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Use of Central Vehicle Wash Facilities in Cold Weather

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The use of existing Central Vehicle Wash Facilities (CVWFs) is limited to above-freezing temperatures. Subfreezing temperatures and a wet environment present safety and health hazards to troops using a wash facility and interfere with the operation of the recycle wash water treatment. Icy surfaces limit control of vehicles and increase the chance of collisions and damage to the vehicles and the facility. Ice will damage plumbing, valves, and waste water treatment structures. This report describes design and operational factors which must be considered when planning and designing a cold weather wash facility. The information can be used to amend existing design guidance for CVWFs and as guidance for retrofitting of existing facilities.

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The use of existing Central Vehicle Wash Facilities (CVWFs) is limited to above-freezing temperatures. Subfreezing temperatures and a wet environment present safety and health hazards to troops using a wash facility and interfere with the operation of the recycle wash water treatment. Icy surfaces limit control of vehicles and increase the chance of collisions and damage to the vehicles and the facility. Ice will damage plumbing, valves, and waste water treatment structures. This report describes design and operational factors which must be considered when planning and designing a cold weather wash facility. The information can be used to amend existing design guidance for CVWFs and as guidance for retrofitting of existing facilities.

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FOREWORD

This report was prepared for the Directorate of Military Programs, Headquarters, U.S. Army Corps of Engineers (HQUSACE), under Project 4A162720A896, "Environmental Quality Technology"; Task Area B, "Environmental Design and Construction"; Work Unit 052, "Technology for Vehicle Cleaning in Adverse Conditions." The applicable Mission Area Deficiency Statement (MADS) is 4.02.003. The HQUSACE technical monitor was Fred Eubank, CEMP-RT.

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COL Everett R. Thomas is Commander and Director of USACERL, and Dr. L.R. Shaffer is Technical Director.

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USE OF CENTRAL VEHICLE WASH FACILITIES IN COLD WEATHER

1 INTRODUCTION

Background

Most major Army installations need to perform maintenance and repair on large numbers of tactical vehicles. An important element of vehicle maintenance is cleaning, including washing the exterior of the vehicles. The exterior of a vehicle must be clean to find any leaks or damaged parts, and to make necessary repairs. It must also be clean for transport from one installation to another or to travel within an installation cantonment area. (During wet weather, a tracked vehicle may carry 1000 lb* of mud back to the cantonment area.) If the vehicles are not cleaned before entering the main post area, mud will be dropped on streets and roadways, where it must be removed by Roads and Grounds personnel.

The concept for Central Vehicle Wash Facilities (CVWFs), developed at USACERL in the late 1970s, allows the exterior of tactical vehicles to be cleaned in an efficient and environmentally safe manner. A CVWF consists of various structures for washing tactical vehicles and a wastewater treatment system for recycling the wash water. Information concerning the planning and design of CVWFs is contained in (draft) Technical Manual (TM) 5-814-9 *Central Vehicle Wash Facilities for TOE Vehicles and Equipment.*

No existing CVWFs were designed to be used in cold weather. While tactical vehicles are used during training exercises throughout the year, it was thought that vehicle soiling would be marginal when the ground is frozen. Winter operation was excluded from the project scope during the planning and programming phases of those facilities. It was assumed the additional expense of cold weather operation could not be justified.

However, requirements for winter washing have been reevaluated. The most severe soiling of vehicles may occur during cold weather, when subfreezing nighttime temperatures are followed by above-freezing daytime temperatures. Frozen mud and slush soften during warm or sunny periods and attach to the tactical vehicles during training exercises. After the temperature drops below freezing, the vehicles return to the cantonment area carrying hundreds of pounds of frozen mud and slush.

These conditions were never more evident than during the Reforger exercise in the winter of 1986. The Army went to great expense to temporarily retrofit the CVWF at Grafenwohr, Federal Republic of Germany, for winter washing. Two huge tents were erected, at a cost of $50,000 each, one to cover the prewash structures and the second to cover the final wash stations. All above ground piping was insulated. The energy costs for this single operation were also very high. Large oil-fired, coil-type, water heaters were used to heat both the settling basin and the supply basin, and a mat of floating styrofoam was placed over each basin to minimize heat losses. Hot air furnaces used to heat each of the tents put out 300,000 Btus/hour. Heating water in one of the basins used 6,000,000 Btus/hour.**

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* Metric conversion factors are given on p 21.

** Reforger information was obtained directly from Grafenwohr DEH personnel, July 1986.

Problems with the CVFW occurred during the Reforger exercise. Fogging inside the tents caused poor visibility. Exhaust from the vehicles maneuvering inside the tents created a health hazard. Floating oils on the settling basin adhered to the floating styrofoam and became a clean-up problem at the end of the exercise. Vehicles were extremely soiled, causing long wash times. In fact, the mud in the training area was so severe that maneuvers could not be performed, and the Reforger exercise was cut short.

Current CVWF design guidance does not address the use of wash facilities in subfreezing temperatures. Experiences in the United States and exercises such as Reforger have indicated the need for design and operational guidance for cold weather washing.

Objective

The objective of this report is to describe design and operational factors which must be considered when planning and designing or retrofitting a CVWF for cold weather use.

Approach

To develop a definitive understanding of the problems of cold water washing, USACERL researchers interviewed installation personnel who had experienced such operations. They also observed winter washing and measured the temperatures of vehicles, surfaces, and wash water. Climatological data was reviewed to predict the frequency of cold weather washing problems at selected installations.

State-of-the-art technology for cold weather operation, including freeze prevention and ice removal techniques, was also investigated. Planning and design recommendations were then developed. The recommendations of this study are intended for CVWFs which will be used in both warm and cold weather.

Mode of Technology Transfer

The guidance presented in this report will be used to amend (draft) Army TM 5-814-9 *Central Vehicle Wash Facilities for TOE Vehicles and Equipment.* Research results will also be presented during the annual User's Group Meeting on Central Vehicle Wash Facilities. This guidance can be expected to be demonstrated in a future Military Construction, Army (MCA) project involving construction of a CVWF.

Corps of Engineers Districts at Louisville, KY, and Sacramento, CA, design Centers-of-Expertise for Central Vehicle Wash Facilities, will use this information as guidance for CVWF design.

2 RESTRICTIONS TO WINTER WASHING AT EXISTING WASH FACILITIES

Structural requirements for winter operation were not included during planning and designing existing CVWFs. Freezing temperatures present serious operational problems, which include: maintaining the safety, health, and comfort of personnel; protecting the facility from damage; ensuring that all elements of the facility function properly during a wide range of weather conditions.

Because of the demand for winter washing, there have been attempts to wash vehicles during cold weather at existing facilities. Following is a discussion of problems encountered during these attempts.

Icy Pavement

Safety is a primary concern when designing for winter washing. One of the most serious problems with washing tactical vehicles in subfreezing temperatures is ice on the pavement. Because all pavements are sloped for drainage, it is difficult to maneuver vehicles safely when pavements are covered with ice. It is also difficult for troops to walk on sloped icy surfaces, and they are further jeopardized by out-of-control vehicles. Wash facility designs must provide for removing ice from pavements or preventing ice from forming.

Troop Comfort and Morale

Winter washing is not just uncomfortable, it can threaten soldiers' health. A winter wash exercise could take 4 hours or more. Severe wind chill combined with a wet working environment would subject the troops to frostbite and exposure. Protecting troops from the weather is absolutely necessary when designing for cold weather operation.

Ice Forming on Vehicles

USACERL field observations show that the exterior surfaces on tactical vehicles rapidly assume the outside air temperature. Exceptions to this are the areas near the engine compartments and the tracks. As the outside temperature drops below freezing, water from washing or precipitation accumulates and freezes on the vehicle surface.

Many hatch handles, releases, and attached equipment fold into recesses in the vehicle's skin and are impossible to use when ice forms. Ice in and around hatch seals freezes them shut. Icy surfaces are also unsafe for troops climbing off the vehicles. Ice is both a safety problem and a cleaning problem since it must be removed and kept from reforming.

Ice Damage to Facility Components

Ice damage to pipes and valves is a well-known problem anywhere the temperature drops below freezing. A CVWF normally has a large number of exposed pipes and valves with potential for extensive freeze damage. Fortunately, all CVWFs have in the current design guidance some provision to drain the plumbing. Past problems with freeze damage were largely operational. Cold weather requires a certain amount of vigilance by the CVWF operators.

Cold Weather Effects on Wash Water Treatment

The recycle treatment system at a CVWF has two components. Primary treatment is provided by sedimentation basins with floating-tube oil skimmers. Secondary treatment consists of either lagoons or equalization followed by intermittent sand filtration. One installation has wetland treatment. At all installations secondary treatment is followed by a clean-water supply basin.

During the winter, wash water must be kept liquid to prevent damage to the treatment structures and ensure a constant water supply to the wash facility. Ice on the basins diminishes the effectiveness of treatment and inhibits the removal of floating oil from the system. Ice impairs biological treatment in the lagoons and the intermittent sand filters. Ice may plug the surface of the filters and restrict the removal of sediment from the sedimentation basins.

3 DESIGN FOR COLD WEATHER OPERATION AT CVWFS

Ice Control on Pavements

To make pavements safe during winter wash exercises, ice must either be kept from forming or be removed. The methods of ice control most applicable to CVWF design and operation are:

1. Applying ice-melting chemicals to the pavement.

2. Incorporating pavement heaters, such as buried hot-water pipes, electric heating elements, or solar heating equipment.

3. Choosing heat-retaining underlay materials.

Other methods considered but eliminated include incorporating ice retardant chemicals or rubber particles into overlaying pavements and using insulating boards as a pavement underlay material.

Ice Melting Chemicals

Ice removal seems to be limited to spreading an ice melting chemical on the pavement. Historically, salt has been used, but other deicing chemicals and mixtures now on the market do not cause the corrosion damage attributed to salt. Calcium magnesium acetate has been an adequate substitute for road salt. One company is marketing an anticorrosive compound mixed with road salt, which is supposed to be less corrosive than distilled water. The most promising chemical now on the market is an organic salt substitute made from grain.

There are several advantages and disadvantages to applying chemicals to pavements.

Advantages include:

1. They can be used at existing installations.

2. They add no capital cost to new construction, other than possibly the need for a chemical storage area.

3. They can be spread with equipment currently used on roads.

4. They may be most cost effective at installations where winter washing is infrequent.

Disadvantages include:

1. They will concentrate in the recycle treatment system, contributing to dissolved solids levels and/or biological oxygen demand (BOD). The organic salt substitute could be removed by the biological treatment, but further research is required before a recommendation can be made.

2. They add labor and material costs to the facility.

3. Pure salt may contribute to corrosion on vehicles and on components of the wash facility.

Heated Pavement

Heating the pavement is the most desirable method of ice control. It does not adversely affect the quality of water in the recycle system and will make the facility more comfortable for the troops. Its major disadvantages are the increased capital cost and a potentially high energy cost. The pavement must be specially designed to include some type of heat conveyer, such as water pipes or electric heat elements as shown in Figure 1. Retrofitting an existing facility is likely to be more costly than constructing a heating system in a new facility.

Designs involving water as the heat transfer medium may incorporate solar gain as the primary or supplemental heat source (see Figure 2), thus reducing the fuel or pumping requirements. A study investigated the feasibility of solar heated runways at Chicago's O'Hare airport and another airport in New York City. The O'Hare study compared an active solar system to electric heat and steam heat and found solar the least costly. The airport study also concluded that solar-heated runways could be practical compared to mechanical and chemical means of ice and snow removal.[2]

Passive solar gain might also be considered as a supplemental heat source. Dyeing the concrete a dark color increases solar adsorption. This was considered during the design of an existing CVWF but was rejected because it was thought the facility would become needlessly hot during the summer. Passive solar might be most beneficial at installations located in northern or temperate climates.

Example of Pavement Heating Design

Suppose Camp Swampy has a CVWF with a three-lane bath and 12 final wash stations. Following is the heat requirement to keep all of the vehicle traffic areas at the Camp Swampy CVWF free from ice:

Parameters

Pavement material -- concrete
Area to be heated -- 67,000 sq ft
Minimum pavement temperature allowed -- 35 °F
Minimum operational air temperature -- 20 °F
Rate of heat loss from concrete -- 1.0 Btu/hr/sq ft/°F[3]
Maximum heat requirement = 1.0 x 67,000 x 15 = 1,000,000 Btu/hr.

Design 1. Ground water at 45 °F is used as a source of heat and is to be pumped through a pipe grid buried in the concrete pavement. Temperature of water returned to the ground is 38 °F, or a loss of 7 °F during heat transfer to the pavement. Flow of groundwater needed would be—

$$1{,}000{,}000 \text{ Btu/hr} \div 7\ ^\circ\text{F} \div 8.3 \text{ lb/gal} \div 60 \text{ min/hr} = 287 \text{ gpm.}$$

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[2] E. Bromley, Jr., H. D'Auleño, and M. Pravda, "Solar Heating System for Airport Pavement Snow, Slush, and Ice Control," *Proceedings of the Symposium on Alternate Fuel Resources, Santa Maria, CA, 25 27 March 1976* (Western Periodicals Company, North Hollywood, CA), pp 58 69.

[3] S.B. Hudson, *The Engineers' Manual*, Second Edition (John Wiley and Sons, Inc., 1939), p 184.

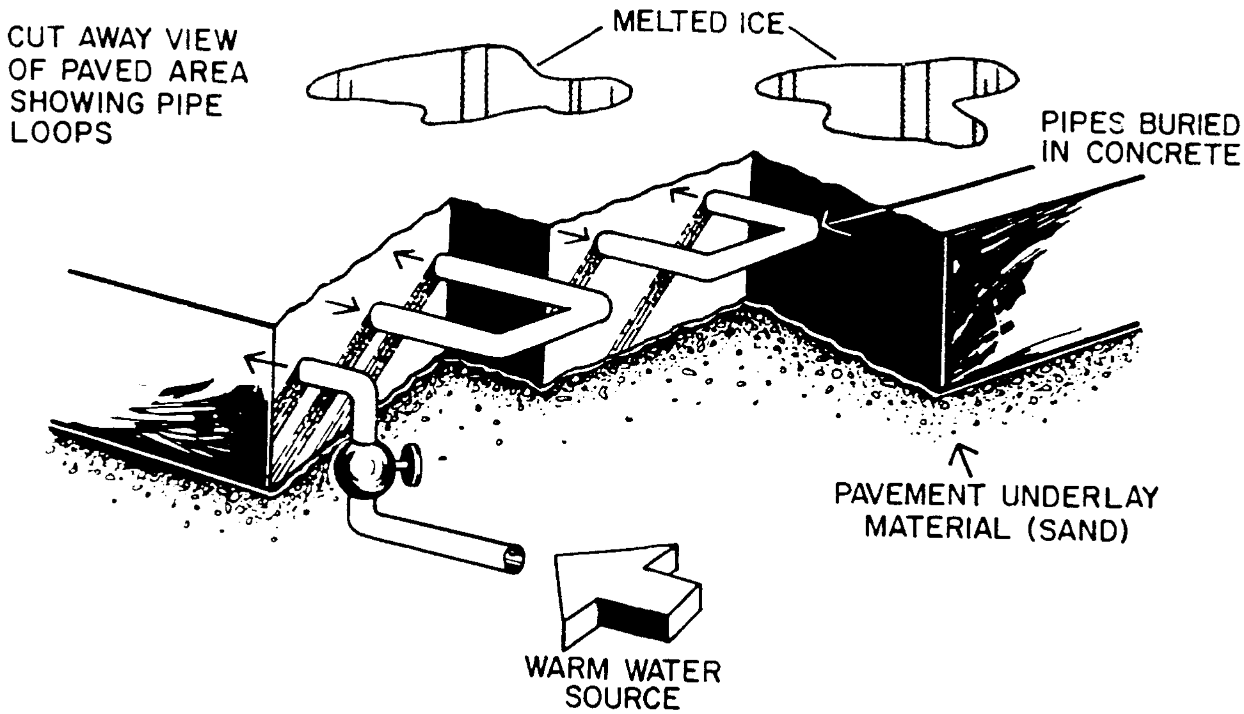

Figure 1. Heating the pavement is the best way to keep it free of ice.

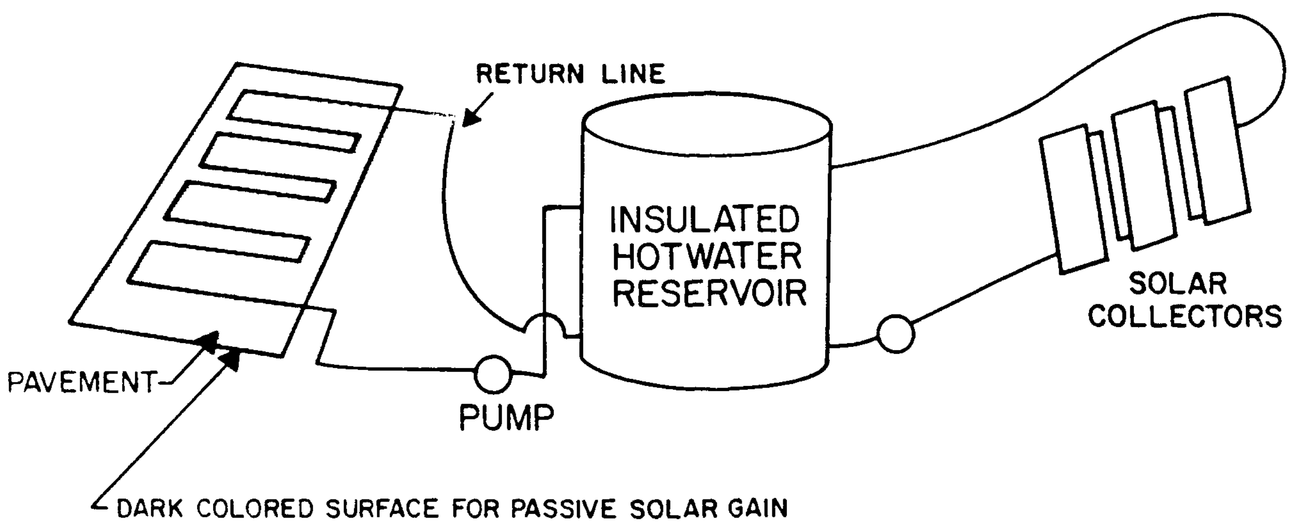

Figure 2. Solar may be used as a primary or supplemental heat source at some locations.

Design 2. A closed loop of heated water is recycled through a pipe grid in the concrete. Water is heated to 75 °F and returns at 38 °F (37 °F drop). Flow of heated water would be—

$$1{,}000{,}000 \text{ Btu/hr} \div 37\ ^\circ\text{F} \div 8.3 \text{ lb/gal} \div 60 \text{ min/hr} = 54 \text{ gpm.}$$

Design 3. Electric heating elements are embedded in the concrete. Power requirements would be—

$$1{,}000{,}000 \text{ Btu/hr} \times 0.01757 \text{ kW/Btu} = 17{,}570 \text{ kW/hr.}$$

Research has been conducted to determine the effect different base-course materials have on the heat retaining capacity of road pavements. One study concluded that paved surfaces over fine-grained base-course material or sand had lower icing potential than dryer materials such as crushed rock and course-grained base-course material.[4] Materials with higher moisture content and density retained and transferred heat the best (see Figure 3).

Troop Comfort

An enclosure will be necessary to protect troops from harsh winter conditions. Local conditions will dictate the area to be enclosed. At minimum, there must be a warming room adjacent to a winter wash facility. At the other extreme, the entire wash facility could be enclosed. Following are a range of options and associated design considerations for wash area enclosures:

1. Enclosing the prewash structure(s). Frequent entrances and exits of vehicles and high concentrations of vehicle exhaust will prohibit any effective conditioning of the air for comfort inside a prewash enclosure. While sidewalls would block winds perpendicular to the bath lanes, other winds may sweep through the facility.

2. Enclosing water cannon stations (Figure 4). An alternative to enclosing the entire bath would be to enclose only the small areas occupied by personnel operating the water cannons. Such an enclosure, or booth, should block all wind, be transparent to allow adequate visibility, be heated with a radiant-type space heater, and have heat elements in the windows to prevent fogging.

3. Enclosing final wash stations (Figure 5). It will be necessary at most installations to enclose a portion or all of the final wash stations. Because soldiers will be washing each vehicle for 20 to 40 minutes, it is practical to condition this area for comfort. The periodic use of overhead doors suggests that overhead radiant heaters may be most effective for troop comfort. Heating the pavement inside the structure would prevent icing as well as serve as a secondary source of radiant heat. Sufficient lighting must be provided at both floor and ceiling level.

Sporadic use of the final wash stations during a wash exercise suggests that each station be partitioned individually. The length of each enclosure may be designed to accommodate one or two vehicles. If two cleaning operations are performed in this structure—final washing and drying—construction should be less costly than if both operations are performed at different locations. This one-stop cleaning will provide maximum troop comfort and energy efficiency. Vehicles will not need to be moved between operations and the overhead doors will not need to be raised as often.

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[4] K. Gustafson, *Icing Conditions on Different Pavement Structures*, Transportation Research Record, N860 (Transportation Research Board Publications Office, 1982), pp 21-28.

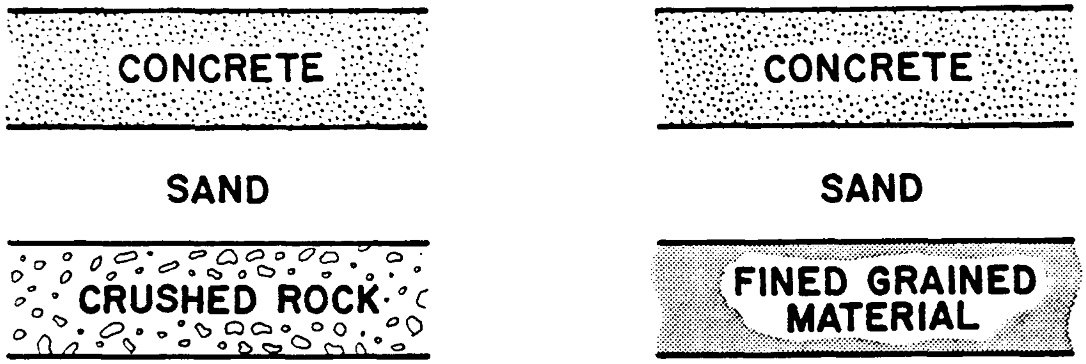

Figure 3. Fine-grained material retains and transfers heat better than coarse-grained, less-dense material.

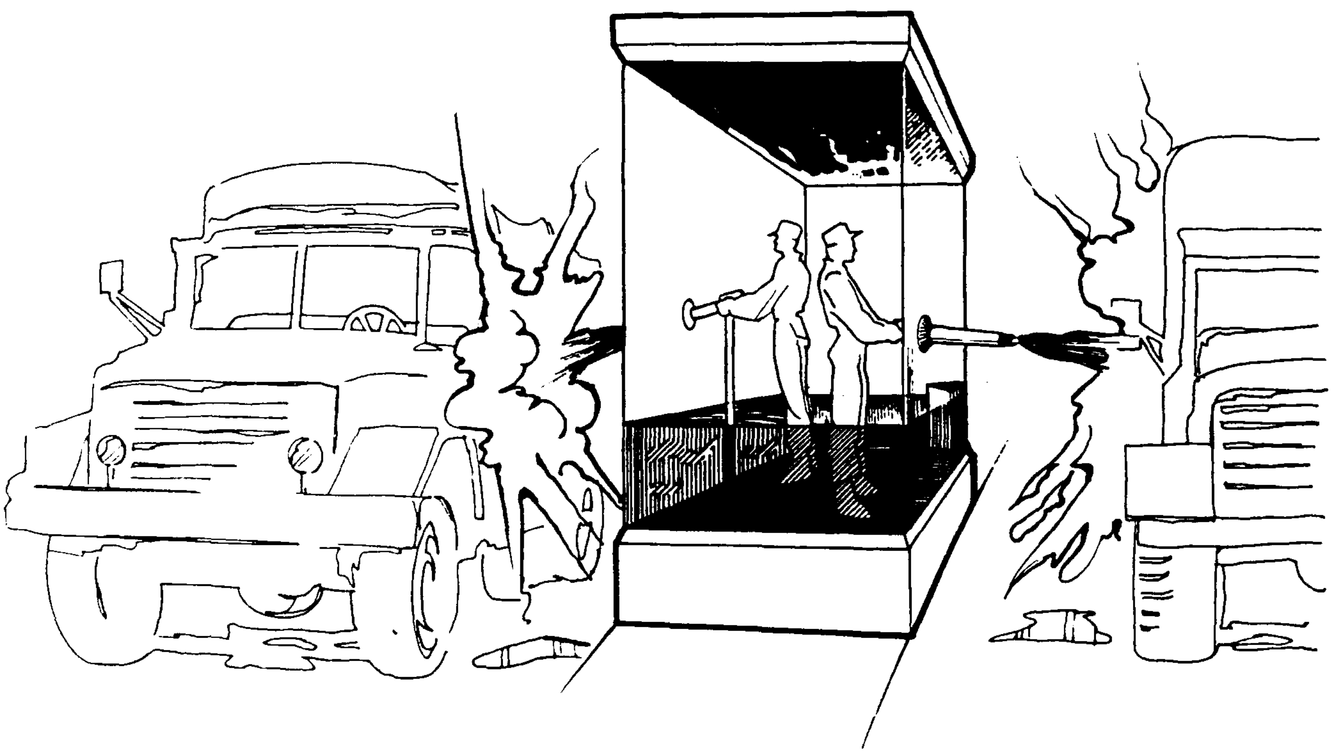

Figure 4. Troops must be protected when using the water cannon.

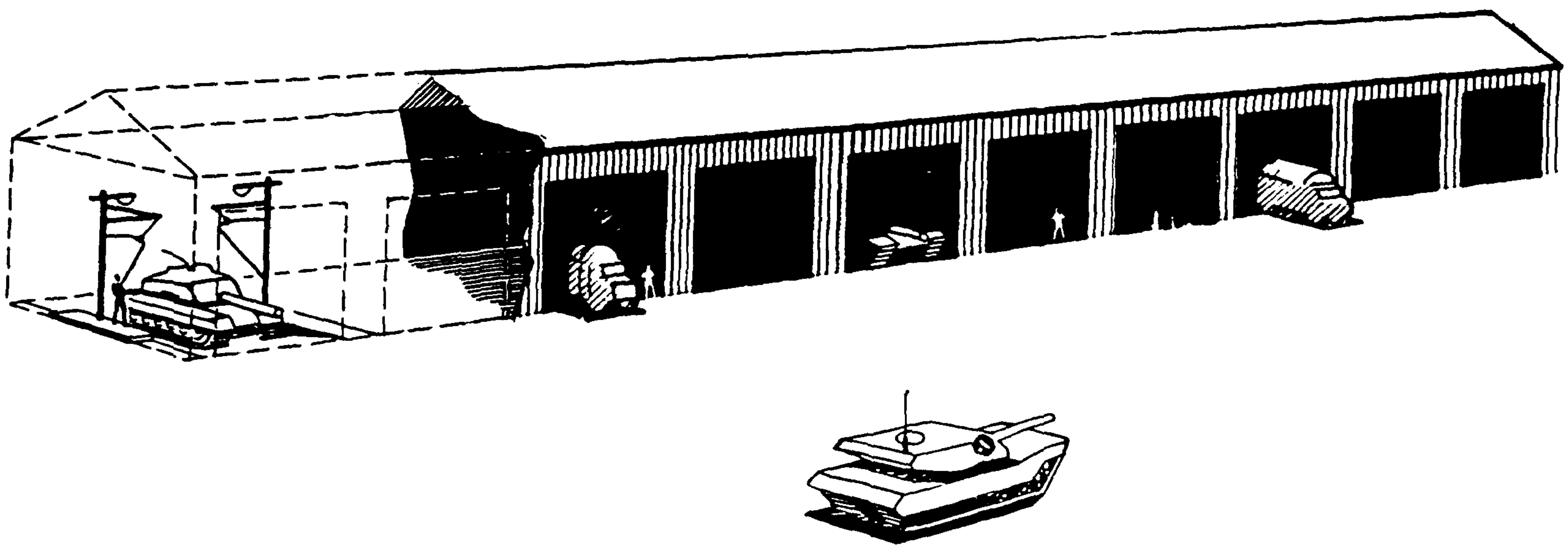

Figure 5. Final wash stations are enclosed to protect the troops, warm the vehicles, and partially dry the vehicles.

Ice Forming on Vehicles

A tracked vehicle coming in from a training exercise may have 1000 lb of ice and slush clinging to the undercarriage. A tremendous amount of heat will be required to remove this ice and to warm the vehicle above freezing. A prewash bath would be the most effective method of removing this ice and slush because of the rapid heat transfer to the submerged portion of the vehicle. Water from the water cannon at the bath will warm the upper vehicle surfaces and prevent ice from forming.

Because the water in the recycle treatment system will cool to near freezing, it will need to be heated to ensure ice-free vehicle surfaces. Excessive heating, however, will create visibility problems from fog and elevate energy costs.

Residual wash water must be removed from the vehicles' seals and recesses to prevent ice from forming when vehicles return to the cold environment. Air blowers may be the most effective method of removing this water with a high-velocity stream of heated air. This is the last step in the cleaning procedure before exiting the wash facility.

Preventing Ice Damage to CVWF Components

There will be little ice damage to the CVWF wash structures during use of the facility. Flowing water is very resistant to freezing, and the water and wetted surfaces are likely to be heated. Damage normally would occur during nonuse periods. The CVWF design must provide for complete drainage of all plumbing, fixtures, and valves above the lowest elevation where freezing can be expected. Preferably, this drainage would be automatic.

Some designs will call for isolating a portion of the facility to be used for winter operation. The designer must ensure that the unused plumbing will not be pressurized and will be completely isolated from the usable facility.

Recycle Treatment System

The designer has three options for recycle treatment. A cost analysis during design will determine which of the following is best:

1. Provide one treatment system which may be used year round. This option would likely be chosen if the entire CVWF were to be used for winter washing.

2. Provide additional treatment structures that will replace or augment the normal treatment system. This option may be used if about half the facility is for winter use.

3. Provide a cold weather pretreatment structure and discharge to a sanitary sewer without recycle.

All options will require a primary treatment structure. Most of the suspended solids and floating oils are removed during primary treatment. Water in the primary basin must be kept from freezing to maintain treatment efficiency and to prevent damage to the structure and oil skimmer. Since wash water will probably be heated for winter washing, freezing is not likely to occur at the primary basin during use. Freezing could be prevented or minimized during periods of nonuse by recirculating water through the basin. A removable insulating cover could be installed over the basin to prevent freezing during extreme cold.

Sizing of the primary treatment basin will be affected by cold-weather operation. Water becomes more viscous as it cools, and settling times become greater. For example, if wash water is 60 °F (16 °C) in summer and 40 °F (4 °C) in winter, according to Stokes's Law, the settling velocity of a particle would be 29 percent slower in the winter than summer. Primary basins for all-weather facilities must be designed larger than for warm weather only.

Ice will certainly form on the surface of an equalization basin, treatment lagoon, or supply basin, but they should continue to function as long as intake and effluent structures are kept ice free. Recirculation pumps may be necessary at those structures.

If intermittent sand filters are draining normally, ice blockage should not be a problem. If the filters become plugged with sediment due to normal treatment operation, it will be necessary to scrape the filter surfaces prior to winter operation. If ice forms on the surface of the sand filters, it can be broken by mechanical means. Flooding the surface with warmed water would also be effective.

All pumps must be inside a heated pump house. Warming is not as necessary to prevent freezing as it is to maintain the viscosity of the pump lubricants.

4 PLANNING THE FACILITY

Assessing Winter Washing Needs

Demand for Washing

Since it is unlikely that winter washing will be more frequent than summer washing at a CVWF, the facility will be sized according to peak warm weather demands.* Still, the planner must determine normal demand and peak demand for winter washing to define what portion of the entire CVWF will be designed for winter operation. "Demand for washing" is defined as the number of tracked and the number of wheeled vehicles which will use the wash facility during a given period, usually 1 week. Peak demand would occur when the largest group of vehicles would need to be washed. Wash facility usage usually corresponds to training activities.

When assessing washing demand, the planner will assemble information such as the following:

1. A peak winter wash exercise would consist of X tracked vehicles and Y wheeled vehicles arriving at the wash facility over Z number of hours.

2. Normal wash demand would consist of V tracked vehicles and W wheeled vehicles during a 1 week period.

Sizing the Winter Facility

The winter facility is sized using the same methodology as for a warm weather facility; however, some parameters must be changed. Because of ice and slush, more time will be needed to wash the vehicles. While there is no operational experience on which to base specific guidance, a suggested rule of thumb is to add 50 percent to the expected warm-weather wash times for each vehicle. For example, if a tracked vehicle wash rate of 8 vehicles/hour/bath lane and 3 vehicles/hour/final wash station was expected during warm weather, then a wash rate of 5.3 vehicles/hour/bath lane and 2 vehicles/hour/final wash station could be expected during cold weather.

Practical Limitations

The portion of the CVWF designed for winter washing will cost considerably more than an equivalent portion designed for above-freezing only. The acceptable duration of a wash exercise should be increased to minimize the size and cost of the winter facility. It will be less expensive to provide for troop comfort during the additional time than to provide a larger winter wash facility.

Table 1 shows cold weather information about several major Army installations. Using this table and expected training schedules, the relative need for winter washing facilities can be determined. If there are few subfreezing days during a normal winter, the requirement for a winter wash facility should be

* Guidance for sizing CVWFs can be found in the draft Technical Manual 5-814-9, *Central Vehicle Wash Facilities for TOE Vehicles and Equipment*.

balanced against providing a secured parking area to store tactical vehicles until warmer weather allows the CVWF to be opened.

Planning Example

Camp Swampy is a hypothetical installation in a Midwest state and is the home of a mechanized infantry division. Training maneuvers occur year round. Each training exercise is followed by washing the tactical vehicles and performing maintenance inspections. A new CVWF is planned because the old TAC Shop wash racks are inefficient and do not comply with environmental regulations.

Table 1

Weather Information for 21 Army Installations

Low < 32—the average number of days per year the low temperature is below freezing
High < 32—the average number of days per year the high temperature is below freezing
Range—limits of the data between 1978 and 1988

INSTALLATION		LOW < 32	RANGE	HIGH < 32	RANGE
Ft. Wainwright, AK	*	216.0	184-246	149.8	124-180
Ft. Greeley, AK		214.4	192-228	152.9	126-173
Ft. Richardson, AK		196.4	156-211	101.8	69-123
Ethan Allen, VT	*	168.3	115-187	76.1	56-97
Camp Grayling, MI		165.4	158-178	71.9	48-86
Yakima Fir Ctr, WA		143.1	109-176	30.6	14-74
Ft. McCoy, WI		142.6	83-157	61.3	36-75
Ft. Carson, CO	*	118.9	83-136	26.9	15-37
Ft. Drum, NY	*	117.9	101-136	70.7	55-96
Ft. Riley, KS		115.8	101-127	29.3	13-47
Ft. Devens, MA	*	113.8	93-124	38.8	30-49
Ft. Indiantown Gap, PA		102.5	81-121	25.3	16-31
Aberdeen P G, MD		96.1	84-104	15.8	11-21
Ft. Dix, NJ		95.2	82-105	21.2	7-28
Ft. Leonard Wood, MO		80.6	64-98	25.8	11-45
Ft. Campbell, KY		78.6	69-90	15.7	7-26
Ft. Knox, KY		77.0	66-91	21.0	7-36
Ft. Sill, OK		57.5	34-70	10.2	1-17
Ft. Bragg, NC		56.6	45-71	1.7	0-4
Ft. Lewis, WA		56.1	34-98	2.4	0-8
Ft. Hood, TX	*	22.8	8-36	3.3	0-10

*Data for some weekends and holidays were not recorded (table entry has been adjusted to account for nonexistent data).

Training exercises involve a brigade or more during the warm months, but seldom more than a battalion during the winter. A five-lane prewash bath (three multipurpose and two tracked lanes) and 20 final wash stations will satisfy Camp Swampy's warm weather washing requirements. The worst-case winter washing requirement is 48 tracked vehicles and 60 wheeled vehicles (30 large) to be washed in a 4-hour period. Camp Swampy has cohesive soils in the maneuver areas, and the winter wash rates were assumed to be as follows: 4 tracked vehicles/bath lane/hour, 2 tracked vehicles/final wash station/hour, 7 large wheeled vehicles/bath lane/hour, and 1.5 wheeled vehicles/final wash station/hour.

If the entire facility were designed for winter washing, the worst-case washing exercise would take about 4 hours. If only one bath and 10 final wash stations were used, the exercise would take 5.5 hours. It was decided to limit the winter-use portion of the facility as shown in Figure 6. The following CVWF components would be included in the concept design:

1. A two-lane bath with tracked flexors,

2. A three-lane bath with multi-vehicle flexors,

3. A pump and gas-fired water heater to recirculate and warm water from either bath,

4. Shelters for the water cannon operators,

5. Ten final wash stations,

6. Ten final wash stations enclosed for winter washing with radiant heaters, compressed air for vehicle drying, and heated slab,

7. A bi-level building to house operating personnel and controls, latrines, equipment storage, a warming area for troops, and storage for deicing chemicals,

8. Two parallel primary treatment basins with removable insulating covers,

9. An equalization basin with recirculation pump near the effluent structure,

10. Intermittent sand filters,

11. A wash water supply basin with recirculation pump near the effluent structure,

12. A small supply basin, insulated, with gas-fired heater.

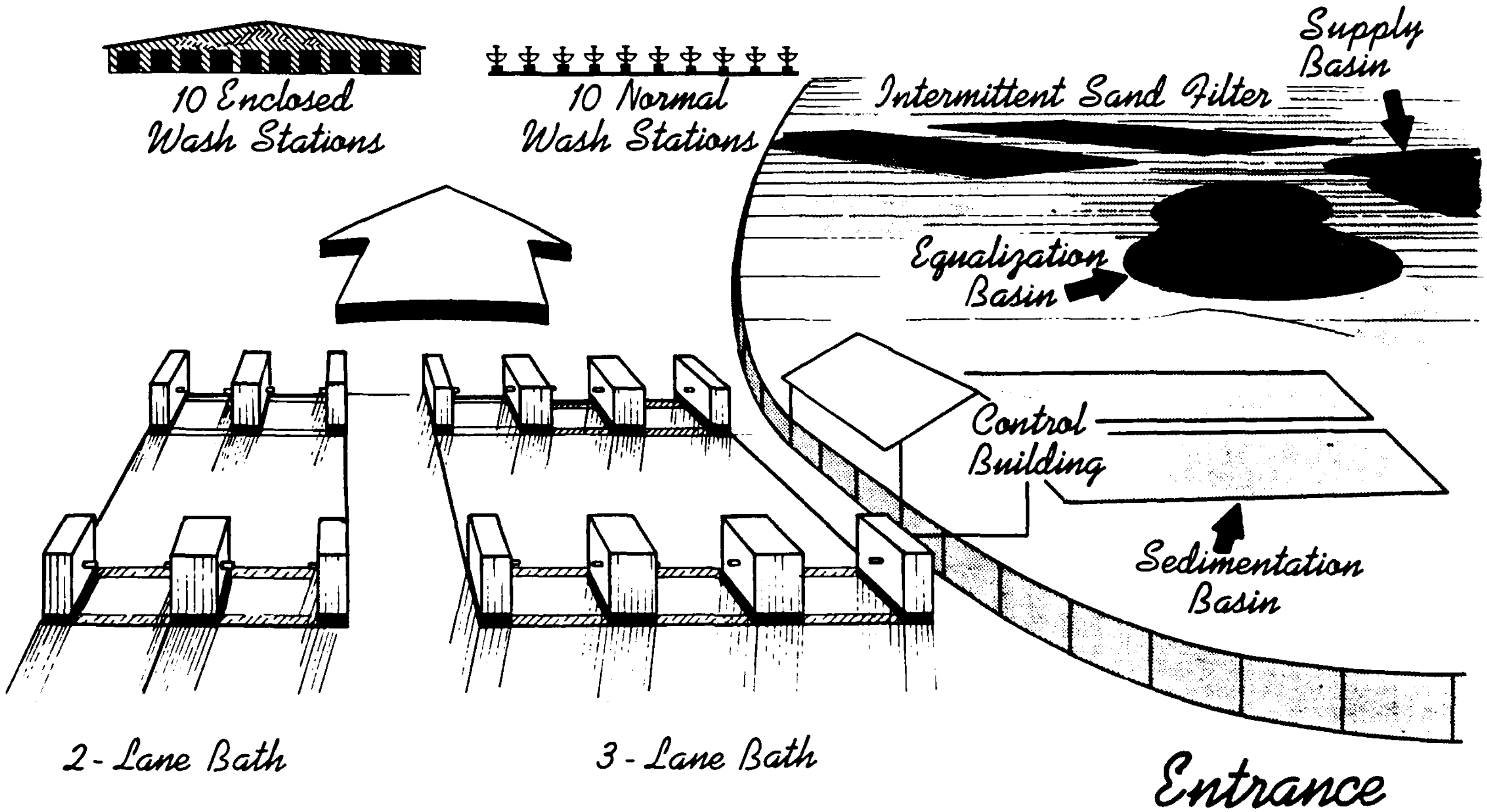

Figure 6. Camp Swampy all-weather CVWF.

5 CONCLUSIONS AND RECOMMENDATIONS

1. The primary considerations when designing a CVWF for winter operation are: icing on pavement and vehicle surfaces; protection and comfort of the troops; prevention of ice damage to facility components; and maintaining recycle water quality.

2. Icing on pavement is best prevented by some type of pavement heating system. An alternative is to use a biodegradable deicing chemical, though this method should be researched further before final operational recommendations are made.

3. Enclosures are necessary to maintain soldier comfort, both at the prewash water cannon islands and final wash stations. Ice forming on vehicle surfaces can be prevented in a properly equipped final wash enclosure.

4. Dense, fine-grained materials should be used to underlay pavements. These materials are best at transferring heat from subsoil to the paved surfaces.

5. Wash water must be warm enough to remove ice and slush from the vehicles and to warm vehicle surfaces to prevent ice from reforming.

6. Recirculation pumps should be available for use near effluent structures and in the primary basins to prevent ice damage to these CVWF components and to maintain operation of the treatment system.

Metric Conversion Factors

1 lb	=	4.536×10^{-1} kg
1 sq ft	=	0.093 m^2
°F	=	1.8(°C) + 32
Btu	=	$1.055 \times 10^{+3}$ J
gal	=	3.785×10^{-3} m^3

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