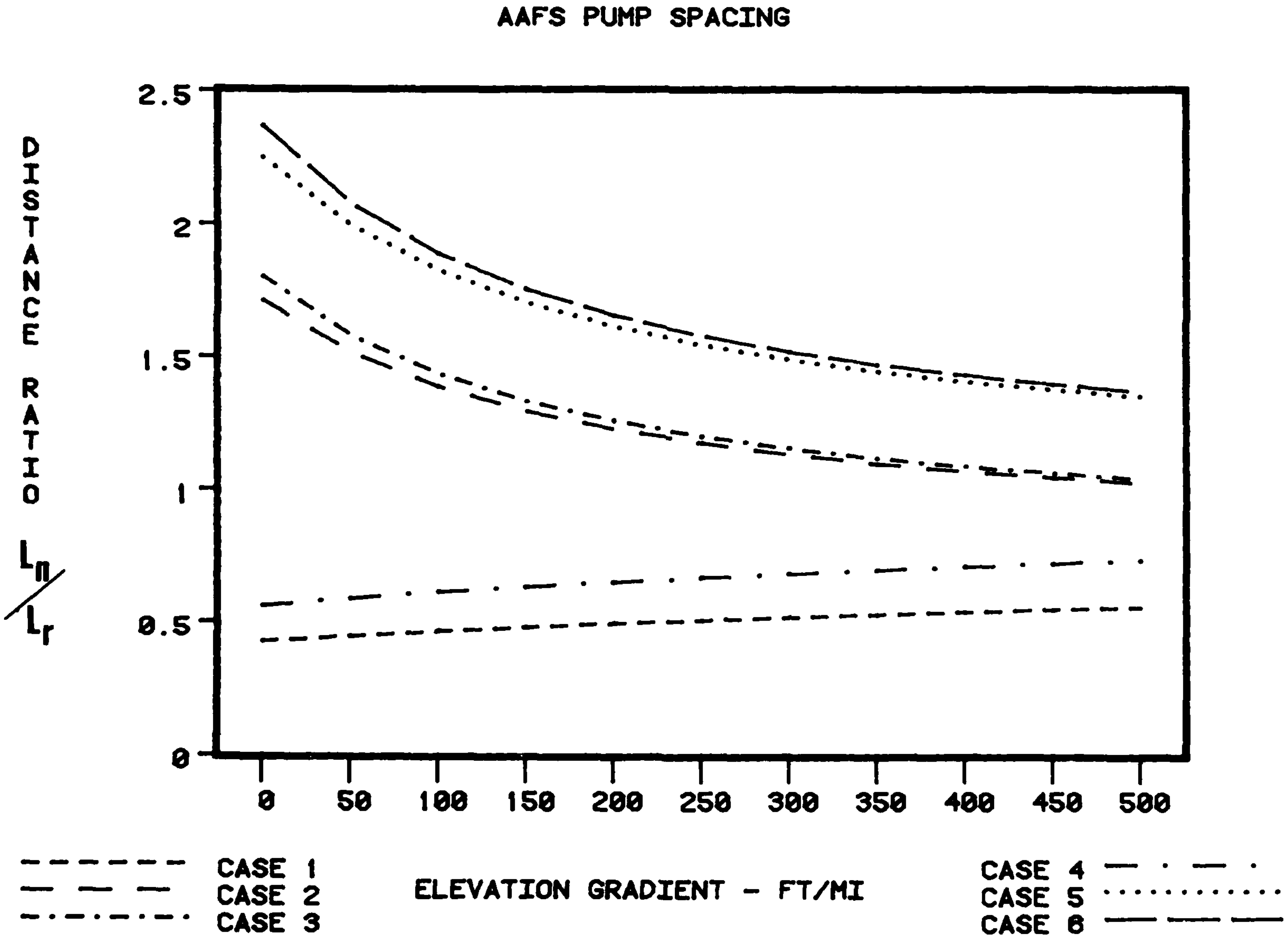


Table 1. Nomenclature and Units Used for Analysis

Symbol	Definition	Units or Value	
		English	SI
D	Hose diameter	in.	cm
f	Friction factor	none	none
K	A constant depending on units	165	83.2×10^{10}
L	Distance between adjacent pump stations (hose length)	ft	km
n	Subscript denoting nth case		
N	Number of parallel hoses connecting adjacent pump stations	none	none
ΔP	Pump discharge pressure = pressure drop in hose connecting adjacent pump stations	psi	kPa
Q	Flow rate	gpm	m^3/sec
r	Subscript denoting reference case		
Z	Hose elevation gradient between adjacent pump stations	ft/mile	m/km

Table 2. Case Identification

Item	Case						
	Reference	1	2	3	4	5	6
600 gpm (0.0379 m^3/sec) flow	x						
800 gpm (0.0505 m^3/sec) flow		x	x	x	x	x	x
Existing pump set	x	x	x	x			
Upgraded pump set					x	x	x
Single 6-in. (15-cm) hoseline	x	x			x		
Parallel 6-in. (15-cm) hoselines			x			x	
Single 8-in. (20-cm) hoseline				x			x

Table 3. Tabulation of Results of Pump Spacing Analysis

Z		Value of L_n/L_r for --					
ft/mile	m/km	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
0	0.0	0.428	1.710	1.801	0.563	2.250	2.370
50	9.5	0.448	1.514	1.578	0.589	1.993	2.076
100	18.9	0.466	1.385	1.433	0.613	1.823	1.886
150	28.4	0.482	1.294	1.332	0.634	1.703	1.753
200	37.9	0.496	1.226	1.258	0.653	1.613	1.655
250	47.4	0.509	1.174	1.200	0.670	1.544	1.579
300	56.8	0.521	1.132	1.155	0.685	1.489	1.519
350	66.3	0.531	1.097	1.117	0.699	1.444	1.470
400	75.8	0.541	1.069	1.087	0.712	1.406	1.430
450	85.2	0.550	1.045	1.061	0.724	1.375	1.396
500	94.7	0.558	1.024	1.039	0.735	1.348	1.367
∞	∞	0.760	0.760	0.760	1.000	1.000	1.000

Table 4. Tabulation of Logistic Burden Per Mile of Fuel Transfer Equipment

Equipment	Reference Case		Case 1		Case 2		Case 3		Case 4		Case 5		Case 6	
	lb	ft^3	lb	ft^3	lb	ft^3	lb	ft^3	lb	ft^3	lb	ft^3	lb	ft^3
Pump Sets[a]	2,164	700	4,643	1,502	1,563	506	1,510	489	3,530	1,142	1,187	384	1,148	372
Collapsible Tanks	8,930	235	19,162	503	6,448	170	6,232	164	14,567	383	4,899	129	4,735	125
Hoseline	12,461	951	12,461	951	24,922	1,901	28,320	2,160	12,461	951	24,922	1,901	28,320	2,160
Totals	23,555	1,886	36,266	2,956	32,933	2,577	36,062	2,813	30,558	2,476	31,008	2,414	34,203	2,657

[a] Based on pump set spacing for 100 ft/mile elevation gradient.

Table 5. Tabulation of Logistic Burden Per Mile (1.6 km) of Fuel Transfer Equipment (Metric)

Equipment	Reference Case		Case 1		Case 2		Case 3		Case 4		Case 5		Case 6	
	kg	m^3	kg	m^3	kg	m^3	kg	m^3	kg	m^3	kg	m^3	kg	m^3
Pump Sets*	982	20	2,106	43	709	14	685	14	1,601	32	538	11	521	11
Collapsible Tanks	4,051	7	8,692	14	2,925	5	2,827	5	6,608	11	2,222	4	2,148	4
Hoseline	5,652	27	5,652	27	11,305	54	12,846	61	5,652	27	11,305	54	12,846	61
Totals	10,685	54	16,450	84	14,938	73	16,358	80	13,861	70	14,065	69	15,514	76

*Based on pump set spacing for 18.9 m/km elevation gradient.

Table 6. Procurement Cost Comparisons Per Mile (1.6 km) of Fuel Transfer Equipment

Equipment	Dollars						
	Reference	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
Pump Sets*	24,214	51,960	17,483	16,897	43,322	14,568	14,081
Collapsible Tanks	12,498	26,818	9,024	8,720	20,387	6,856	6,627
Hoseline	61,618	61,618	123,236	223,767	61,618	123,326	223,767
Totals	98,330	140,396	149,743	249,384	125,327	144,660	244,475

*Based on pump set spacing for 100 ft/mile (18.9 m/km) elevation gradient.

Table 7. Reliability and Life Cycle Cost Data From the Appendix

Case	Reliability[a]	Life Cycle Cost[b] ($K)
1	0.87823	830
2	0.86390	1,073
4	0.88584	745
5	0.86423	1,096

[a] Based on equipment required for 5 miles (8.0 km) of cross-country fuel transfer with 50-foot (15-m) hose lengths and an elevation gradient of 50 ft/mile (9.5 m/km).

[b] Figures comprise maintenance and replacement costs for the same 5-mile (8.0-km) cross-country equipment operating for 5,000 hours evenly distributed over a 10-year period.

Appendix

RELIABILITY/LIFE CYCLE COST (LCC) ANALYSES, MARCORPS FUEL TRANSFER EQUIPMENT

CONTENTS

LIST OF FIGURES

LIST OF TABLES

I. INTRODUCTION

This report provides the results of a Reliability and Life Cycle Cost (LCC) Assessment conducted on MARCORPS Fuel Transfer Equipment.

The MARCORPS Fuel Transfer Equipment is described in Civil Engineering Laboratory draft of proposed Technical Memorandum (TM) No.

"Influence of Overland Transfer Hose Size Number and Pump Set Choice on MARCORPS Amphibious Assault Fuel System."

The reliability assessment was performed by developing a Reliability Model for each of four equipment configurations (Cases one, two, four and five), assigning comparative failure rates and exercising each model to determine a comparative result of reliability (probability of success) of each specific configuration.

The LCC assessment was performed by assigning costs to each anticipated maintenance action based on the frequency of repair and expected replacement due to useful life limitation.

A. Purpose

To perform reliability and LCC assessment of four equipment configurations of MARCORPS Fuel Transfer Equipment to determine which configuration provides the highest reliability and lowest LCC.

B. Scope

The reliability and LCC assessment of the four equipment configurations (Cases one, two, four and five) of MARCORPS Fuel Transfer Equipment encompassed a detailed study of the Technical Memorandum, establishing telephone contact with the hose, coupling, pump and diesel manufacturers and researching various reliability textbooks and data banks for failure rate data.

The equipment configuration for each case was determined from the previously mentioned TM and a Reliability Model was developed for each configuration. MIL-HDBK-217 provided guidance in the development of the models. Each Case model was exercised with the results providing the reliability of each case.

The total number of repairs, overhauls, and replacements and repair costs associated with each of these actions were determined to provide the comparative LCC analysis.

II. RELIABILITY

A. Summary

The reliability assessment produced the results listed in table I. These comparative values are based on the capability to provide a continuous fuel supply of 800 gpm over five miles at an elevation gradient of 50 feet per mile.

TABLE I. RELIABILITY ASSESSMENT RESULTS

Case	Description	Reliability
1	800 gpm, single 6-inch line, 95 psi	0.87823
2	800 gpm, dual 6-inch line, 95 psi	0.86390
4	800 gpm, single 6-inch line, 125 psi	0.88584
5	800 gpm, dual 6-inch line, 125 psi	0.86423

Both single line Cases (one and four) produced higher comparative reliability over the dual line counterparts. This is attributed to the reduced number of hoses/couplings required in the single line over the dual line.

B. Technical Approach

The technical approach used in determining the reliability (e.g. probability of success - to provide 800 gpm continuously) is to define the components required for each case, develop a reliability model, establish and/or determine the failure rates of each component, and exercise the model by inserting the failure rates. The results of exercising the model will provide the reliability.

An analysis of TM No.   "Influence of Overland Transfer Hose Size/Number and Pump Set Choices on MARCORPS Amphibious Assault Fuel System", subsequent direction and discussion with CEL personnel, and for purposes of this analysis, the MARCORPS Fuel Transfer Equipment consists of:

1. Diesel, 3-53/3-53T
2. Pump, Model 604
3. Hoses, 6-inch and 4-inch, 50-foot lengths
4. Hose Couplings
5. Fuel Bladder

The following reference information was used in the reliability analysis and extracted directly from the previously referenced TM.

CASE IDENTIFICATION

Case No. 1	800 gpm flow, single 6-inch hose, 95 psi
Case No. 2	800 gpm flow, dual 6-inch hose, 95 psi
Case No. 4	800 gpm flow, single 6-inch hose, 125 psi
Case No. 5	800 gpm flow, dual 6-inch hose, 125 psi

PUMP SPACING ANALYSIS

ft/mile*	M/KM	Case 1	Case 2	Case 4	Case 5
50	9.5	0.448	1.514	0.509	1.993

*Hose elevation gradient

The factors presented in the reference information for each case are then multiplied by 3,730 feet to determine the pump spacing. The table on page 8 of the referenced TM establishes this reference distance (L_R = 3,730 feet) when the hose elevation gradient is 50 ft/mile. Figure 1 shows the impact of elevation gradient on reliability.

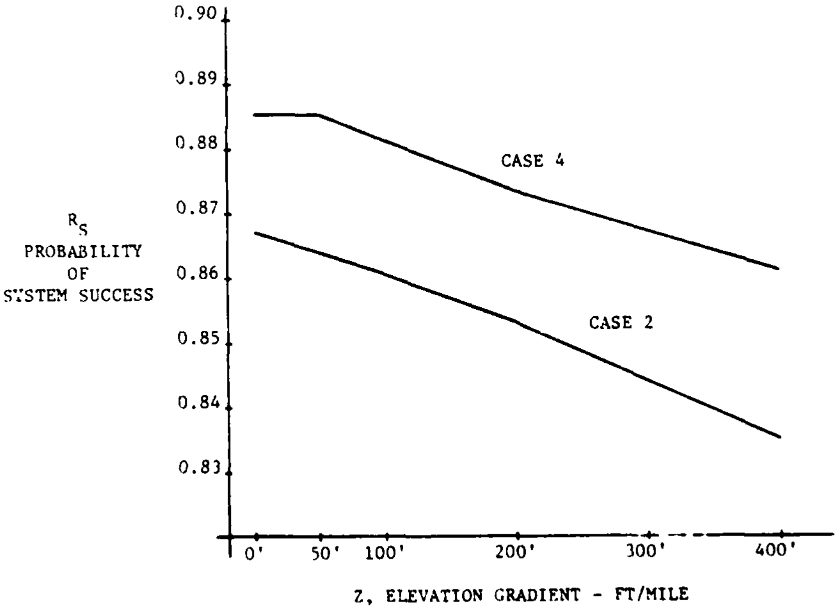


Figure 1. Elevation Gradient versus Reliability

Figure 1 reveals the impact of the elevation gradient upon system reliability. The reliability for two sample cases (two & four) was calculated at Z=0 ft/mi, 50 ft/mi, 100 ft/mi, 200 ft/mi and 400 ft/mi. The distance was held constant at five miles (26,400 feet).

From reliability modeling, it was determined that case four was the most reliable and case two was the least reliable system of the four configurations examined. The reliability curves reveal a gradual degradation of system reliability as the elevation gradient increases. This degradation is due chiefly to the increased number of pumps required to transport fuel over higher elevations. For example, in the Case four configuration, twelve pump sets are required at Z=0 ft/mile, while 18 pump sets are needed at Z=400 ft/mile.

Quantities of 50-foot hoses and pump sets for each Case (one, two, four and five) were determined by a model distance of five miles (26,400') with an elevation gradient of 250 feet (50 feet/mile).

To determine the number of 50-foot hose lengths, the distance of 26,400 feet, was divided by 50, which equals 528. The combination of fuel bladders and 4-inch suction/discharge hoses reduces the 6-inch hose quantities by two for each pumping station.

The number of pump sets for each Case was determined by multiplying the reference distance (L_R = 3,730 feet) by each Case's pump spacing factor (for Z = 50 ft/mile, gradient) and then dividing the results into the total distance (26,400 feet). For Case one, the pump spacing factor is 0.448, so the computation would be:

$$3730' \times 0.448 = 1671'$$

$$26{,}400' \div 1671' = 15.8$$

The value derived from this calculation is rounded up to <u>16</u> to determine an adequate number of pumping stations.

MIL-HDBK-217 provides the direction in developing the reliability model. A reliability model was constructed and based on those active elements of the system relative to a cross-country routing of the Amphibious Assault Fuel System (AAFS). Tank farms, dispensing stations, beach unloading stations, monitor and pressure regulator assemblies were excluded from this study. The models for each Case are illustrated in figures 2 through 5. The relaibility model represents the series path and associated equipment for accomplishing the fuel transfer function at the specified flow rate of 800 gpm. A series path as illustrated in figures 2 through 5 indicates that all fuel transfer equipment is required to accomplish the function of delivering fuel at 800 gpm.

For purposes of comparing the reliability of each Case, it is assumed that all components exhibit useful life characteristics. Component reliability, as defined in MIL-HDBK-217, a probability of success with respect to time is represented by:

$$R(t) = e^{-\lambda_c t}$$

where: t = mission time

λ_c = component failure rate

For a series path, the reliability is the product of individual component reliability. The mathematic expression would be:

$$R_s(t) = (e^{-\lambda_{c_1} t}) (e^{-\lambda_{c_2} t}) (e^{-\lambda_{c_3} t}) \cdot \cdot \cdot (e^{-\lambda_{c_8} t})$$

t = mission time

$\lambda_{c_1}\ \lambda_{c_2}\ \lambda_{c_3}, \ldots, \lambda_{c_8}$: component failure rates.

The component failure rate for the Fuel Transfer Equipment are contained in table 2. Sources are provided adjacent to the failure rate. All failure rates (lambda:λ) are expressed in failures, per 10^6 hours.

The mission time (t), was provided by CEL personnel; for purposes of this assessment, the mission time was 20 hours/day.

The failure rates, as reflected in table 2, are then inserted in the model. The series mathematical expression is then computed, resulting in the reliability of the model. Computations for each Case are contained with the model. The models for each Case are illustrated in figures 2 through 5.

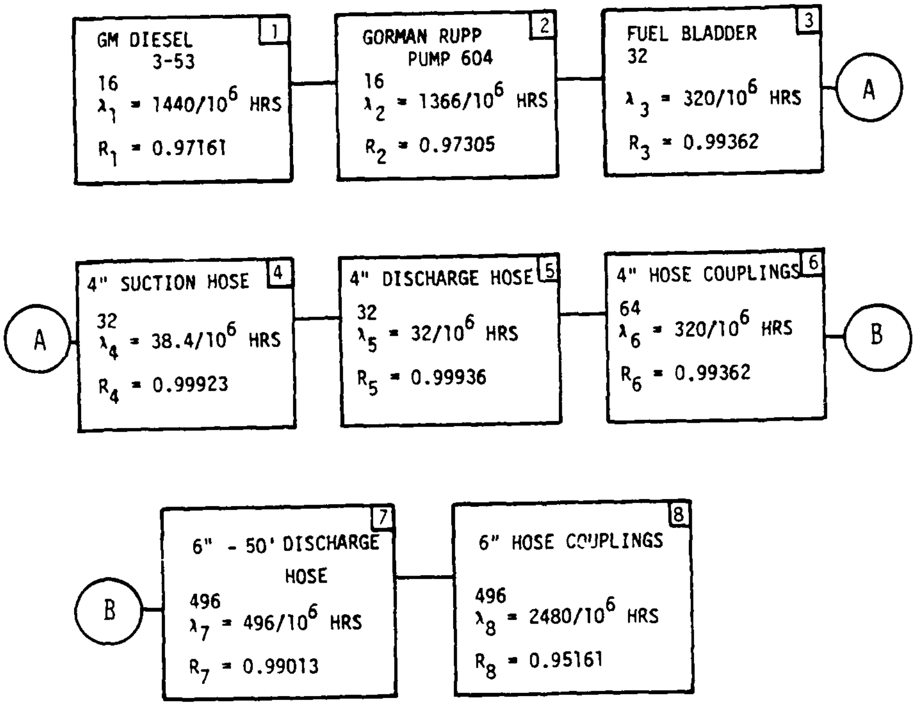
TABLE 2. COMPONENT FAILURE RATES

Equipment	λ	Data Source
1. GM Diesel 3-53	90	Mechanical Fault Diagrams R. A. Collacott, 1977
2. GM Diesel 3-53T Turbocharger	112.5	25% increase over diesel model per phoncons J. Crider and W. G. Thorsby, GM Diesel, Dec 11, 1979
3. Pump (Gorman Rupp 604) used with 3-53	85.4	NAVSEC Reliability-Maintainability Data Bank - 1975
4. Pump (Gorman Rupp 604) used with 3-53T	93.5	10% increase over pump (in item 3.) per phoncon J. Crider and R. Owens, Gorman-Rupp, Dec 27, 1979
5. Hose, 6" & 4", Discharge (Used with 95 psi system)	20*	Reliability Technology, A. G. Green and A. J. Bourne, 1977
6. Hose, 4", Suction (Used with 95 psi system)	24*	20% increase over suction 95 psi per phoncons between J. Crider and R. Furness, Uniroyal, Jan 7, 1980
7. Hose, 6" & 4", Discharge (Used with 125 psi system)	21*	5% increase over 95 psi per phoncons between J. Crider and R. Furness, Uniroyal, Jan 7, 1980
8. Hose, 4", Suction (Used with 125 psi system)	25*	20% increase over suction 125 psi per phoncons between J. Crider and R. Furness, Uniroyal, Jan 7, 1980
9. Hose Coupling	5	Bourne, 1977
10. Fuel Bladder	10	Bourne, 1977

*per 1000 feet

CASE 1: 800 GPM, $D_1 = 6"$, $N_1 = 1$, $\Delta P_1 = 95$ psi

$Z = 50'/\text{MILE}$



Reliability Prediction Analysis

Pump Spacing: $L_1 = 3730'(.448) = 1671' \geqslant 1650'$

1) No. of Pump Sets: 16

2) No. of 4" - Discharge Hose Lengths: 32

3) No. of 4" - Suction Hose Lengths: 32

4) No. of Fuel Bladders: 32

5) No. of 6" - Discharge Hose Lengths: 496

6) Sample Serial Component Reliability Computation:

$$R_7(t) = e^{-\lambda_7 t};\ R_7(20) = e^{-(.00992)} = 0.99013$$

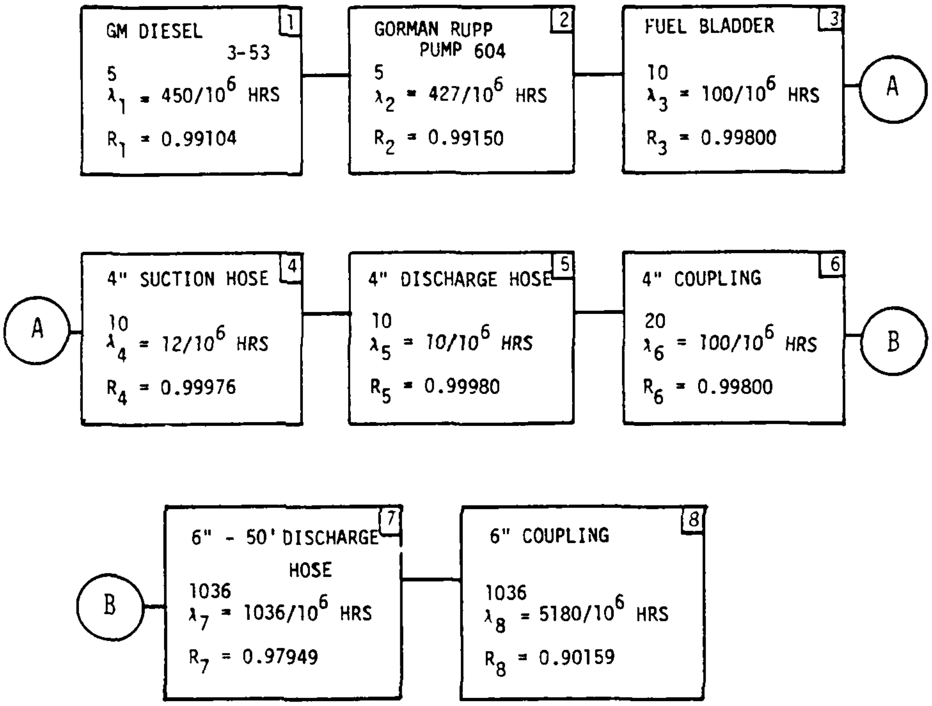
7) System Reliability Computation:

$$R_{s_1}(t) = \prod_{i=2}^{8} R_i(t);\ R_{s_1}(20) = \prod_{i=1}^{8} R_i(20) = \underline{0.87823}$$

Figure 2. Reliability Model, Case 1

CASE 2: 800 GPM, $D_2 = 6"$, $N_2 = 2$, $\Delta P_2 = 95$ psi

$Z = 50'$/MILE



Reliability Prediction Analysis

Pump Spacing = L_2 = 3730' (1.514) = 5647' ⇒ 5600'

1) No. of Pump Sets: 5

2) No. of 4" - Discharge Hose Lengths: 10

3) No. of 4" - Suction Hose Lengths: 10

4) No. of Fuel Bladders: 10

5) No. of 6" - Discharge Hose Lengths: 1036

6) Sample Serial Component Reliability Computation:

$$R_7(t) = e^{-\lambda_7 t};\ R_7(20) = e^{-(.02072)} = 0.97949$$

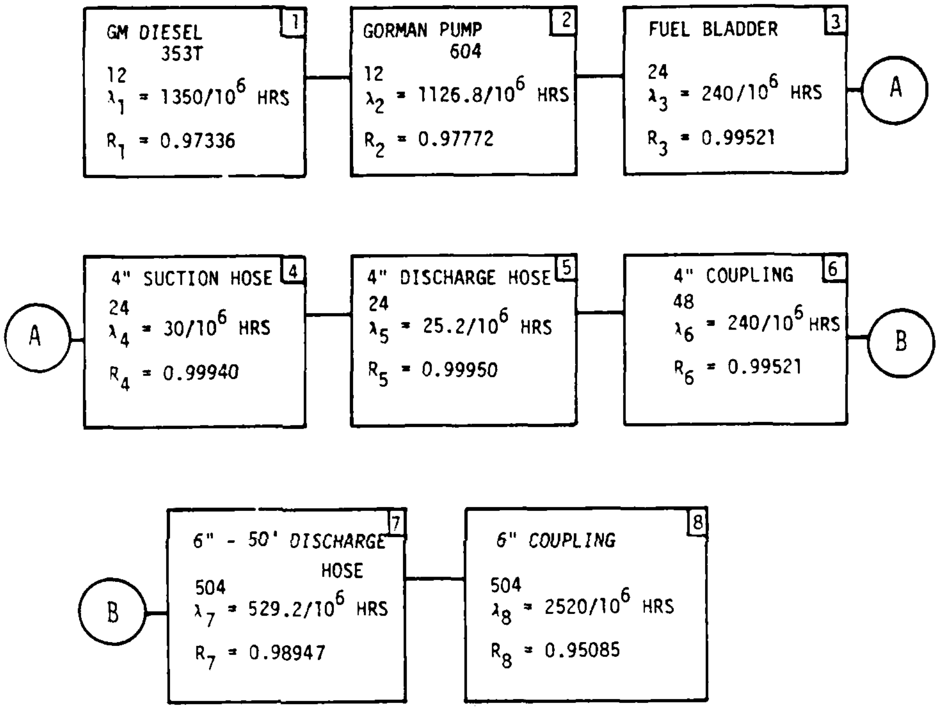
7) System Reliability Computation:

$$R_{s_2}(t) = \prod_{i=1}^{8} R_i(t);\ R_{s_2}(20) = \prod_{i=1}^{8} R_i(20) = \underline{0.86390}$$

Figure 3. Reliability Model, Case 2

CASE 4: 800 GPM, D_4 = 6", N_4 = 1, ΔP_4 = 125 psi

Z = 50'/MILE



Reliability Prediction Analysis

Pump Spacing: L_4 = 3730'(.589) = 2197' $\geqslant$ 2150'

1) No. of Pump Sets: 12

2) No. of 4" - Discharge Hoses Lengths: 24

3) No. of 4" - Suction Hose Lengths: 24

4) No. of Fuel Bladders: 24

5) No. of 6" - Discharge Hose Lengths: 504

6) Sample Serial Component Computation:

$$R_7(t) = e^{-\lambda_7 t};\ R_7(20) = e^{-(.010584)} = 0.98947$$

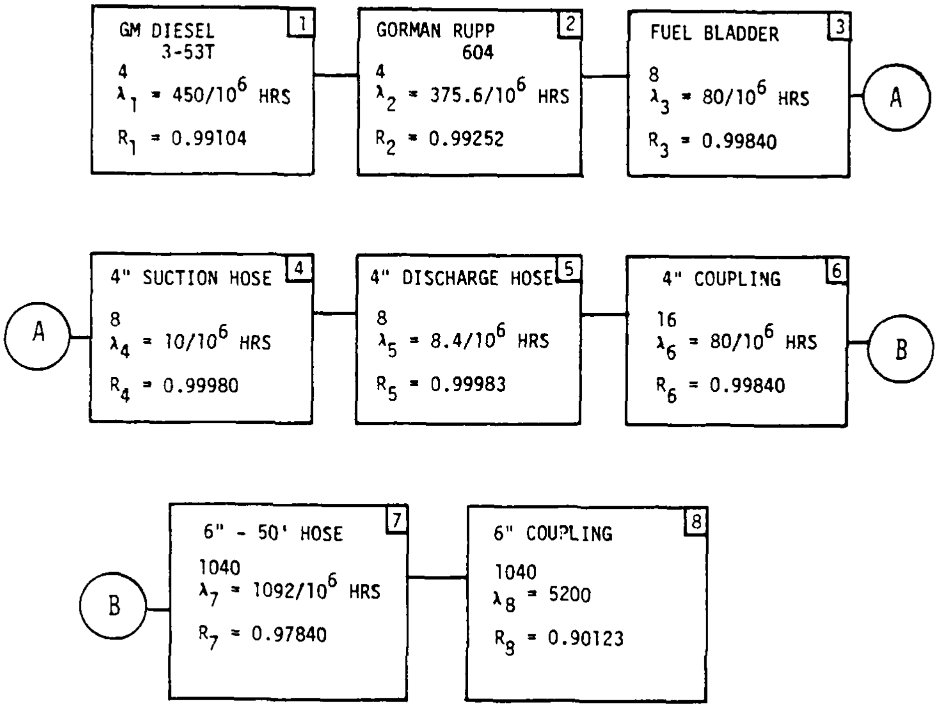
7) System Reliability Computation:

$$R_{s_4}(t) = \prod_{i=1}^{8} R_i(t);\ R_{s_4}(20) = \prod_{i=1}^{8} R_i(20) = \underline{0.88584}$$

Figure 4. Reliability Model, Case 4

CASE 5: 800 GPM, $D_5 = 6"$, $N_5 = 2$, $\Delta P_5 = 125$ psi

$\bar{Z} = 50'/\mathrm{MILE}$



Reliability Prediction Analysis

Pump Spacing = L_5 = 3730'(1.993) = 7434' $\geqslant$ 7400'

1) No. of Pump Sets: 4 3) No. of 4" - Suction Hose Lengths: 8

2) No. of 4" - Discharge Hose Lengths: 8 4) No. of Fuel Bladders: 8

5) No. of 6" - Discharge Hose Lengths: 1040

6) Sample Serial Component Reliability Computation:

$$R_7(t) = e^{-\lambda_7 t};\ R_7(20) = e^{-(.02184)} = 0.97840$$

7) System Reliability Computation:

$$R_{s_5}(t) = \prod_{i=1}^{8} R_i(t);\ R_{s_5}(20) = \prod_{i=1}^{8} R_i(20) = \underline{0.86423}$$

Figure 5. Reliability Model, Case 5

III. LIFE CYCLE COST (LCC)

A. Summary

The LCC analysis is based on the anticipated number of repairs, overhauls and replacements of each Fuel Transfer Equipment Component, for 5000 hours of operation, over a 10 year period. The results of the assessment are:

Case 1	$ 829,154
Case 2	$1,072,385
Case 4	$ 744,148
Case 5	$1,095,068

The major cost factor in this comparative LCC analysis was the replacement of hoses due to the expected useful life. The hoses are non-repairable and would require replacement twice during the LCC scenario. Those cases which have the greatest number of hoses (both dual line) are cases two and five.

B. Technical Approach

The technical approach used in determining the LCC associated with each case is to determine, for each fuel transfer equipment component, the anticipated number of repairs and/or replacements, based upon the random failure rate of the component supplemented with storage/shelf-life characteristics. Repair/replacement costs are then estimated and the number of repairs/replacements throughout the life cycle of 10 years and 5000 hours of operation is determined. The product of the number of repairs/replacement and estimated costs provide the total LCC for the component.

The information for each fuel transfer equipment component was extracted from Technical Manual TM-06674A-15 and telephone conversations with equipment manufacturers. This information provides the basis for supplementing the number of random failures resulting in repairs/replacements during the life cycle and establishing the estimated repair costs.

The GM Diesels 3-53 and 3-53T are completely repairable and will require a complete overhaul every 3000-5000 hours of operation. Standard maintenance practices are to make repairs until the age and cost of the repair exceed a predicted life expectancy. The repair costs are cumulative and a determination by the secondary repair facility on whether a component will be repaired or discarded is made at that time. For purposes of this comparative LCC, it is assumed that the diesels will be completely repairable and require one major overhaul during the 10 years - 5000 hours of operation. Average estimated repair costs for each random failure is $200, with a complete overhaul costing approximately $2500, based on a telephone conversation with diesel manufacturer personnel.

The pump is a completely repairable component. Shaft seals have the highest mortality, with a useful life of approximately two years, based upon a telephone conversation with manufacturing personnel. The useful life is based on continuous operation of approximately 2000 hours/years. The average estimated repair costs for each random failure is $100. One additional repair, estimated at $5000, for shaft seal replacement, is postulated for the 10 year - 5000 hours of operation.

The fuel bladder is non-repairable. Useful life with intermittent use is estimated between two and three years and shelf life is estimated between three and five years. The estimated failure rate and two replacements for each fuel bladder is used to determine the number of replacements during the 10 year- 5000 hour scenario. The replacement cost is $4000.

Hoses are non-repairable unless the rupture is close to the coupling or only the outside material is frayed. For purposes of this analysis, all hose repairs are remedied by hose replacement. The Technical Memorandum indicates a cost of $9.18/ft for a 6-inch hose. For a 50 foot length, the cost for a hose replacement is $459. The couplings are assumed to be reusable. In addition, the useful life of the hoses is three years with intermittent use, and five to seven years in storage. In addition to the random failures, it is estimated that all hoses will be replaced twice during the 10 year LCC scenario. The cost replacement will be $459. The same rationale will be used for the 4-inch suction and discharge hoses.

With the exception of some minor repairs (gaskets, handle replacement) the repair of all couplings is performed by replacement. Replacement costs are estimated at $100.00.

Tables 3 through 6 present the LCC for each Case. The Component column indicates components which comprise the fuel transfer equipment. The Quantity column lists the total amount of components. The λ_{tot} column represents the total failure rate contribution for that component. The number listed is expressed in failures, per 10^6 hours. The Number of Repairs / Overhauls/Replacements column is calculated by multiplying the 5000 hours of operation and the failure rate to derive the number of times a specific component will be repaired in 5000 hours of operation. The numbers shown at the right of the slash mark are an estimate of the number of overhauls or replacements planned during the LCC scenario.

The Repair Cost column shows the average repair/replacement cost for the repair of a specific component. The number shown at the right of the slash mark indicates the overhaul or replacement cost. The Total column is calculated by multiplying the number of repairs by the repair cost and adding the product of the number of overhauls/replacements and overhauls/replacements costs.

Table 3. CASE 1 - 800 gpm, single 6-inch line, 95 psi

Component	Qty	λ_{tot}	Number of Repairs/overhauls-Replacements	Repair Costs	Total
1. GM Diesel 3-53	16	1440	7.2/16	$ 200/2500	$ 41,440
2. Pump	16	1366	6.83/16	100/500	8,663
3. Fuel Bladder	32	320	1.6/64	4000/4000	262,400
4. 4" Suction Hose	32	38.4	0.192/64	459/459	29,464
5. 4" Discharge Hose	32	32	0.16/64	459/459	29,449
6. 4" Hose Coupling	64	64	0.32	100	32
7. 6" Discharge Hose	496	496	2.48/992	459/459	456,466
8. 6" Hose Coupling	496	2480	12.4	100	1,240
					$829,154

Table 4. CASE 2 - 800 gpm, dual 6-inch line, 95 psi

Component	Qty	λ_{tot}	Number of Repairs/overhauls-Replacements	Repair Costs	Total
1. GM Diesel 3-53	5	450	2.25/5	$ 200/2500	$ 12,950
2. Pump	5	427	2.135/5	100/500	2,713
3. Fuel Bladder	10	100	0.5/20	4000/4000	82,000
4. 4" Suction Hose	10	12	0.6/20	459/459	9,455
5. 4" Discharge Hose	10	10	0.05/20	459/459	9,202
6. 6" Hose Coupling	20	100	0.5	100	50
7. 6" Discharge Hose	1036	1036	5.18/2072	495/495	953,425
8. 6" Hose Coupling	1036	5180	25.9	100	2,590
					$1,072,385

Table 5. CASE 4 - 800 gpm, single 6-inch line, 125 psi

Component	Qty	λ_{tot}	Number of Repairs/overhaul-Replacements	Repair Costs	Total
1. GM Diesel 3-53 T	12	1350	6.75/12	$ 200/2500	$ 31,350
2. Pump	12	1126.8	5.63/12	100/150	6,563
3. Fuel Bladder	24	240	1.2/48	4000/4000	196,800
4. 4" Suction Hose	24	30	0.15/48	459/459	22,100
5. 4" Discharge Hose	24	25.2	0.126/48	459/459	22,089
6. 4" Hose Coupling	48	240	1.2	100	120
7. 6" Discharge Hose	504	529.2	2.646/1008	459/459	463,886
8. 6" Hose Coupling	504	2520	12.6	100	1,260
					$744,148

Table 6. CASE 5 - 800 gpm, dual 6-inch line, 125 psi

Component	Qty	λ_{tot}	Number of Repairs/overhaul-Replacements	Repair Costs	Total
1. GM Diesel 3-53 T	4	450	2.25/4	$ 200/2500	$ 10,450
2. Pump	4	375.6	1.88/4	100/500	2,188
3. Fuel Bladder	8	80	0.4/16	4000/4000	65,600
4. 4" Suction Hose	8	10	0.05/16	459/459	7,366
5. 4" Discharge Hose	8	8.4	0.04/16	459/459	7,366
6. 4" Hose Coupling	16	80	0.4	100	40
7. 6" Hose Discharge	1040	1092	5.46/2184	459/459	1,004,962
8. 6" Hose Coupling	1040	5200	26	100	2,600
					$1,096,068

EFFECT OF 6" - 400' DISCHARGE HOSE LENGTHS UPON SYSTEM RELIABILITY

The following assessment provides for the option of including 6" - 400' discharge hose lengths (in lieu of 50' hose lengths) as an integral part of the AAFS configurations - cases one, two, four and five. With distances less than 400' remaining between pump sets, 50' hose lengths were incorporated. The model distance of 26,400' and the elevation gradient of 50'/mile were retained from the initial analysis. The comparisons in system reliability between 400' hose length and 50' hose length configurations are:

Case Number	R_S(400' Hose Length)	R_S(50' Hose Length)
1	0.91590	0.87823
2	0.94488	0.86390
4	0.92254	0.88584
5	0.94391	0.86423

Computations were made in the same manner as presented in figures 2 through 5 in the body of this report. The increase in reliability (of 400' hose length configuration over 50' hose length configuration) is directly related to the decrease in the amount of 6" hose couplings employed. For each 400 feet of 6" discharge hose, the number of couplings decreased by 88 per cent, a factor significant enough to effect system reliability.

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