A WATER CURTAIN FOR CONTROLLING EXPERIMENTAL FOREST FIRES

Von J. Johnson

Experimental forest fires are often required for studying fire behavior, effects, and control techniques. Fires set by North Central Forest Experiment Station researchers for this purpose range from 10 to 40 acres in size in stands where the average tree height seldom exceeds 60 feet. Many of the fire sites are within ½ mile and 100 feet elevation of a natural water source. Confinement of these simulated wildfires to specific areas is essential, and for this reason a high-capacity water pumping and distributing system was developed to provide a three-dimensional water curtain barrier around fires. The following is a description of the water curtain and an evaluation of its preliminary performance.

WATER CURTAIN SPECIFICATIONS

The water curtain delivery system was assembled from commercially available components. The initial design called for lifting water 100 feet over a horizontal distance of 2,500 feet with an average total discharge rate of 1,200 gallons per minute at two-thirds of maximum power capacity. This discharge requirement was based on preliminary tests conducted by the Michigan Department of Conservation, which showed that an optimum spray height could be obtained at 100 p.s.i. by moving about 11.4 gallons of water per minute through a ¼-inch orifice.[1] One hundred and twenty nozzles spaced at 20-foot intervals were used around the perimeter of a 10-acre burning block. A discharge of 1,200 gallons per minute furnishes 10 g.p.m. for each nozzle at an average pressure of 35 p.s.i. Reducing the pipe size toward the downstream end reduces power requirements and increases nozzle pressure up to 100 p.s.i.

Power needed for the system was estimated to be 130 usable horsepower. Five Model VG4D Wisconsin[2] air-cooled gasoline engines met this requirement when operating at about 70 percent maximum capacity. Horsepowers at 60° F. and barometric pressure of 29.92 inches of mercury for the Wisconsin Model VG4D air-cooled engine are as follows:

R.p.m.	*Horsepower*
1,400	25
1,600	29
1,800	32
2,000	34
2,200	36
2,400	37

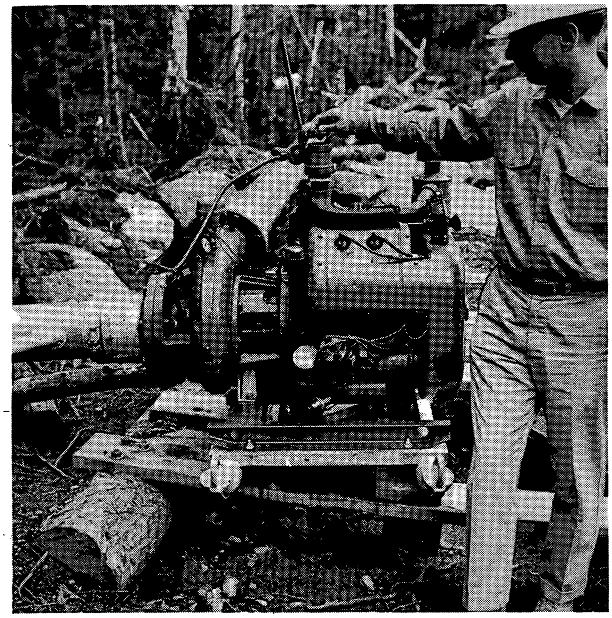
Each engine has a total displacement (four cylinders) of 154 cubic inches. Close-coupled to the engines were 6-inch end-suction centrifugal Model S30Z FM 6/B Jacuzzi pumps. The empty weight of each pump unit, equipped with a 12-volt battery, starter, and 4-inch iron-pipe skids, is about 750 pounds.

Engine exhaust primers, installed on two pump units (fig. 1), facilitate priming the centrifugal pumps through 20 to 60 feet of 8-inch suction pipe. Long suction distances are usually necessary to reach suitable water sources from a riverbank (fig. 2) or lakeshore.

To partially compensate for friction loss, maintain needed pressure, and increase efficiency, the pump units are used in series along the 2,500-

[1] *Personal correspondence with Steve Such, Michigan Department of Conservation, Roscommon, Michigan, 11/16/67, on file at the North Central Forest Experiment Station, St. Paul, Minnesota.*

[2] *Mention of trade names does not constitute endorsement of the product by the USDA Forest Service.*



F-520037
Figure 1.—Exhaust primer used to evacuate 8-inch suction line. Engines having a displacement of not less than 20 cubic inches are required for this conversion.

foot main line. Several safety mechanisms prevent damage to the units during unattended operation. A type 154MP11 loss-of-prime protector on the volute of each pump (fig. 3) prevents impeller cavitation and damage to the packing gland by opening the ignition circuit whenever line pressure drops below a specified setting. A type YC-48-51 oil pressure switch on each engine (fig. 4) protects against damage whenever engine oil pressure falls below a specified amount. A Wisconsin Model YC-66D-S1 high-temperature safety switch on a cylinder head boss of each engine automatically shorts out the distributor timer whenever the cylinder head exceeds safe temperature. About 10 minutes elapses before the switch cools sufficiently to restart the engine.

The 2,500-foot main line consists of 20-foot sections of 8-inch, smooth, aluminum irrigation pipe (0.072-inch wall thickness). Quick-connect couplers[3] welded to each section have a safe working limit of 150 p.s.i. and allow for about 11 degrees of leak-free lateral movement. Each

[3] *Series* 1000 *John Bean Division, FMC Corp., Lansing, Michigan.*

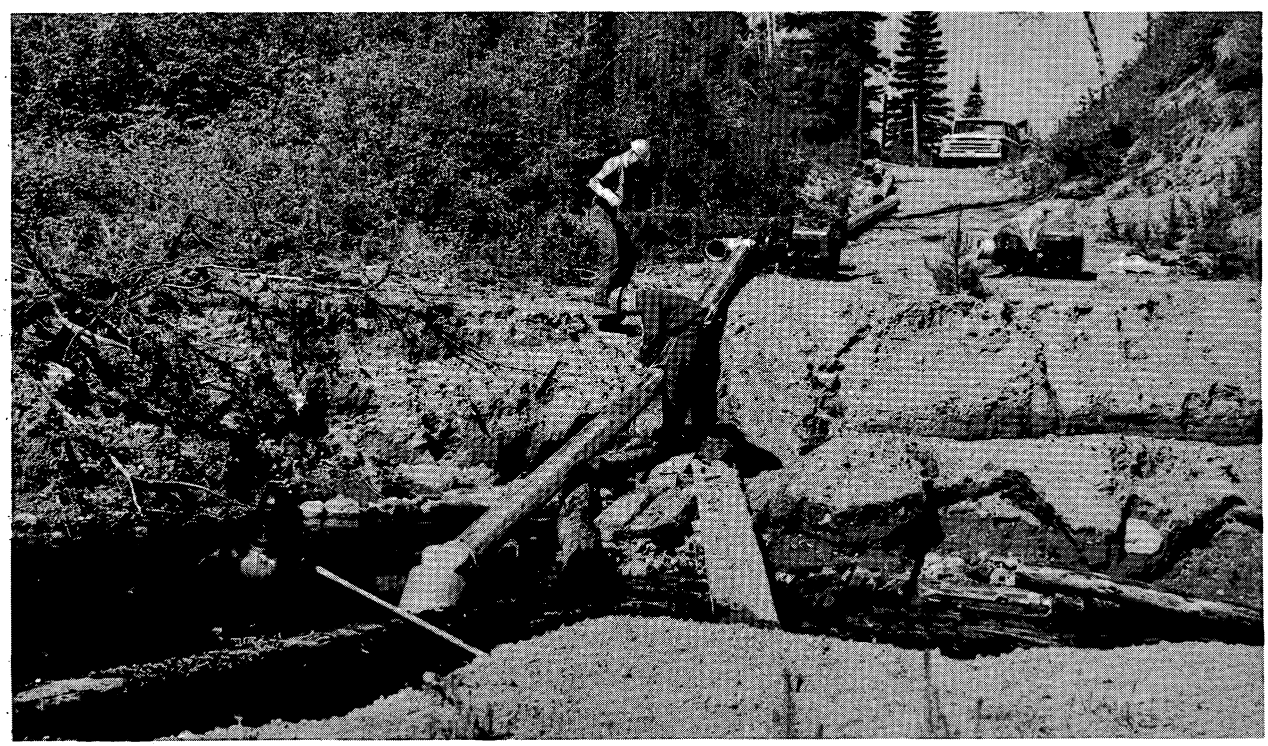


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Figure 2.—Forty feet of 8-inch suction line being used to reach a water sourch over an eroded bank.

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Figure 3.—Loss-of-prime protector installed on the volute. A pressure gage taped in at the base of the protector assists in setting the "cutout" mechanism whenever line pressure drops below 10 p.s.i.

F-520040
Figure 4.—An oil pressure switch opens the electric circuit in case of pressure failure.

20-foot section weighs 60 pounds. A 10- to 18-foot telescoping intake elbow is used with the in-line series pump units (fig. 5). This elbow permits a pump to be moved up to 8 feet for positioning to avoid obstacles.

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Figure 5.—A telescoping elbow attached to the intake of an in-line pump unit. The 1½-inch gate valve allows for drainage of the downstream line and an outlet for standard 1½-inch fire hose.

The lateral line is comprised of 2,400 feet of 5-inch, heavy-duty aluminum pipe (0.052-inch wall thickness) in 20-foot sections. Each section weighs 32 pounds. Quick-connect couplers[4] welded to each section with a ball check riser coupling attached permit about 11 degrees of lateral leak-free movement. Flow from the main line is regulated through a valved reducer-tee. The risers, which are 60 inches long, are made from 1-inch heavy-duty aluminum pipe (fig. 6) and can be rotated 360 degrees in the ball-check coupler while under pressure.

Nozzles are assembled on the threaded end of the riser from iron pipe fittings and a ¼-inch brass nozzle head. They are adjustable on a 360-degree vertical arc (figs. 7 and 8).

[4] *Series* 400, *John Bean Division, FMC Corp., Lansing, Michigan.*

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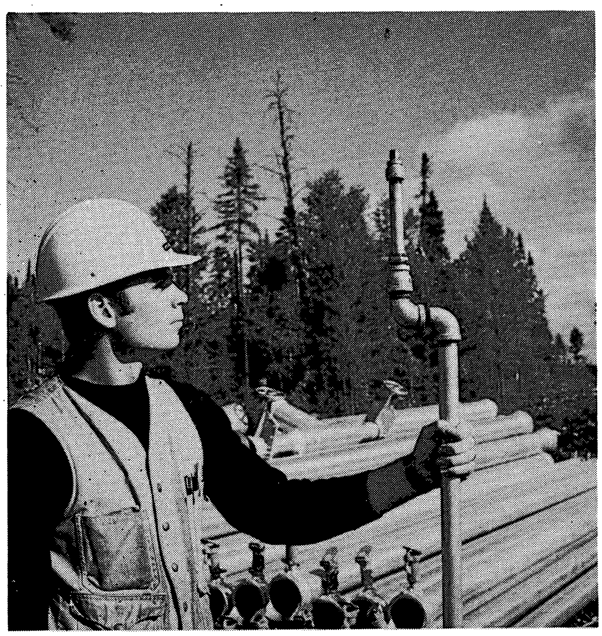
Figure 6.—Aluminum riser installed in quick couplers on a section of lateral pipe.



F-520043
Figure 7.—Nozzle assembly consists of two iron pipe elbows, two bell reducers, two bushing reducers, one 8- by ½-inch nipple, and a brass nozzle head.

F-520044
Figure 8.—The nozzle is adjustable through a 360-degree vertical arc.

The system is also equipped with a fertilizer injector[5] to add chemical fire retardants such as diammonium phosphate (DAP), low-sudsing biodegradable detergents, or water-soluable dyes. The injector venturi is installed near the downstream end of the main line so that corrosive materials are not circulated through the pump units.

PERFORMANCE

Preliminary testing of the water curtain system was done to determine approximate rates of discharge, friction losses in the lateral line, and spray patterns at various windspeeds. The preliminary test assembly consisted of three pump units, 480 feet of main line, and 1,000 feet of lateral line. Suction lift at the test site was 4 feet through 20 feet of 8-inch tube. Total discharge lift was 20 feet. Pump units were positioned at 0, 250, and 490 feet along the main line. The 1,000-foot lateral line, fed from one end of the reducer-tee, was laid along an abandoned

[5] *Dragon Model 20, 8-inch venturi. Dragon Engineering Company, Oakland, California.*

roadbed. Sensitive pressure gages were tapped to the end of nozzle assemblies at 20 and 980 feet. Six rain gages were spaced at 10-foot intervals midway between risers at 770 feet on an axis perpendicular to the lateral line. Approximate rates of discharge were determined from 18 runs of 20 minutes each at four average pressures (table 1). Water collected in the rain gages was measured after each run. This gave a conservative estimate of the total water volume discharged through the 48 nozzles. Pressure head values (table 1) were derived from mean readings of the two gages located on the first and last riser. As head pressure or windspeed increased, additional water atomized and drifted beyond the collection gages. Under a head of 50 p.s.i. and winds less than 5 m.p.h., this drift was about 3 gallons per minute. At 70 p.s.i. of head and windspeed greater than 10 m.p.h., 144 g.p.m. or about 20 percent of the total volume drifted downwind.

Table 1.—Measured rates of discharge for forty-eight ¼-inch nozzles compared with theoretical rates

Average pressure head (p.s.i.)	Replications	Average windspeed[1/]	Total discharge (q) Measured	Total discharge (q) Theoretical[2/]	Differential
		M.p.h.	G.p.m.	G.p.m.	
50	5	<5	598	601	-3
60	4	5	606	659	-53
70	4	>10	568	712	-144
88	5	5	711	798	-67

1/10-minute observation at a height of 6 feet and direction parallel or within 45° of rain gage axis.

2/ $q = 29.85 \cdot Cd^2 \sqrt{P}$ (Addison 1964)
Where C = 0.95, coefficient of velocity
d = 0.25 inch, diameter of nozzle
P = pressure in pounds per (inch)^2

Assuming no loss from friction, the 5-inch conduit can supply sufficient water volume for about 400 ¼-inch nozzles. However, friction is a major source of loss and for a given pipe size it is about proportional to the square root of the pressure. At an average of 88 p.s.i., maximum variation between the pressure gages located at 20-foot and 1,000-foot risers was 10 percent (15 p.s.i.). Computed friction losses, using Scobey's coefficient of discharge equation for various pressure heads, were consistently lower than observed losses (Scobey 1930) (table 2). This was due in part to our measurement techniques and to the roughness of the couplings (Scobey's coefficient of 0.32 is applicable to smooth, new iron pipe).

Table 2—Computed vs. measured friction loss for 960 feet of 5-inch aluminum conduit with outlets at 20-foot intervals

Computed[1/] discharge P.s.i.	Computed[1/] discharge G.p.m.	Computed[1/] discharge P.s.i.-loss	Measured[2/] loss p.s.i.	Differential
50	598	9.6	10.4	-0.8
60	606	9.9	10.0	0
70	568	8.6	10.0	-1.4
88	711	13.8	15.4	-1.6

1/Table 1 and Christiansen 1942

$$H_f = \left(\frac{K_s L V^{1.9}}{1,000\ D^{1.1}}\right) F$$

H_f = loss in feet of head (p.s.i. = 0.43352 H_f)
K_s = 0.32, Scobey's coefficient of retardation
L = 960, length of pipe in feet
V = mean velocity in feet/sec. from g.p.m.
D = 0.4167, diameter of pipe in feet
F = friction recovery factor for 48 outlets

$$= \frac{1}{m+1} + \frac{1}{2N} + \frac{\sqrt{m-1}}{6N^2}$$

= 0.355

2/Mean difference between first (20-foot) and last (1,000-foot) riser gages during each of 18 20-minute runs.

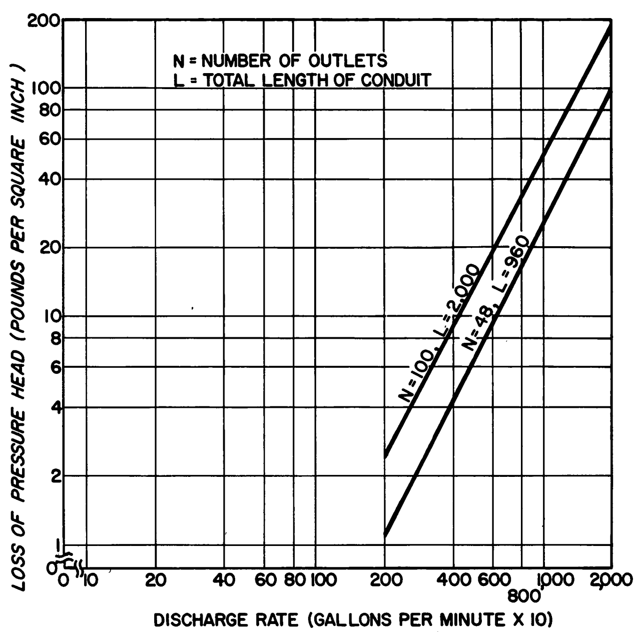


Figure 9.—Friction loss for 5-inch aluminum conduit with outlets at 20-foot intervals.

A chart was prepared from which friction losses for 5-inch aluminum conduit having outlets at 20-foot intervals can be estimated within 10-percent accuracy (fig. 9).

Heights of the visible spray column at the first and last nozzle were measured with an Abney level during each run. Average heights ranged from 35 feet at 70 p.s.i. with a 10 m.p.h. wind to 50 feet at 88 p.s.i. with 5 m.p.h. wind (fig. 10). An additional 5 to 10 feet of mist above the spray was visible against a clear sky. Injection of Rhodmine B or Methylene blue dyes into the line did not appreciably improve the visibility of the mist.

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Figure 10.—Performance tests of the water curtain being conducted at 60 p.s.i. pressure head, under 5 m.p.h. winds. Visible spray height is 45 feet. A hand-held anemometer is used to determine average windspeed at height of nozzle.

Total horizontal dispersal of the spray was much more difficult to measure. After each run, vegetation beyond the rain gages was examined for water droplets. Visible dispersal ranged from 45 feet at 50 p.s.i. and calm conditions to 130 feet at 88 p.s.i. and 10 m.p.h. winds. The average spray dispersal dimensions for all runs, including mist height, were 55 feet high and 60 feet wide.

OPERATIONAL TEST

Subsequent to the preliminary performance tests, all components of the system were assembled for use on an experimental 15-acre burn near August Lake in northern Minnesota. A main line of 2,520 feet of 8-inch pipe and 450 feet of 5-inch pipe was required for a 172-foot vertical lift over a horizontal distance of 2,450 feet. A lateral distribution line of 1,000 feet with 50 nozzles was used (fig. 11). Pump units were located at 20, 470, 850, 1,410, and 1,750 feet from the water source. By operating the five pump units at 2,200 r.p.m., an average nozzle pressure of 80 p.s.i. was maintained without serious malfunction. Under calm wind conditions, this assembly provided a water curtain 55 feet high, 60 feet wide, and 1,000 feet long. However, the fire burned discontinuously in surface fuels and the low intensity and rate of spread provided a less-than-adequate test of the system. Further tests on experimental fires are planned.

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Figure 11.—Lateral distribution line at August Lake experimental burn area.

POSSIBLE USES

The system is designed to control prescribed fires and is not sufficiently mobile for controlling fast-spreading wildfires. However, it could be effective for extended "mop-up" operations on large fires when used in conjunction with relay tanks and portable fire pumps. Under a 100-foot pressure head, it can provide sufficient water volume to supply 20 type "Y" 1½-inch portable fire pumps.

Mobility of the system depends on accessibility of the water source, topography, and physiography of the site. Where water sources are accessible by road, the pump units may be mounted on trailers for increased mobility. Pipe handling time is minimized whenever the lines are located near roads or trails. Approximately twelve 8-hour man-days are required to assemble the full system under average field conditions. Three men equipped with mobile radios are adequate to operate the system. Under average operating loads each pump unit burns 3 gallons of regular automotive fuel per hour. Total initial investment for the components is about $20,000. Maintenance cost based on two seasons operations (including fuel) is about $10 per hour of running time for all pumps. This includes lubrication of units and replacement of line valves and gaskets due to corrosion and breakage.

The water curtain appears to be particularly suited for controlling prescribed fires in areas having adequate water sources nearby and minimal topographic relief. However, its effectiveness in reducing spotfire propagation during high-intensity burning requires further testing.

LITERATURE CITED

Addison, Herbert. 1964. A treatise on applied hydraulics. Ed. 5, 808 p. London: Chapman-Hill, Ltd.

Christiansen, J. E. 1942. Irrigation by sprinkling. Calif. Coll. Agr. Bull. 670: 52-116.

Scobey, Fred C. 1930. The flow of water in riveted steel and analogous pipe. U. S. Dep. Agr. Tech. Bull. 150, 136 p.

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