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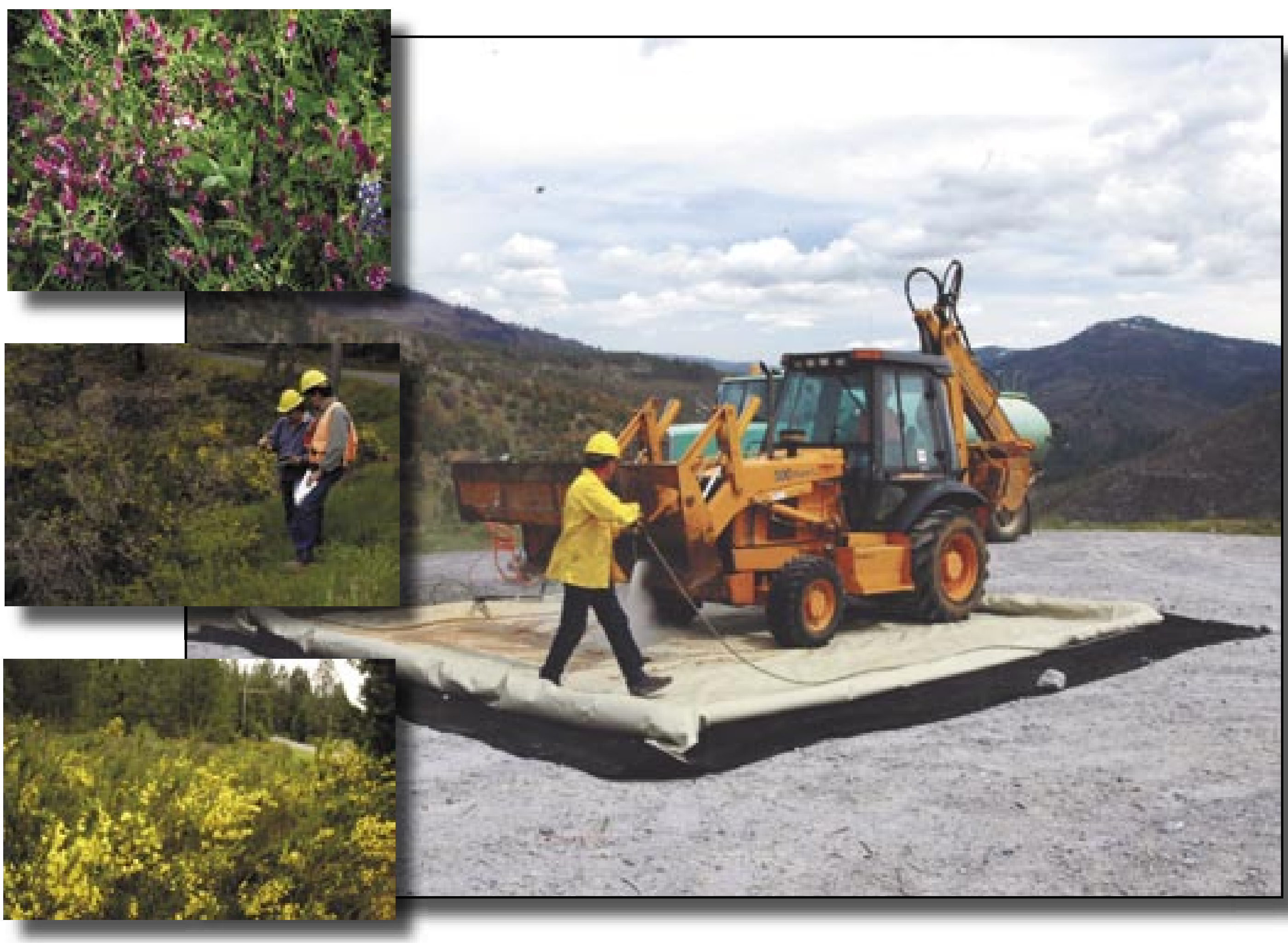
Vehicle Cleaning Technology for Controlling the Spread of Noxious Weeds and Invasive Species



Vehicle Cleaning Technology for Controlling the Spread of Noxious Weeds and Invasive Species

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INTRODUCTION

Many silvicultural and land management activities on national forest land involve moving vehicles and equipment at off-road locations. As a result, seeds and spores can be picked up, transported, and transplanted over great distances. Hand and power tools transport seeds, the invasive and nonnative plant and fungi species become established in new areas, and the native ecosystem is affected. Some prolific plant species dominate new environments and upset the natural plant life and wildlife balance and endanger other species and resources. This publication summarizes the concepts for removing seeds from vehicles and equipment to control the spread of noxious weeds, invasive species, and disease. The appendixes contain vendor information and other resources.

In 2001, the U.S. Department of Agriculture (USDA) Forest Service published *The Guide to Noxious Weed Prevention Practices* that discusses strategies to minimize the spread of noxious weeds. To access the guide, visit http://www.fs.fed.us/rangelands/ftp/invasives/documents/GuidetoNoxWeedPrevPractices_07052001.pdf.

Plant seeds and fungal spores often are transported in the dirt and mud on vehicles and equipment. Seeds also are picked up directly by undercarriage components that strike the host plant. This document focuses on equipment and methods to remove these seeds from vehicles before they are transported to other locations.

San Dimas Technology and Development Center (SDTDC) was tasked by the USDA Forest Service's Washington Office national engineering steering committee to research technologies available for cleaning vehicles and equipment after use in undeveloped areas. This 2-year effort included developing, fabricating, and testing concepts for remote-location washing facilities under real-time conditions.

Washing equipment before it leaves an area prevents transporting seeds and spores. Seeds and spores are found in vegetation, dirt, and mud clinging to the undercarriage or underbody parts (such as wheels, wheel wells, drive train, and bumpers). Cleaning focuses on these areas. No study has determined which washing method is best for remote locations or how clean vehicles must be to prevent the spread of invasive seeds and fungi. It is unknown whether all debris must be removed from equipment before it leaves an area or if eliminating the loose debris is sufficient. Hardened clots that adhere to the body are unlikely to come loose before the equipment can be taken to a commercial washing facility. Any remote-location wash system should concentrate on debris likely to come loose.

Washing takes time, labor, clean water, energy, and in many cases containment and proper used-water disposal. Where clean water is not abundantly available and wastewater disposal is an issue, filter, treat, and recycle the washwater. Consider the cost of recycling washwater versus the cost of providing freshwater and hauling the waste to an appropriate sewage disposal facility. With short-term projects involving few pieces of equipment, it can be more economical to remove wastewater to a sewage disposal facility rather than to recycle. Wastewater containment is not mandatory for machinery used in emergency fire situations.

Service contractors provide most materials, hardware, and labor to clean vehicles and equipment in remote areas. If few machines or vehicles require washing each workday over a several- week period, a contract wash service might be too expensive. Appendix A lists contract service providers. Many washing service contractors are listed on the Internet, but not all are equipped to wash vehicle underbodies. When considering contractor services, ensure that contractors have the equipment and experience to remove debris from the vehicle's underbody, fender wells, and odd, hard-to-reach areas. Washing the exterior body panels does little good.

Technicians will use this publication to decide whether to use contract services, or to purchase or rent equipment and assess resources available, equipment limitations, and prices. Anyone considering a washing system for weed management for a specific project, or as a general practice, can use this information to determine the most efficient strategy and hardware.

WASHING EQUIPMENT

Many systems are built from commercial hardware. Some vendors are listed in appendix A, however it is wise to research alternatives prior to purchasing equipment. The following equipment and technologies are discussed:

- Runoff containment
- Spraying equipment
- Water supply
- Filtration
- Water treatment
- Waste containment
- Pumping equipment

Runoff Containment

Most runoff from washing equipment does not require containment for compliance with Federal, State, or local wastewater discharge regulations. Even when containment is used, invasive seeds may be blown beyond the containment system during washing. Inspect wash sites regularly and treat for weeds as necessary. Wastewater containment can be accomplished several ways and the three forms of containment discussed below are consistent with best management practices.

Geotextile Cloth

Geotextile cloth can be an alternative to wastewater containment when loading heavy equipment after an emergency fire incident. The cloth captures large particles in the permeable barrier and allows water to percolate back into the soil. Because most seeds are larger than 200 micron, the cloth prevents or reduces seed transplantation at the loading area. Geotextile cloth is made of a polycarbonate fiber with a natural affinity for hydrocarbons, which prevents oil or grease from draining into the soil.

Geotextile cloth comes in many grades, tensile strengths, and porosity. Amoco(r) 4553 is a 6-ounce cloth with a 100-micron opening size. A 15- by 360-foot roll of Amoco 4553 costs $360 and is available in partial rolls. Geotextile cloth is inexpensive, lightweight, and fairly durable. Because the cloth is permeable, its use may not be in compliance with wastewater discharge regulations for activities other than emergency fire incidents. Do not use permeable mats in areas close to a water source, drainage, or ground water, and consult appropriate wastewater authorities before using geotextile as a washing surface.

Flexible Mat

Flexible mats come in many sizes and styles (figure 1). They serve as portable berm systems to contain washwater and debris. They are a durable, chemical-resistant rubber material. Some models have berms that are permanently attached to the perimeter, while others have removable inserts. Permanent berms on flexible mats can make storage difficult. One plain rubberized mat has polyvinyl chloride sewer pipe tucked under the sides with foam cushions under the approach and departure ends. Lay geotextile or similar cloth underneath to prevent sharp rocks from penetrating the mat. The plain mat rolls or folds up for handling and storing.

Figure 1—Flexible mat.

Flexible mats may tear, but onsite repairs are easy. Use conveyor belting in the wheel tracks to help prevent punctures or tears. Flexible mats, and the materials used to form containment berms, can be installed by two people. The material is easily transported in a 1/2- to 3/4-ton truck. Low-ground-clearance vehicles are not a problem. Flexible mats may create sludge puddles that vehicles track through, picking up the just washed off mud. Flexible mats require workers to bend over more often than when using an elevated rack system to wash vehicles.

Elevated Washrack

At least two domestic manufacturers build portable elevated washracks (figure 2). One company builds washrack panels in 10-, 12-, and 14-foot widths. The 8-foot-long panels are placed side by side to the desired length. They are designed to carry axle loads of 12 tons, and need support on just two sides. Another company offers a similar modular washrack with 6- by 8-foot panels designed to handle 15,000-pound wheel loads. Both systems can handle wheeled or tracked equipment, and the runoff is collected in the center or in a gutter alongside. Raised panels make it easier to wash the underbody.

Figure 2—Elevated washrack.

Containment walls are available that allow access to both sides of the vehicle and reduce overspray when the walls are set in a staggered position. The tread surface has deep channels to collect runoff so vehicles do not track through their own wastewater and muck. The heavy solids settle out in the gutters and the design allows for a deeper sump than a surface mat. Low-ground-clearance vehicles can be a problem if the ramps are too short, but using timbers reduces the step and provides a shallower approach. The panels are fairly heavy and require a sizeable forklift or other heavy equipment to position. A 12- by 32-foot washrack assembly weighs more than 10,000 pounds. SDTDC tested this washrack system at the Grand Prix firecamp in October 2003 with positive results. The General Services Administration contract price for the washrack, four panels, gutters, and ramps is $13,200.

Spraying Equipment
Two methods of spraying are used in the vehicle- and equipment-washing industry: high pressure with low volume and low pressure with high volume. High pressure is above 1,000 pounds per square inch (psi), and high volume is more than 10 gallons per minute (gal/min). In both categories, hand-held (wand) systems and automated systems are available. Although simplicity of operation might favor an automated system, reliability, effectiveness, efficiency, and economy favor manual sprayers.

Manually raising the vehicle's hood to wash debris in the engine compartment is often necessary. Certain areas in the engine compartment should not be sprayed directly, and it takes judgment to avoid them. Other areas of the vehicle also require careful washing. Some manual followup spray cleaning should accompany automated systems use.

High-Pressure, Low-Volume Spraying
Many household and industrial pressure washers have outputs of up to 4,000 psi. Flows generally range from 2 to 5 gal/min and with attachments, these high-energy spraying systems can remove the most tenacious debris. Models are available at home improvement stores. The low-water consumption reduces supply water and wastewater needs. However, these high-pressure sprayers produce large amounts of debris scatter and overspray. Use caution to prevent sensitive component damage. Wear personal protective equipment and use caution to avoid injection injuries and other flesh wounds.

Figure 3—High-pressure washer.

Low-Pressure, High-Volume Spraying
The 1-inch combination barrel nozzle (combi) commonly used for firefighting is particularly effective for equipment washing. It uses 13 gal/min at 50 psi when adjusted for a narrow cone spray pattern. A 1-inch ball shutoff ahead of the nozzle minimizes spray pattern adjustments and enables instant shutoff. The long spray range and low-pressure coverage minimizes injury. The combi requires a high-water volume compared to other high-pressure washing systems.

Figure 4—Barrel nozzle with shutoff.

Undercarriage Spray Bars
Undercarriage spray bars (and other somewhat automatic systems) use lower pressure and higher flow. The number, size, nozzle shape or holes in a spray bar, and water pressure determine water-use rate. The washing industry uses spray bars with multiple nozzles, but testing to determine the most effective and efficient configuration for undercarriage washing is incomplete. Spray bars fabricated from pipe with threaded ports and individual nozzles have many

spray patterns. Simple pipe spray bars with multiple-drilled holes may be adequate, but no data is available on the ideal undercarriage spray system.

Optimizing an effective spray-bar system for a wide variety of vehicle and machine configurations is beyond the scope of this project. Effective designs will evolve through trial and error, and entrepreneurs already have developed some interesting designs. Generally, fewer moving parts means greater reliability; more water means greater debris removal, but not without penalties. Debate also exists regarding fan nozzles compared to straight stream. Fan nozzles give greater coverage but lose energy in a fairly short distance, while straight-stream nozzles concentrate water in a smaller area. More nozzles are required to get the same coverage and water demand is greater. Moving-straight-stream nozzles provide greater coverage, but their complexity may lead more downtime. SDTDC plans to conduct undercarriage-spray system evaluations in 2006. Water-use rate, process rate, and total debris removed will be recorded to quantify each system's performance.

Water Supply

Water trucks and trailers from 500 to 3,000 gallons can be rented by the day, week, or month. They are equipped with a high volume, low-pressure pump on the discharge end. Some models can draft. Water trucks and trailers have opaque tanks that prevent sunlight from reaching the water, reducing algae growth. Algae reduction is important for projects lasting more than 1 week.

Most fire caches stock portable folding tanks in several sizes and styles. Tank size is 600 to 5,000 gallons. Some tanks have rigid folding frames, while others are free-standing "pumpkin" tanks. Their open-top design allows insects and debris to fall into the tank. Free-standing models used for settling are harder to clean. Rigid-frame models can be covered with a tarp and anchored with bungee cords or zip-ties. Both styles are lightweight and easily set up by two people. Portable folding tanks with rigid frames cost $700 for a 600-gallon tank and $1,500 for a 5,000-gallon tank.

Lightweight polyethylene tanks are available in many sizes and configurations. They can serve as supply, treatment, or settling tanks, but are bulky. Costs range from $350 for a 200-gallon tank to $700 for a 500-gallon tank. Larger sizes are available for permanent installations. Some opaque polyethylene tanks are designed specifically for water storage. They block sunlight and minimize the potential for algae growth .

Figure 5—Folding tank.

PUMPING EQUIPMENT

Water trucks, water trailers, fire engines, and portable wildfire pumps could provide primary spray or recovery pumps for wash systems. Water trucks and fire engines can draft and pump simultaneously without drawing from their reservoir; however, most USDA Forest Service fire engines and water trucks have a bypass line that constantly sends a small amount of process water back to the freshwater tank. This line gradually depletes the process water while contaminating the freshwater. For that reason, fire engines or water truck pumps are not recommended for drafting unless they are drafting from a postfilter sump.

Pump Types

Spraying, recovering, and filtering operations require pumps. A wash system has at least two pumps-a sump pump and a pressure pump-and, depending on filtration methods for water recycling, a third pump for the filters. Pump manufacturers provide performance curves for their products and offer technical advice to select a suitable pump. A pump curve is shown in figure 6.

Pump selection should consider its uses-supply or spraying with clean water, return of contaminated water, transfer between holding tanks, or a filtration feed. If a pressure spray system requires 26 gal/min at 50 psi, the pump size should deliver 15 to 20 percent more to ensure the pump's long life.

Calculate the pump ratings required as follows:

- Start with required flow: 26 gal/min.
- Amount to increase: 20 percent or 0.2.
- Add 1 to the percent increase: 1.2.

- Take the square root of the value (square root of 1.2 = 1.095).
- Multiply required flow (26 gal/min) by the square-root value (1.095) to get 28.48 and round it to 28.5.
- Repeat this procedure for the system demand pressure (50 psi) to get a target value of 54.75, or 55 psi.

Select a pump that delivers the pressure and flow values derived from the calculations. The results do not account for changes in elevation or barometric conditions.

The sump return pump should handle the same flow rate, but the pressure is less critical because it will usually discharge into a settling tank or wastewater holding tank through a coarse filter. Where water is recycled, fine filtration occurs between the settling tank and the supply tank. That filtration requires a pump, too. Consider the type of filtration, particle size in the input water, process rate, and pressure rating of the filter housings to select the best pump.

P	F	HU	P	F	
50	26	1300	54.77226	28.48157	1560
50	26	1300	53.61903	27.88189	1495

F	P		
50.3	5.0	46.37431	4.609772
50.2	10.0	46.28211	9.219544
50.0	15.0	46.09772	13.82932
49.1	20.0	45.26796	18.43909
47.8	25.0	44.06942	23.04886
46.5	30.0	42.87088	27.65863
45.0	35.0	41.48795	32.26841
43.0	40.0	39.64404	36.87818
39.0	45.0	35.95622	41.48795
34.0	50.0	31.34645	46.09772
28.5	54.8	26.25871	50.49752
20.0	60.0	18.43909	55.31727
13.0	62.0	11.98541	57.16118
7.0	63.5	6.453681	58.54411
4.0	64.5	3.687818	59.46606
2.0	64.8	1.843909	59.74265
1.0	65.0	0.921954	59.92704

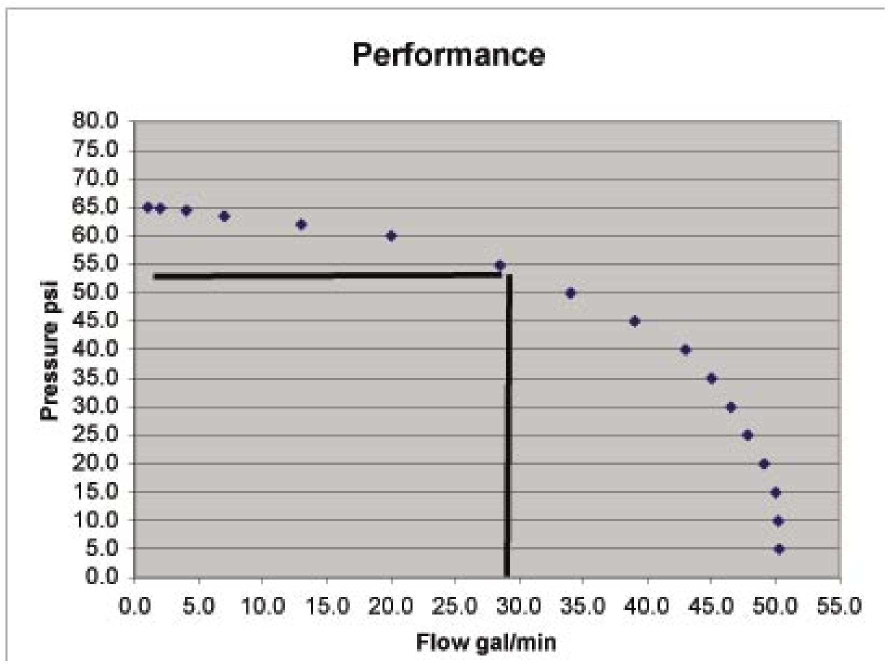


Figure 6—Pump curve.

Vacuum Systems
Manufacturers now offer vacuum-type recovery systems that combine the basic wet vacuum mechanism with a liquid-return pump in the vacuum chamber. This system works well for recovering water from shallow sumps with heavy solids, but for continuous operation its use is limited to lower flow rates. Vacuum systems can recover from shallow sumps without damage from running dry.

Diaphragm Pumps
Diaphragm pumps are the only positive-displacement pumps appropriate for contaminated water because they withstand heavy-solids loading. Piston, gear, rotor, and vane pumps are not recommended. Several manufacturers offer air-operated or engine-driven diaphragm pumps suitable for runoff recovery. A 4-horsepower (hp) pump delivers 60 gal/min at 12 to 15 psi. High-pressure models with engines developing 25 hp deliver more than 20 gal/min at 800 psi. The pumps are self-priming and can run dry without damage. Because low-power models deliver less pressure, they are better suited to the recovery end of a wash station where they discharge to a settling tank. The cost for a 4-hp-engine-driven model is $1,600.

Centrifugal Pumps
Centrifugal trash pumps work well to reclaim wastewater and can run dry briefly without damage. If the sump level gets too shallow they lose prime. Centrifugal sump pumps are available for commercial and household applications with drafting depths to 1 inch. The impeller inlet must be flooded to maintain output, but they will recover prime whenever the water is up to minimum drafting depth. Some electric versions have a float switch to prevent extended dry runs. Engine-driven modular centrifugal trash pumps are commonly available at rental yards and construction-supply stores. A 1/2-hp submersible electric trash pump costs $450, and a 5-hp, engine-driven model costs $1,000. Other centrifugal water pumps are less tolerant of large solids and abrasives because of impeller clearances, but they work for filtration or spray applications. To ensure long pump life, select a centrifugal pump that runs at 80 to 85 percent of its maximum hydraulic power rating (pressure multiplied by flow) during normal operation. Manufacturers provide performance curves showing the best pump efficiency point. Also, ensure that the pump does not run at full shutoff, or damage to the seal results.

Plunger Pumps
Plunger pumps are used on portable pressure washers that develop 1,000 to 4,000 psi with flows from 1 to 4 gal/min. These pumps require a clean water supply with no particles greater than 50 micron. For long service life, filter the input water to 5 micron. A positive inlet supply pressure is best, but a flooded inlet is adequate. Use a plunger pump or pressure washer for a final rinse with clean water following a coarse wash with recycled, mildly turbid water. Gasoline-powered pressure washers cost $200 to more than $1,000 depending on their output power range.

Table 1 gives a summary of applicable pump characteristics and costs.

Table 1—Pump summary - typical

	Maximum*	Maximum*	Solids			
Type	**Flow gal/min**	**Pressure psi**	**<50 m**	**>1/8 in**	**>1/4 in**	**Cost (in dollars)**
Vacuum	20	-	Yes	Yes	Yes	1,800
Diaphragm trash	60	20	Yes	Yes	Yes	1,700
Centrifugal trash	110	55	Yes	Yes	Yes	600
Centrifugal utility	70	130	Yes	n/r	n/r	50
Plunger washer	2 to 4	1,000 to 4,000	Only	No	No	300

n/r: Not recommended

*Maximum pressure is at minimum flow and vice versa.

Recycling
Recycling used washwater greatly reduces the amount of water required as well as the water that requires disposal. Washwater is scarce and expensive to haul in remote areas. Even commercial carwash stations with closed bays and floor sumps lose water due to carry off, filter flushing, and evaporation. Recycling systems at commercial carwash installations recover 75 to 90 percent of their washwater depending on filtration method and climate. These systems are largely enclosed so that overspray is prevented, and therefore an open-bay system would have difficulty recovering more than 85 percent of all water used. A system that recycles water in a preliminary coarse-wash phase and gives a final rinse with clean, fresh water can compensate for lost water. The final rinse could replace some of the water lost in the process.

FILTRATION

If washwater will be recycled and reused in any wash system, use filtration to remove invasive seeds from the used washwater and prevent vehicle cross-contamination. In addition, water treatment may be necessary to kill small bacteria, fungi, or neutralize other contaminants. Before dumping in a sanitary sewer system, wastewater often requires filtration or treatment. Several types of water filters are suited for this purpose. Often, filter technology developed for agriculture (irrigation), industrial waste treatment, and household swimming pools can be adapted to wash-station water treatment.

Filter types include the following:

- Gravity
- Centrifugal
- Screen
- Disk
- Bag
- Cartridge
- Particle media (sand)

All filters have limitations regarding the particle size they can trap. Filters are rated by mesh size (screens) or micron. Table 2 compares micron to millimeters, inches, and mesh size.

Table 2—Particle size

Micron	Inch	Mesh	Millimeter
1	0.00004		0.001
10	0.0004		0.01
50	0.002	270	0.05
100	0.004	140	0.1
200	0.008		0.2
300	0.012	50	0.3
400	0.016		0.4
500	0.02	35	0.5

Most weed seeds exceed 100 microns, and most fungal spores exceed 5 microns. Filtration below 10 microns is possible but not practical at higher flows in heavily contaminated water with a portable system. Most filtration systems incrementally reduce particle size by stages. The first stage might be a coarse bag filter and/or a settling tank. Other stages could be used depending on the final particle size to be removed and the systems flow rate.

Filtration Methods

Gravity Filters

Gravity filters (settling tanks) are the oldest filtration technology. They are effective, but require space, and fine-particle settling takes considerable time. Table 3 shows typical settling rates for various soil particles.

Table 3—Settling rates

Soil Texture	Inches	Millimeters	Micron	Settling Velocity feet/minute (meter/minute)
Coarse sand	>.02	>.50	>500	>126 (38)
Medium sand	.01 to .02	.025 to .050	250 to 500	Average 71 (22)
Fine sand	.004 to .01	.10 to .25	100 to 250	Average 16 (5)
Very.fine sand	.002 to .004	.05 to .10	50 to 100	Average 2.8 (0.9)
Silt	.8-4 to .002	.002 to .05	2 to 50	Average 0.05 (0.015)
Clay	<.8-4	<.0025	<2	<.0002 (.0006)

Time for particles to settle is the vertical distance divided by the settling velocity

T = D/Sv,

where T = time (minutes), D = vertical distance (feet), and Sv = settling velocity (feet per minute [ft/min]). The rate suspended particles settle varies inversely with their size. All rates in the table are based on a particle specific gravity of 2.65 grams per cubic centimeter (g/cm^3). Given the settling velocity of 0.05 ft/min for silt, it will take 1 hour to settle a depth of 3 ft in calm water (3 ft/0.05 ft/min = 60 min). For clay particles, the time is much greater at 10.5 days (3 ft/0.0002 ft/min = 15,000 min).

Centrifugal Separators

Centrifugal separators work best for applications requiring heavy solids removal, with high and constant flow rates. The higher the separator velocity, the more effective the separator is in removing smaller particles. As with any filter, they must be purged periodically, and the solids stored. Rinse-water use is fairly low. Because centrifugal separators are ineffective at removing particles with a specific gravity less than 1.5 g/cm^3, they may not be effective at removing low-density vegetation and seeds. Water demand in most portable wash-system operations is intermittent and variable, so centrifugal separators may be impractical.

Screen Filters

Screen filters remove coarse particulates and vegetation well. As with any two-dimensional filter, however, they clog quickly with heavy solids loading. Some designs are self-cleaning but require clean water. The removed solids must be stored, and the rinse water can be filtered, settled, and reused.

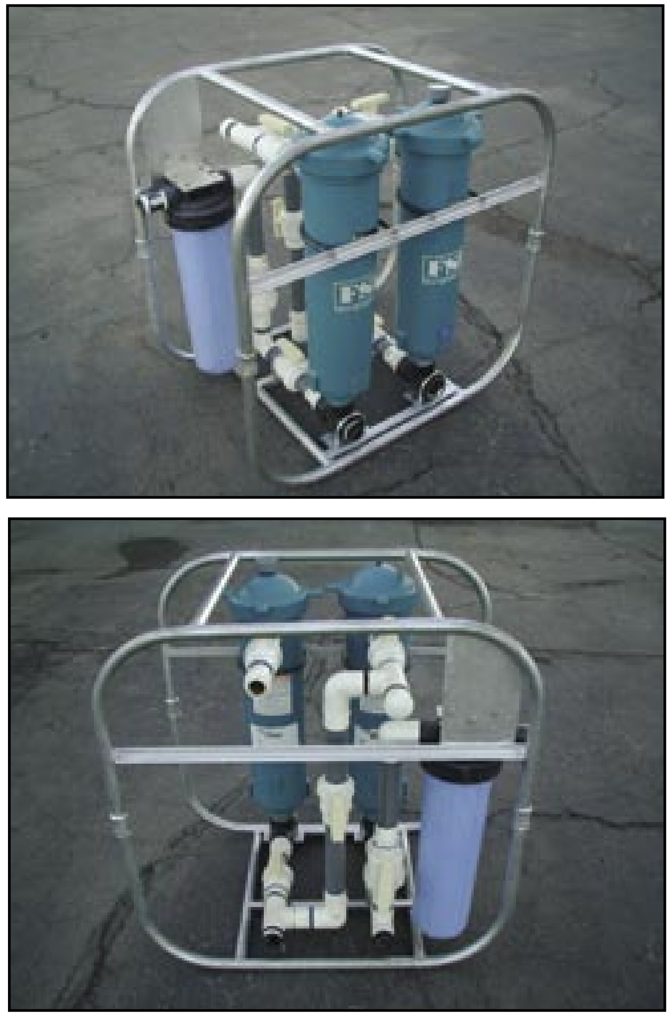
Bag Filters

Inexpensive bag filters can capture solids in water. They are available in several standard sizes, and the membrane can be specified to filter particles 2 microns and greater. Standard bags are designed for standard canister use. Table 4 shows standard filter bag sizes.

Table 4—Filter bags

Size	Dimension (inches)	Area (square inches)
#1	7 by 16.5	52
#2	7 by 32	101
#3	4 by 8.25	26
#4	4 by 14	44
X01	6 by 20	63

Bag-filter canisters of carbon steel, stainless steel, aluminum, or plastic compounds are available for different pressure ranges. The nonmetallic housings have lower pressure ratings and are safe below 100 psi. Steel or stainless canisters are rated higher, but weigh considerably more. SDTDC constructed a filter module (figure 7) with two X01 canister bag filters. Filter bags were in the 50- and 5-micron range, and the module weighed 80 pounds empty. The canisters could be used independently, in series, or in parallel. This filter system also included an oleophilic cartridge (oil trapping) as a final stage that removed hydrocarbons from the water for final disposal. Prefilter the water to 5 microns before it goes through the final stage because the oleophilic cartridge is costly, and the filter medium only comes in a 5-micron size.



Figures 7a and 7b—Bag and canister filter modules.

Bag filters are two-dimensional surface filters and the bag membrane area determines how quickly it clogs. If bag material and micron rating are equal, an X01 bag with a 63-square inch (in^2) area only passes 60 gal of water before clogging, while a #2 bag with 101 in^2 area clogs after passing 96 gallons of the same water. Filter bags can be rinsed and reused.

Geotextile Bags

Geotextile bags can be ordered in any size and variety of mesh fabric. Geotextile cloth has a natural affinity for hydrocarbons that tends to trap any oil or grease and, may serve as a discharge filter for wastewater. Geotextile bags can act as silt filters for pumping away ground water at construction sites. The fabric is durable, and bags have withstood 100 psi without rupture.

Another option for filtering larger solids is to specify a bag with larger openings. A 500-micron bag captures medium and large sand particles plus other large debris. Fine clays and ash pass freely without bridging. SDTDC experimented with small, custom-made 500-micron geotextile bags on a sump return. The bags measured 16 in^2 , with an inlet spout sewn on one corner. The bags were effective, durable, and manageable when filled with 40 pounds of wet sand and solids. The bags can be reused if a disposal container is available for the waste material.

Figure 8.—Geotextile bag.

Cartridge Filters

The SDTDC filter-canister module shown in figure 7 can be equipped with bag or cartridge filters. This filter module is compact, portable, and best suited for flow rates less than 10 gal/min, unless the water is relatively free of cohesive fines. This approach can be the final treatment before discharge for disposal with the appropriate cartridges.

SDTDC staff conducted an experiment to compare cartridge-filter capacity with an equivalent particle-size bag:

- Empty bags were weighed, and a slurry of potter's clay, charred wood and ash, soot, soil, and vegetation was pumped through the filters until they clogged.
- Bags with 50-micron ratings were used and pumping continued until the pressure drop across the filter was 20 psi.
- The bags were removed, dried, and reweighed.
- The experiment was repeated with 50-micron-rated cartridges.

Because the cartridges are three dimensional, it took longer to reach the same pressure drop, although time and flow were not measured. When the filters were dried and reweighed, the net weight gain in the 50-micron bag filter was 34 grams, and there was a 1,100-gram gain (32 times more particulate) for the cartridge filter. Although filter cartridges cost four to five times more than bag filters of equivalent size, their added capacity may be worth the additional cost.

Particle Media Filters

Particle media filters are a universally effective filtration method using a container or vessel filled with fine sand or other mineral particulate. Contaminated water is injected below the filter media, and as the water rises through the sand, it follows a path where entrained particles become lodged or trapped. The depth of the media provides a three-dimensional filtration process with more capacity than screens or bags. Sand filters are rated for flow based on filter-media area. The maximum flow rate for moderately contaminated water is 20 gal/min/ft^2 and 10 to 15 gal/min/ft in^2 for dirty water. Backflush heavily contaminated media filters. This process requires significant amounts of clean water, depending on filter size. Backflushing a sand filter takes 3 minutes at its maximum rated flow. A sand filter rated at 30 gal/min requires 90 gallons of clean water for each backflush cycle.

Table 5 lists various filter media and the mean particle size they filter. A typical media for this application might be #20 silica sand with a uniformity coefficient of less than 1.75. (A uniformity coefficient of 1.0 means all particles are exactly the same size.) Silica sand is available at most pool supply stores.

SDTDC mounted a 20-inch sand filter (figures 9a and 9b) in a frame to make it a mobile, modular unit. According to suggested limits for this type filter, it should be effective at 22 gal/min in heavily-loaded water. Plastic models used for swimming pools are fairly lightweight when empty. The lighter-weight housings generally are rated for pressures less than 60 psi, so overpressurization could pose a hazard. A properly-sized relief valve protects the housing against overpressurization, and the module shown in figure 9a uses an adjustable 1-inch relief valve set at 60 psi on the filter inlet. Bypass water returns to the tank. When empty, the module weighs 98 pounds, making it easy for two people to load. One person can move it by handcart. Filled with dry sand, it weighs 175 pounds. Wet weight is 200 pounds. The frame corners have a wide radius, making the filter easy to roll on its side or to invert for cleaning or servicing.

Table 5—Filter media

Media #	Media type (millimeter)	Effective diameter @ 15 to 25 gallon/minute/square foot (in millimeters)	Mean filtration capability
12	Round Monterey sand	1.3	0.21 to 0.16 (70 to 90 mesh)
16	Round Monterey sand	0.65	0.15 to 0.12 (100 to 125 mesh)
8	Crushed granite	1.5	0.15 to 0.11 (100 to 140 mesh)
12	Crushed silica	1.2	0.11 (130 to 140 mesh)
20	Round Monterey sand	0.5	0.11 (130 to 140 mesh)
11	Crushed granite	0.78	0.11 to 0.08 (140 to 200 mesh)
16	Crushed silica	0.7	0.10 to 0.08 (150 to 200 mesh)
20	Crushed silica	0.47	0.08 to 0.06 (200 to 250 mesh)

Pool-supply stores carry a variety of inexpensive sand filters. This module cost less than $1,000 to build.

Figures 9a and 9b—Sand filter module.

Disk Filters

The disk filter is an innovative concept in filtration technology. A disk-filter system is a relatively lightweight modular design with one or more filter housings, each containing an automatic disk cartridge. Each disk cartridge has a stack of plastic circular disks installed vertically and tightly compressed by a spring during filtration mode. Dirty water passes through the disk media from the outside. The individual disks have molded grooves across their faces. The groove depth controls the particle size filtered. Disk size ranges from 20 to 200 microns. As dirty water passes through the three-dimensional disk media from the outside, a “caking effect” is achieved across the disk depth, filtering increasingly finer particles.

When in backflush mode, the spring normally compressing the disks in filtration mode is overcome by water pressure, decompressing the entire disk stack. Simultaneously, high-pressure filtered water is uniformly reversed through the disk media from the inside out, thoroughly cleaning the individual disks. During the backflush cycle, compressed air introduced into the backwash water stream reduces the total volume of backflush water required to clean the filter. For example, a single filter housing rated for 50 gal/min only requires 3 gallons of water for each backflush cycle. (Note: If a water truck or fire engine serves as the water source and primary pump, the air brake system can provide compressed air. The backflush cycle is electronically controlled, drawing minimal current, and can be powered by 120-volt alternating current or 12-volt direct current.)

Figure 10 shows a single-stack disk filter module built by SDTDC for evaluation as part of a portable system. The pod on the right contains the disk stack, and the other pod is a reservoir of clean water for backflushing. One reservoir pod can serve several disk pods if higher flows are desired.

This system was used by personnel at the Grand Prix firecamp in Glen Helen, CA, during October 2003. It performed flawlessly using 100-micron disks and was the only filter used for a preliminary coarse-wash phase. Backflushing was infrequent, and the minimal backflush-water was contained, settled, and reused. This module weighs 144 pounds and is easily moved with a handcart or lifted by two people.


Figures 10a and b—Disk filter module.

Turnkey Recycling Systems
Hybrid water recycling systems are available at various flowrates. Some incorporate chemical treatments, activated charcoal, or ozone to remove hydrocarbons and other organics. These systems may be considered portable but most require a forklift or a flatbed truck or trailer to transport. Power is required for operation and most require 120- or 240-volts alternating current. Wastewater recycling systems typically cost $12,000 to $35,000, depending on process rate, disinfection system, and processed water purity.

Rental Systems
At least one manufacturer offers rental wastewater recycling equipment. Currently, a 25-gal/min system-with ozone injection and 10-micron filtration-rents for $425 a month with a 1-month minimum. Other rental recycling systems may become available as demand increases and shorter rental periods become available. Other wash-related support items, such as generators, trash pumps, pressure washers, and water trailers or trucks are widely available for rent by the day, week, or month. The wash-system containment part is not readily available for rent, and some consider flexible mats expendable.

Weekly rental rates are four to five times the daily rate. Table 6 shows the weekly rental cost for a complete system based on Los Angeles area daily rental rates.

Table 6—Rental costs

Item	Cost (in dollars)
25 gallon per minute recycling system	425/month (minimum)
500 gallon water trailer	70/day 315/week
Trash pump	35/day 157/week
Pressure washer	25/day 112/week
Containment mat (10 by 30 feet)	225 (expendable)
Geotextile underlay	40 (expendable)

This scenario costs $1,275 for 1 week (plus labor and transport). The recycling system is currently available for 1-month-minimum periods, with a reusable mat.

WATER TREATMENT

Chemical treatment such as chlorine or any swimming pool clarifiers and antibacterial agents can eliminate many water-borne pathogens and destroy fungal spores, but their use complicates disposal issues. Consult the appropriate sewage disposal treatment facility before adding chemicals or detergents to the washwater. The facility may reject the wastewater, resulting in a longer haul distance for disposal.

Flocculants that attract small particles to one another are available to assist in settling and filtration. This attraction causes them to combine into larger particles that settle quickly and are filtered out easily. Inexpensive flocculants are often sold as “clarifiers” through pool supply outlets or home improvement stores. Some waste disposal facilities, however, do not accept water containing flocculants.

Ozone treatment may be an appropriate step in the recycling or disposal process, particularly where spores, microbes, hydrocarbons, and other organics are present. Ozone is formed when biatomic oxygen molecules, O^2, are split by forces such as an electric arc. The free radical oxygen atom bonds temporarily with an O^2 molecule forming ozone, O^3. This powerful oxidant effectively destroys organic matter. O^3 is unstable and within seconds reverts back to oxygen. Thunderstorms, photocopiers, and electric motors produce ozone. Most people have noticed its odor, although they may not have recognized it. At concentrations above 0.1 parts per million (ppm), ozone constitutes a health hazard for sustained exposure; therefore, exercise caution to minimize exposure. If the ozone is pumped into a closed container in which it bubbles into the water through a diffuser, any escaping gasses should be minimal. Keeping the container about 10 feet from workers makes encountering dangerous concentrations unlikely. Ozone odor is generally detectable in concentrations around 0.02 to 0.05 ppm, or less than half the unhealthy amount, so if the odor is undetectable, no hazard is present. Installing an activated carbon filter eliminates any residual ozone before it is sprayed. But, if no odor is present, no danger exists.

Figure 11—Ozone generator module.

SDTDC built the portable ozone generator module in figure 11 for field use. It combines a corona discharge ozone generator, desiccant air dryer, regulator, and buffer tank. The supply air is processed through the dryer at 100 psi and then reduced to 5 psi before the generator. Desiccant dryers work more efficiently at high pressures and the generator requires clean, dry air. This ozone generator; however, cannot handle pressures above 10 psi, so a regulator was placed downstream of the dryer. SDTDC staff customized a cover to protect the unit from overspray or rain while still allowing operators to inspect or adjust it depending on use rate. This unit has manual analog controls for simplicity, reliability, and affordability, although automated digital control models are available. It produces 10 ft^3/h of pure ozone, which is appropriate for water-use rates to 20 gal/min. This module cost $2,500 to build.

TECHNOLOGY AND DEVELOPMENT SYSTEMS AND FIELD TESTS

MTDC System

The Missoula Technology and Development Center (MTDC) built a trailer-mounted mobile wash unit that can be pulled by a 3/4-ton truck when the water tanks are empty. The MTDC system is described in detail, with some of the field-testing results, in publication 0434-2826-MTDC, July 2004. The unit recycles the washwater as much as possible and carries all necessary hardware to set up a washing station that can be deployed and operated by two people. Two units have been built and delivered to the Los Padres National Forest (Region 5). The portable MTDC systems were built for onsite vehicle washing. The estimated cost to build each unit is $27,000. Fabrication drawings are available through MTDC.

SDTDC Systems

SDTDC built washing systems for remote applications. SDTDC's primary purpose was to evaluate concepts and components for remote vehicle-washing applications. Each modular SDTDC system component or subsystem can be evaluated separately, and different systems can be "plugged in" to replace any inadequate componentunder certain conditions. In 2003, SDTDC hardware was used for two projects that required portable equipment washing systems.

Dogtown Lake

The Dogtown Lake campground improvement project operated machines in an area infested with toadflax. A backhoe and a skip loader were the only heavy machines used in the weed management area (WMA), and they had to be washed before they could leave. The WMA was adjacent to the lake, which also served as a reservoir for the local community around Williams, AZ. A flexible containment mat was placed at the edge of the WMA to avoid the unacceptable option of running washwater into the soil. The machines had been working in muddy conditions and were heavily soiled. Because only a few machines needed to be cleaned, and an ample water was available, the washwater did not need to be recycled. The machines were cleaned with a high-pressure commercial washer to minimize runoff disposal issues in the end. A 1/2-hp household sump pump collected the wastewater and pumped it into a holding tank, where it was later settled, filtered, and disposed of in a sanitary sewer. Sludge was shoveled off the containment mat and onto a tarp to dry. The entire operation only used 75 gal of water, so recycling was neither necessary nor practical. The Dogtown Lake project is a good example of a situation requiring minimal hardware, most of which could have been rented. Hiring a service contractor to bring a washing station to the jobsite and wait until the equipment was ready to wash would have cost more than $5,000.

Figure 12—Loader at Dogtown Lake.

Grand Prix Fire

In 2003, SDTDC equipment was used to wash vehicles at the Glen Helen, CA, firecamp. This major fire involved hundreds of trucks and several heavy machines. Two other fires erupted nearby while the Grand Prix fire was far from contained. In fact, spot fires from blowing embers engulfed the entire area surrounding the firecamp including the staging area where the wash systems were deployed.

The staging area was a large parking lot that provided ample room for drive-through washing on both an elevated washrack and a flexible mat running parallel. The firecamp team used the washrack for most of the equipment, and the mat for trucks with low clearance and trailer axles with up to eight wheels in a row running 10 feet wide. Ramps leading to and from the wash rack were set up for dual-wheel axles with an 8-foot overall width. More ramps would have accommodated the wider axles. Separate sump pumps, at 1/2 hp each, returned water from the mat-and-rack gutter to a 600-gallon portable folding tank.

A 3-hp electric centrifugal pump was used for the filter system, spray bar, and two 1-inch combi nozzles. A 9-kilowatt generator provided power for the main pump, sump pumps, and compressor. A spray bar system was set on the washrack with four fixed nozzles and five nozzles arrayed on a rotating cross bar. The system, configured for vehicles with at least 5 inches of ground clearance, made it inappropriate for some heavy equipment trailers. The spray-bar system and two hand-held, 1-inch barrel nozzles used reclaimed water filtered to 100 microns using the SDTDC disk-filter module. All ran water at 40 to 60 psi. The spray bar produced 16 gal/min, while the barrel nozzles were set to 13 gal/min. A second filtration stage followed the disk filter. The bag- and cartridge-filter module was set up to filter progressively through 50- and 5-micron bags. The filtered water supplied a pressure washer at 3,700 psi and 4 gal/min for the final rinse. The high-ash content of the washwater clogged the bag filters after washing seven trucks. The bags were replaced but needed changing again after six more trucks were washed. This service interval was unacceptable, so the bags were removed and replaced with cartridge elements of the same particle-size rating. Washing continued without changing the cartridges.

For reasons unrelated to wash-system hardware, only a small portion of the vehicles scheduled to be washed at the Grand Prix firecamp were washed. Around 50 vehicles (1/2-ton trucks to heavy equipment haulers) used the washing station. Sudden changes in strategy sent many crews to another camp where a washing-service contractor was already set up.

OTHER ISSUES

Heavy equipment is a concern. Trying to remove enormous amounts of debris picked up by earth moving equipment with water spray is often wasteful. SDTDC strongly recommends that heavy debris first be removed manually by trowel, shovel, or brush before the vehicle returns to the loading area. All remaining debris can be washed off before the equipment is loaded. During a fire emergency, runoff containment is not required, but a geotextile mat is recommended to help trap any seeds and hydrocarbons. In addition, the area should be monitored and treated if necessary.

WASTE DISPOSAL

Wastewater

Even if a wash system only uses freshwater, and all the wastewater is hauled to a treatment facility, some minimum quality standards must be met. Unless a waste-oil contractor hauls and disposes of the water, hydrocarbons should be removed as is most practical. Because different sewage facilities have different standards for waste acceptance, it is best to filter the water to a fine-particulate size and remove hydrocarbons and other organic compounds to the greatest extent practical.

If wastewater is discharged where it could enter a storm drain, the regional water quality authority has maximum allowable limits for hydrocarbons and suspended solids. Generally, these limits are low.

The Los Angeles Regional Water Quality Control Board, stringent as any in the country, has specified limits for stormwater discharge of 100 milligrams per liter of total suspended solids and 15 milligrams per liter of oil and grease. (Note: U.S. Environmental Protection Agency regulations regarding stormwater discharge permits do not apply to emergency firefighting activities.) Other entities with jurisdiction in a specific area may have additional requirements, however, and in general follow best management practices. Firefighting equipment may be washed off with freshwater, and no containment is required unless the ground water is close to the surface, or the runoff would enter a nearby culvert, stream, body of water, or stormwater conduit. Installing a geotextile mat or similar permeable particle barrier where the equipment is washed is recommended. This layer catches most seeds while absorbing oily hydrocarbons and can be disposed of properly when time allows. Monitor areas where equipment has been washed to ensure that no weed or fungal infestations develop in the future.

Solid Waste

Solid waste processed out of the washwater that contains no detectable concentrations of oil or grease probably can be disposed of in a sanitary landfill. One anecdote from a wash-station service vendor in August 2004, however, indicates that contamination levels in the solid waste may be unacceptable at some landfills. Waste from a washing station was collected and sent out for laboratory analysis. More than 200 fire engines and similar vehicles were cleaned at a wash station during a Riverside County, CA, fire. Traces of hydrocarbons and heavy metals were detected, but the quantities were small enough that they did not rise to the level of hazardous waste. The water, however, would be rejected at some landfills. Sludge may not be accepted at some landfills either, but it can be converted easily to solid waste by spreading it on a tarp or sheet of plastic and allowing it to dry. Consult the proper authority before disposing of solid waste.

SERVICE CONTRACTORS

Many service contractors offer a variety of mobile wash-unit solutions with varying complexity and price. Internet searches for “mobile wash service” returns thousands of matches, of which several hundred may be useful. Listed below are the names of several vendors who have provided service to the USDA Forest Service.

ACME Endeavors, LLC, offers washing services for remote locations with five optional configurations. Containment is a 12- by 38-foot flexible mat with a diaphragm pump sump pickup. Wastewater may be disposed of immediately, stored, or treated and recycled, and the system cost varies because of the preferred water supply and waste disposal method.

The underbody washing system includes a drive-over spray bar assembly that can clean all terrain vehicles, minivans, and semitrucks. The area between the outside of the vehicle's frame and inside the body is cleaned by oscillating or rotating nozzles mounted on spring-loaded swinging booms pushed out of the way by the vehicle's tires that automatically swing back into place after the tires pass. Lightweight ramps can be placed on the mat to assist low-clearance vehicles over the spray bar.

The basic wash system includes the containment mat, all necessary pumps, an 1,800-gallon supply tank, spray bar, manual spray wand, and an operator. Production rate is 5 minutes for an average fire engine, and water use is 70 gallons per truck if the water is not recycled.
The contracting agency must provide the following:

- All fresh water.
- All disposal of waste.
- A crew of two for setup and takedown (temporary). Additional helpers can be assigned to expedite washing with additional wands.

Option 1-$2,000/day. This option provides an operator, the basic drive-over underbody washer, hand-held wand, pump, miscellaneous plumbing, and 1,800-gallon water tank.

Option 2-$2,400/day. This option provides the above plus a water recovery system that pumps the used washwater away from the wash site.

Option 3-$2,450/day. This option provides the above plus an 1,800-gallon storage tank for the used washwater.

Option 4-$2,800/day. This option provides the above plus a sand/oil separator that permits the used washwater to be recovered by graywater trucks and disposed of at a water treatment facility.
Option 5-$3,200/day. This option provides the above, plus it recirculates the used washwater for use in the drive-over wash assembly, followed by a clean-water rinse to minimize cross contamination. A full-size truck can transport all options that Acme Endeavors provides. Setup time once onsite is 1 to 3 hours.

Contact:
David Dieziger
ACME Endeavors, LLC
9755 Horseback Ridge Road
Missoula, MT 59804
Phone: 406-543-7440; Cell: 406-207-2275
E-mail: acme@montanadsl.net
Web site: http://www.acme-endeavors.com

All Clean Water Solutions is a full-service wash station contractor with a self-contained mobile wash unit. The equipment is delivered on a flatbed trailer, and the company provides its own forklift for setup and reload.

The system consists of an elevated washrack with sump, two spray wands, water reservoir, and all related pumps, hoses, filters, and ancillary hardware. All labor is provided and the company is fully insured.

The washrack is 32-feet long, 10-feet wide, and 10-feet high. It can withstand 12-ton axles and the approach-departure ramps provide a sufficiently shallow lead to prevent undercarriage contact from most low-profile trailers.

The spray wands are high-pressure, low-flow style, and All Clean claims average process rates of 2 minutes per vehicle. Used water is filtered to 0.2 micron and reused. All wastewater also is treated and disposed of properly by the contractor. Full lighting is available for night use.

Prices start at $295/hour for travel time and $2,360/day for a single shift. Additional hours are $295/hour.

Contact:
Anthony Borgatello
All Clean Water Solutions
P.O. Box 4552
Santa Barbara, CA 93140
Phone: 888-896-8047; Cell: 805-896-8047
Web site: http://www.allcleanwash.com

Breezeco offers a mobile full-service washing system that can be transported to areas where access is difficult. All containment, pumping, water storage, spray, recovery, and filtration equipment is provided. A water truck also is available.

Containment is a flexible mat with berms 15-feet wide by 75-feet long. Initial wash is a drive-through spray bar system with multiple nozzles delivering 125 gal/min at 90 psi. Manual targeted spray nozzles can follow the spray bars to remove any remaining debris. Primary wash water is filtered to 30 micron, and chlorine or ozone treatments are available. A secondary Zelbrite filter medium removes particles to 5 micron if needed, and an optional additional finish wash with fresh, clean water is available.

Process time ranges from 10 to 20 seconds with no manual washing, to 5 minutes for an average fire engine with second- and third-phase washing. Water use is 40 gallons for an average fire engine without manual washing and 200 gallons for a thorough wash. Assuming 90 percent recovery, net water use ranges from 4 1/4 to 20 gallons per truck. The contractor provides all water.

Use fee is $2,775 per 12-hour shift and is charged from the time equipment is dispatched until it returns. The fee includes a crew of three.

Contact:
Richard Breeze
Breezeco
P.O. Box 16
Davis Creek, CA 96108
Phone: 530-233-3179; Cell: 530-640-3179
E-mail: rbreezeman@aol.com

Delco Cleaning Systems maintains a list of power washing contractors by State. Services and capabilities are listed, but prices are negotiated with the individual vendor. Check their Web site for details.

Contact:
Delco Cleaning Systems
2513 Warfield Street
Fort Worth, TX 76106
Phone: 800-433-2113
Web site: http://www.dcs1.com

Diamond Fire Resources is a full-service wash system provider. They supply all water, labor, and power. Waste disposal is included, and its filtration system can restore graywater to a sanitary condition for dust-abatement use. The system uses an elevated washrack 14-feet wide by 70-feet long and a surrounding spray bar 16-feet high. This height allows loaded machinery to pass, and a manual spray follows to remove any missed debris. A typical wildland fire engine is claimed to be processed in less than 1 minute if manual cleaning is unnecessary. In October 2003, the service cost $7,500/day, with no other expenses.

Contact:
Jim Butler or Pat Butler
Diamond Fire Resources
P.O. Box 698
Banning, CA 92220
Phone: 909-849-7447
E-mail: diamondfire@hotmail.com

Spence Industrial Supply offers a full-service wash system with all support equipment and personnel. The system uses a drive-through elevated washrack with containment walls and gutter sumps. Spray nozzles on the sides and bottom deliver 60 gal/min of freshwater, and a hand-held wand can be added to the process for areas where the nozzles did not clean effectively. When used strictly as a drive-through wash, process time can be as little as 15 to 20 seconds, and the system can process one truck after another, continuously. Optional manual washing uses an 1,800 psi, 5-gal/min pressure washer, which adds to the process time. Multiple pressure washers also can be used at an increased cost.

All process water is recovered to the greatest extent possible, injected with ozone, and filtered. Oils and hydrocarbons are removed, and final filtration is a 5-micron bag filter. Waste disposal is the contractor's responsibility, and pricing for this service has been arranged under emergency agreement. A complete wash station with operator and 3,200-gallon support water truck costs $2,460/day for a single shift, and $4,672/day for a double shift. The same service with a 2,000-gallon tank costs $2,052/day for a single shift and $3,632/day for a double shift.

Spence Industrial Supply offers wash-station equipment for rent without operators on a monthly basis as well.

Contact:
Steve Rooks
Spence Industrial Supply
2700 Broadway
Baker City, OR 97814
Phone: 800-285-9266

CONCLUSIONS

Noxious weed and invasive plant infestations are a costly problem. The cost of eradicating or spraying established infestations exceeds the cost of prevention more than tenfold. Discuss weed control during the planning phase of any project that involves the movement of vehicles and equipment in areas where weeds may exist. A survey of the worksite by a knowledgeable botanist also would be a good first step. Knowing what species may be present in the area, when they will be producing seeds, and the size of the seeds is useful. Washing equipment that moves between work areas helps reduce the spread of invasive plants and prevent diseases from infecting another area or destructive insects from inhabiting a new area. Agencies performing activities that involve the movement of vehicles and equipment between undeveloped areas have a responsibility to show good stewardship and take the necessary precautions to prevent the spread of any undesirable elements.

A self-contained washing station based at a work center or equipment yard would be useful for thorough cleaning before equipment goes to any new location. If the washing station were portable, it could be set up in other areas as needed.

Whether washing should be contracted or performed by agency employees depends on economics and logistics, but the equipment is available. For short-term, unplanned situations such as wildfires, a service contractor is the best option unless qualified agency personnel are available and the agency has other uses for a mobile wash system throughout the year. If an agency has a steady demand for washing equipment, many options are available to build a system. Using the information provided in this publication, only limited mechanical skill is required to construct an appropriate system.

For design advice or details on any of the hardware or topics discussed in this report, contact
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Suite 200
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APPENDIX A
Vendors and Products

VENDORS	PRODUCTS
Washing and Recycling Equipment	
Hydro Engineering 865 W. 2600 South Salt Lake City, UT 84119 Phone: 800–247–8424 Web site: http://www.hydroblaster.com	Hydroblaster(r) Pressure Washers Hydropads(r) Washracks
InterClean Equipment Inc 3918 Varsity Drive Ann Arbor, MI 48108 Phone: 734–975–2967 Web site: http://www.interclean.com	Complete vehicle wash systems Wastewater recycling systems
Riveer Co. 233 Veterans Boulevard South Haven, MI 49090 Phone: 888–857–7304 Web site: http://www.cyclonator.com	Washracks Recycling systems
Western Water Products 21756 Twinford Drive Lake Forest, CA 92630 Phone: 949–581–8998 Web site: http://www.wateruse.com	Suction type recycling systems Hybrid filtration systems (Rentals available)
CARBTROL Corp. 955 Connecticut Avenue Suite 5202 Bridgeport, CT 06607 Phone: 800–242–1150 Web site: http://www.carbtrol.com	Wastewater Recycling Systems
Spraying Systems Co. P.O. Box 7900 Wheaton, IL 60189-7900 Phone: 630–665–5000 Web site: http://www.spray.com	Spray nozzles & accessories
Filter Equipment	
Frank Roberts & Sons, Inc 1130 Robertsville Road Punxatawney, PA 15767 Phone: 800–262–8955 or 814–938–5000 Web site: http://robertswholesale.com	Geotextile filter bags Custom filter bags
Filter Specialists Inc. 100 Anchor Road Anchor City, IN 46360 Phone: 800–348–3205 Web site: http://www.fsifilters.com	Standard filter bags

MYCELX Corporation 961 Chestnut Street Gainesville, GA 30501 Phone: 888–306–6843 Web site: http://www.mycelx.com	Oleophilic filter elements
Miller-Leaman, Inc. 800 Orange Avenue Daytona Beach, FL 32114 Phone: 800–881–0320 Web site: http://www.millerleaman.com	Turbo-Disk(r) filters Sand Filters Screen filters
Ozone Water Systems 5401 S. 39th Street Phoenix, AZ 85040 Phone: 480–421–2400 Web site: http://www.ozonewatersystems.com	Ozone generators and systems
Pumps	
Honda Power Equipment Web site: http://www.hondapowerequipment.com	Pumps, generators Pressure washers
Mats	
D.S. Sewing P.O. Box 8983 260 Wolcott Street New Haven, CT 06513 Phone: 800–789–8143 203–773–1344 Web site: http://www.ds-sewing.com	Plain rubberized mats
Water Trailers	
C & I Equipment Company, Inc. 9421 N. Casa Grande Highway Tucson, AZ 85743 Phone: 888–580–8330 Web site: http://www.ciequip.com	Water Trailers
Geotextile	
Amoco Fabrics & Fibers Co. 260 The Bluffs Austell, GA 30168 Phone: 800–445–7732 Web site: http://www.geotextile.com	Geotextile fabric manufacturer
Reed & Graham 26 Light Sky Court Sacramanto, CA 95828 Phone: 916–381–9900 Web site: http://www.rginc.com/geo	Geotextile Cloth Geotextile Bags

Water and Storage Tanks

Fol-Da-Tank
1275 W.11th Street
P.O. Box 110
Milan, IL 61264
Phone: 800–637–8265
Web site: http://www.foldatank.com

Portable folding water tanks

P.E.P Polyethylene storage tanks
50 Tannery Rd., Building #3
Branchburg, NJ 08876
Phone: 800–407–3726
Web site: http://www.pep-plastic.com

APPENDIX B
Additional Sources

Additional Resources

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California State Water Resources Control Board
Web site: http://www.swrcb.ca.gov/stormwtr/index.html

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Trent, Andy; Karsky, Dick; Harding, Chuck; Gilmour, Scott. 2004. MTDC Portable Vehicle Washer. 0434 2819. Missoula, MT: U.S. Department of Agriculture, Forest Service, Missoula Technology and Development Center. 14p.

Additional information regarding vehicle cleaning technology for controlling the spread of noxious weeds and invasive species may be found on the San Dimas Technology and Development Center Intranet web site at: http://fsweb.sdtdc.wo.fs.fed.us/
Electronic copies of SDTDC's publications are available on the Internet at:
http://www.fs.fed.us/eng/pubs/

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Joe Fleming is a mechanical engineering technician with experience in electronics, machine design, and heavy equipment operation. Before coming to the center in 1990, he worked for FMI a private contract engineering company where he developed a substitute earth anchoring system. Joe provides technical support to all program areas. He holds U.S. Patent No. 6,622,957 issued September 23, 2003 for a hose winding device. In 2003 he received the Chief's Engineering Technician of the Year award.

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