UNIVERSITY OF ALBERTA

THE FEASIBILITY OF USING A GARDEN-TYPE SOAKER HOSE TO CONTAIN WILDLAND FIRE

BY

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A Thesis submitted to the Faculty of Graduate Studies and Research in partial fulfilment of the requirements for the degree of MASTER OF SCIENCE

DEPARTMENT OF FOREST SCIENCE

EDMONTON, ALBERTA

SPRING, 1992

ISBN 0-315-73200-8

UNIVERSITY OF ALBERTA

RELEASE FROM

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TITLE OF THESIS: THE FEASIBILITY OF USING A GARDEN-TYPE SOAKER HOSE TO CONTAIN WILDLAND FIRE

DEGREE: MASTER OF SCIENCE

YEAR THIS DEGREE GRANTED: SPRING, 1992

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ABSTRACT

Water to contain wildland (forest, shrub and grass) fires is not always available or in amounts demanded by most conventional fire fighting systems. In addition, even when water is plentiful, the money may not be available to purchase the sprinkling systems presently used to contain wild or prescribed fires. The goal of this study was to test the suitability of using commonly available 15-m long plastic or vinyl garden-type soaker hose as an efficient tool for containing wildland fires. Hoses were tested in series and parallel configuration. The bursting strength of various soaker hoses, the volume discharge rate, and the height of water spray were determined. These characteristics were measured along each length of soaker hose and for all soaker hoses along the length of the hose lay. Results showed the RCR-strata[1] had the highest mean instantaneous bursting strength (1039 kPa) of the three garden-type soaker hoses tested. But the RCR-strata hose commonly failed when subjected to internal water pressures of > 570 kPa for long periods of time.

In the "series" configuration when the internal water pressure at the pump discharge nozzle was 565 kPa, the height of water sprayed averaged 385 cm, the discharge rate averaged 30 l/hr and the width of area wet was 8 m for the first soaker hose in the series. At a point 75-m down the

soaker hose lay, the water pressure dropped to 0 kPa. The performance characteristics of this system were not considered adequate to control most prescribed and wildland fires.

In the "parallel" configuration, the pressure of water at the pump was 620 kPa when the pump is operated at full speed. The equation: $P_m = 538.74 - 5.527d + 0.035d^2 - 0.00007d^3$ ($p<0.001$) explains 86% of the variation in pump pressure as distance from the pump is increased. This equation pertains to water pushed by a Wajax Mark III pump, through 3.8 cm (1.5 in) dia line hoses. The height of water sprayed was about 385 cm, and the discharge rate was 0.62 l/sec. The relationship between water spray height and pressure can be described mathematically as: $h = 0.088\ p^{0.61}$, while the relationship between discharge rate (q) and pressure (p) is $q = 3.024*10^6 p^{2.03}$. Both relationships are highly significant ($p<0.001$) with R^2 values of 0.58 for pressure/height and 0.84 for pressure/discharge rate. The zone of wetted area was about 8 m wide at the 22.9 m from the pump and 4 m wide at the 229 m, which is the longest control line that can be established with one pump. If two pumps, one on each end are used then this line can be extended to another 300 m.

ACKNOWLEDGEMENTS

Several individuals and organizations have contributed to the successful completion of this thesis. I would like to express my sincere thanks to all of them.

I wish to express my deepest gratitude to the Canadian International Development Agency (CIDA) and the ASEAN Institute of Forest Management (AIFM) for the financial support for all of the time during my study. Also I gratefully acknowledge the Royal Forest Department (RFD) of Thailand, for granting me the opportunity to study abroad.

I sincerely thank my supervisor, Dr. Paul M. Woodard for his encouragement, invaluable advice, patient guidance, and all his kindnesses to me during studying and living in Canada. I am also grateful to my graduate committee members: Dr. Richard L. Rothwell and Dr. Peter G. McCornick for the time that they have provided me. Without their encouragement and help, this study would not have been finished. Special thanks are extended to Mr. Apiwat Sretarugsa for his help, his sustained interest and his precious concern during I am studying.

I also extend thank to Parks Canada, and specifically the staff at Elk Island National Park for providing me with equipment and study site. I also would like to thank RCR international Inc. for providing me with free garden type soaker hoses. A special thank also goes to Mr. Supparat Samran and Mrs. Babara Koch for their gracious cooperation and assistance in the field during this study. I greatly enjoyed our friendship.

I gratefully recognize the Department of Forest Science and staff, fellow graduate student, and Thai students of University of Alberta for their help and warmth during my study in Canada.

Without a loving, caring, and understanding family this opportunity would not have been possible. Therefore, I dedicate this manuscript and the work that went into it to my wife -Jetsara Kanjanakunchorn, my family, Jetsara's family and my energetic daughter -Jiradchaya Kanjanakunchorn who was born in Canada during my studies.

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1. INTRODUCTION

Water is frequently used to control or contain wild and prescribed fires. The cost of delivering the water is highly influenced by the availability of the water and the cost of moving it. In some protection areas water is not readily available, while in others the money required to transport the water may be limiting. Hence the cost of protecting the forest from fire may be influenced by water related factors.

Minimizing the costs associated with delivering effective wildland fire protection is the responsibility of managers. Sometimes these costs can be reduced by using water more efficiently or by reducing delivery costs. In this thesis, I described two studies that assessed the feasibility of using commonly available garden-type soaker hoses to accomplish both of these fire protection goals. The performance characteristics of this hose type and its low retail price suggest it may contribute to more efficient fire protection, particularly when compared to existing water delivery systems.

Garden-type soaker hose is commonly found in the "Garden Section" of most hardware and department stores. The hose is usually fabricated from plastic or vinyl and is green in colour. The dimensions of the hose vary by manufacturer. Thickness ranges from 3 mm to 6 mm and width from 2.5 mm to 4.5 mm but the length of the hose is usually 15.2 m (50 feet). Soaker hoses are fitted with one (female only) or two (male and female) threaded brass couplings. These couplings are the standard 2.54 cm (1") inside diameter fittings, which make them compatible with hoses used by most homeowners in North America. Hoses that have both male and female couplings usually come with plastic caps on the male fitting. The cap allows these hoses to be used singly or in a "series" configuration.

Soaker hoses are perforated. The size and density of these holes vary by hose type. Holes in the hose are usually created by cutting 0.5 - 1.0 mm long slits in one side of the hose. The height of water spray and the discharge rate is determined by internal water pressure and the size of the perforations.

The goal of this thesis was to evaluate the feasibility of using the garden-type soaker hose system to control or contain wild and prescribed fires. Specifically, the objectives were:

1. To determine the bursting strength of various types of commercially available garden-type soaker hose.
2. To evaluate the performance characteristics of a garden-type soaker hose system in a "series" and a "parallel" configuration.
3. To determine the pressure along the length of mainline and the garden soaker hose.

4. To determine the water delivery rate for various lengths of garden type soaker hose lays (fire perimeter).

5. To determine the height of the water spray at various locations along the length of the hose lay.

6. To determine the water distribution pattern along the length of the hose lay.

7. To determine the effectiveness of this hose type in hydrating surface fuels and in creating a water air curtain.

This thesis follows the paper format. This chapter (Chapter 1) is an overview of the problem and an introduction to the thesis. Chapter 2 describes the results of testing these hose materials in a "series" configuration. While Chapter 3 presents similar results for a "parallel" configuration. In Chapter 4, I show how information from previous research can be used to determine the amount of water and time required to hydrate organic soil layers of various types and thickness. In Chapter 5, I summarize the significant findings of this work and in Chapter 6, the last chapter, I discuss future research needs. Each Chapter is presented in such a way as to enable it to be an entity in and of itself.

2. THE GARDEN-TYPE SOAKER HOSE USED "IN SERIES" TO CONTAIN WILDLAND FIRES[1]

2.1 INTRODUCTION

Plastic and vinyl garden-type soaker hoses are commonly used to rehydrate narrow strips of soil usually for the purpose of maintaining healthy lawns in urban areas. It occurred to us that this same technology might be applied to wildland fire fighting situations. A continuous fine mist of water 50-75 cm in height could be used effectively to contain some fast moving grass fires. Perhaps more importantly, this water delivery system could also be used to rehydrate deep organic soils that are water saturated below a dry zone.

Deep organic fuel types are common in the boreal forest of Alberta. Often these soils are cool, even frozen at times, but when the upper layers are removed as part of fuelbreak construction, the exposed organic material warms to the ambient air temperature, drys and becomes available fuel, thus contributing to fire spread. It is virtually impossible to construct manual or mechanical fuelbreaks to mineral soil

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[1] This paper was presented at the 11th Conference on Fire and Forest Meteorology, April 16-19, Missoula. It will be published in the proceedings of that conference. The authors were Kanjanakunchorn, S, P.M. Woodard, and H. McDonald.

in this fuel type. Instead, rehydrating the dry surface layers of this fuelbed will enable fire fighters to contain most surface and all ground type fires in this fuel type.

Garden-type soaker hoses are inexpensive when compared to the most commonly used alternative, the Buckner 512 M rocket jet sprinkler system (Quintilio et al. 1971). Soaker hoses were available from retail stores in Edmonton, Canada for about $15.00 CAN each. These hoses were 15-m in length with couplings on both ends. To hydrate, a comparable length of fireline with the sprinkler system described above would cost $45.00 CAN.

The garden-type soaker hose would also be a more efficient water delivery system when compared to the sprinkler system. Without a doubt, less surface area would be hydrated with this hose system as compared to sprinkler containment system commonly used in Alberta (Quintilio et al. 1971); however, there are situations when very little would be required to contain a fire.

The primary objective of the study was to determine the suitability of using the garden soaker hose "in a series" configuration (Figure 1) to contain wildland fires. This hose was never designed to be used under wildland fire fighting situations. Pump pressures in urban situations rarely exceeds 260 kPa while the pump most commonly used in forest fire fighting, the Wajax Mark III, can produce internal water pressures in excess of 2137 kPa. Also, the

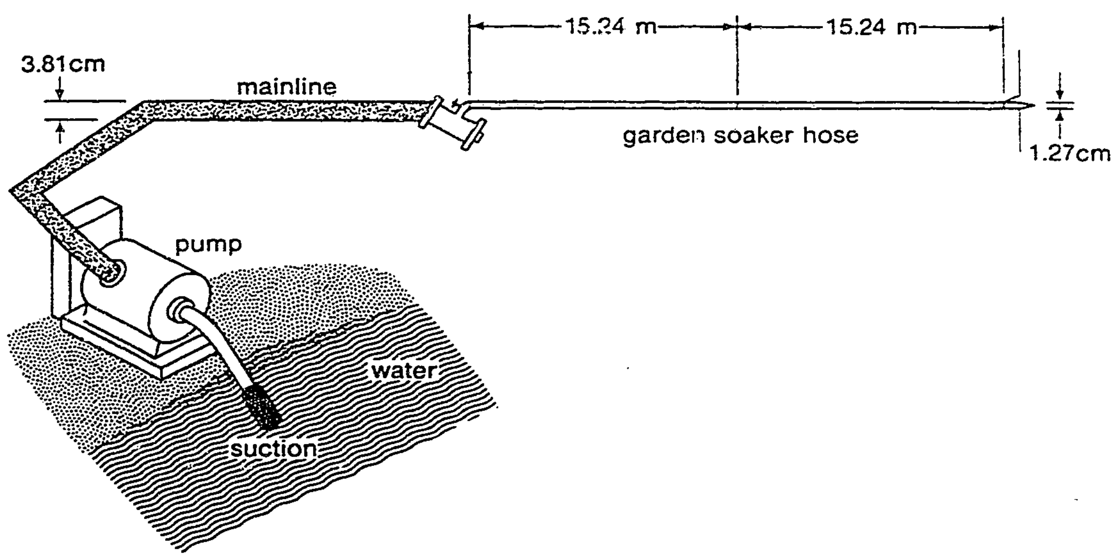

Figure 2.1 A garden-type soaker hose laid in a "series" configuration.

water to be transported during wildland fire conditions is usually not as debris free as water used for domestic purposes. Therefore, as part of this work the bursting strength for the three garden-type soaker hoses, most commonly available in the Edmonton, Alberta, Canada area, was determined. This study also determined, under field conditions, the drop in water: (1) pressure, (2) height, (3) discharge rate, and (4) pattern as the distance along the soaker hose from the pump is increased.

2.2 METHODS

The "Series" Configuration

The materials used to deliver water to the containment perimeter were similar for all tests. Water was pumped with a Wajax Mark III pump through 3.8 cm (1.5") diameter unlined fire hose. A T-type connecting pipe was adapted to fit on the end of the 30-m long, 3.8 cm dia. mainline. The end of the connecting pipe was sealed such that the water forced through the mainline was diverted through a 1.9 cm (3/4") threaded fitting into the soaker hoses. All soaker hoses were then connected in series.

Bursting Strength and Pressure

Bourdon-type pressure gauges were established at the discharge nozzle on the pump and at all hose junctions. The bursting pressure (kPa) of the soaker hoses was measured using the pressure gauge at the junction of the mainline and the start of the soaker hose lay. The pressure was increased until the bursting strength of each hose type tested was determined. All tests were preformed on level terrain, and along a 3-m wide trail in a > 9-m tall aspen stand. Therefore, water pressure characteristics along the hose lay were not affected by slope and the water pattern was not affected by wind.

Performance Characteristics

Water delivery heights, volumes and patterns were determined at 3-m intervals along each of the 15-m long soaker hoses "in the series". The water height (cm) was measured using a graduated pole while standing in the column of water spray. The volume of water (l/hr) discharged was determined by collecting water in a 7.9 cm diameter can for a specific time period. The pattern of water dispersal was determined by measuring the width of wetted fuel along both sides of the soaker hose.

2.3 RESULTS

Bursting Strength

Three different garden-type soaker hoses were tested for instantaneous bursting strength. They were: the RCR - strata, the 3 tube, and the Robinson type soaker hoses. The results of these tests are summarized in Table 1. The common retail price in 1990 Canadian dollars for these hoses are also provided in this table.

Table 2.1 The mean instantaneous bursting strength of each type of soaker hose tested, and the price of that hose in 1990 Canadian dollars. Letters after means indicate significant differences at the $p < 0.001$

Hose Type[1/]	n	Mean (kPa)	Range (kPa)	Price ($)
RCR-strata	15	1038.83a	827.37 - 1206.58	15.99
3-tube	12	942.31b	827.37 - 999.74	13.99
Robinson	3	379.21c	365.42 - 393.00	15.39

[1/] Nothing printed in this paper is intended to suggest endorsement of any products used as part of this study. This product information is provided for clarity in scientific methodology only. Robinson Products Ltd., Box 90, Concord, Ontario L4K 1B2. Triple tube green polyvinyl chloride. Regal Home Products Inc., 40 Queen Elizabeth Blvd., Toronto M8Z 1M2. RCR-Strata. RCR International Inc.

There were significant differences ($p<0.001$) between the strength characteristics of the three hoses tested. The RCR-strata hose type withstood the greatest water pressure; hence, it was used in all subsequent tests. No other factors were considered in selecting the hose type to be further tested.

The average instantaneous bursting strength for the RCR - strata hose was 1038.8 kPa; however, this hose frequently failed when water pressures inside the hose exceeded 570 kPa. The length of time to failure varied among hoses and by water pressures > 570 kPa. Hence, the water pressure at the start of the soaker hose lay never exceeded 565 kPa for all subsequent tests, which resulted in a failure rate of 0.01%.

Performance Characteristics

The water pressure decreased exponentially as distance along the soaker hose increased (Figure 2a). This rapid loss of pressure had a direct effect on height of water sprayed (Figure 2b), and the volume of water discharged (Figure 2c) along the hose lay. Within about 75 m from the start of the soaker hose lay, the water pressure had dropped to 0 kPa.

The variations in water spray heights and volume rates along the hose lay are principally due to variations in the sizes of hose perforations, distortions in openings due to high water pressure over time, and the presence of organic material in the water, which at times occlude some holes. Equations that describe the relationships between water

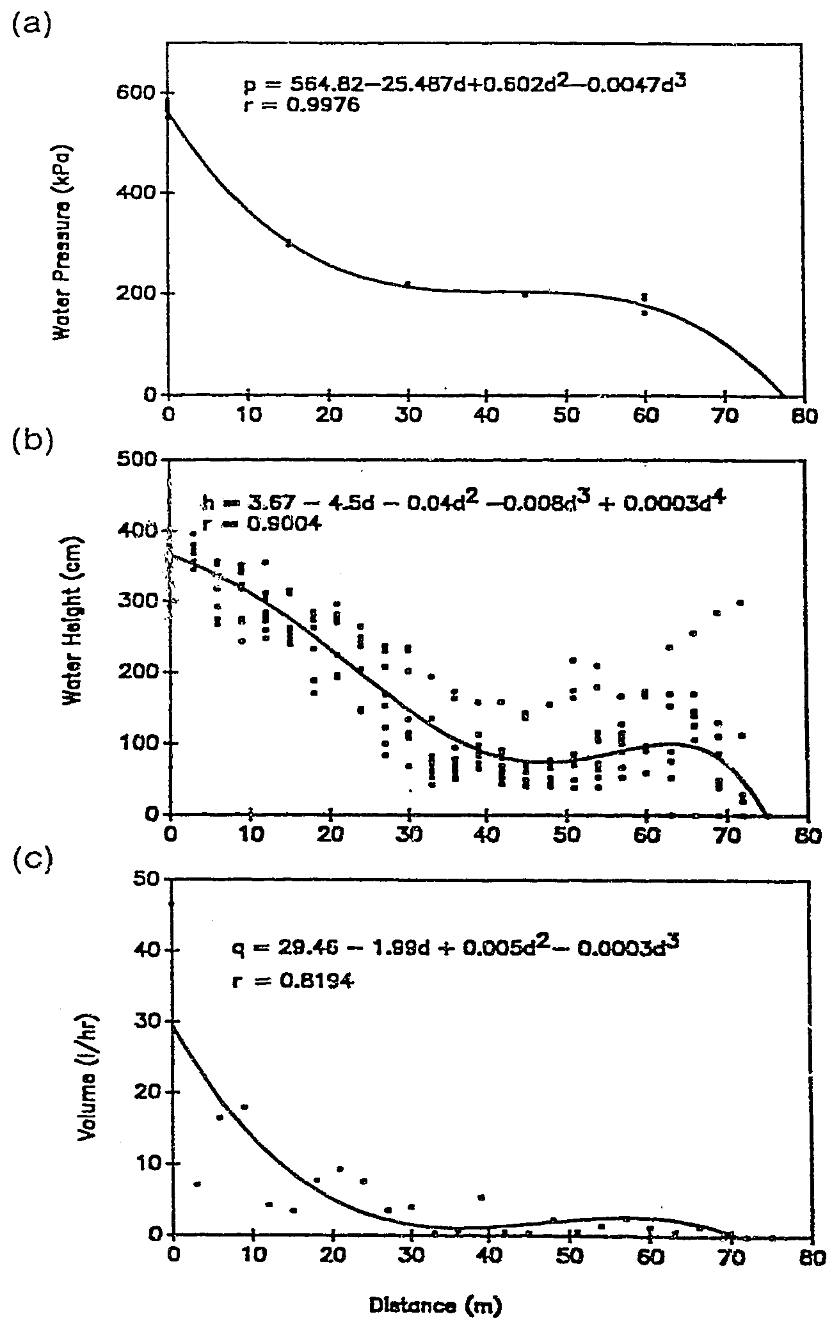

Figure 2.2 The change in water pressure (a), height of water spray (b), and volume of water flow (c) in a garden-type soaker hose systems used in a series configuration as distance increases.

pressure, height and volume relative to distance along the garden-type soaker hose are also presented. The coefficient of correlation (r) for these equations were high (0.82 - 0.99) and all relationships were highly significant ($p<0.001$). Figure 3 shows the water dispersal pattern along the length of the soaker hose. As, expected, the width of fuel hydrated narrows as water pressure decreases to zero.

2.4 DISCUSSION

The garden-type soaker hoses were about a 1/3 the cost of the sprinkler system normally used for containing wildland fires in Alberta. The hoses were readily available and durable when not subjected to "FATAL" pressures. Unfortunately, the hoses did not have the strength to withstand the pressure produced by a Wajax Mark III pump. The pump had to be "throttled back" for all trials to prevent the first hose in the series from rupturing. All failures occurred just past the junction of the 3.8 cm (1.5") dia. mainline and first soaker hose in the series.

The garden-type soaker hoses are not suited to wildland fire containment when they are employed in a "series" configuration. This is particularly true if the perimeter of the burn is large or the length of the fire-front long. Also, a water delivery system that will not extend past 75 m on one pump has limited utility in forest fire fighting situations.

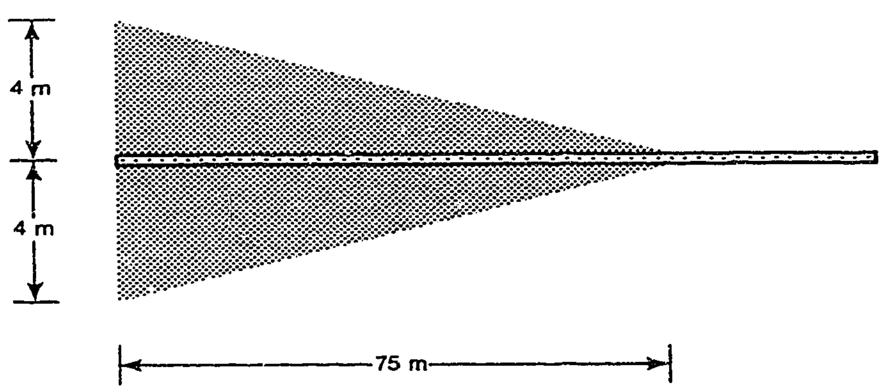

Figure 2.3 The water dispersal pattern for a garden-type soaker hose system used in a "series" configuration.

The internal diameter of the soaker hose was the major problem limiting its value as a containment tool. In a "series" configuration, the restricted water flow due to the size of the soaker hose increases the internal hose pressures. This increased water pressure if higher than 565 kPa resulted in hose failure. Perhaps this limitation could be overcome by manufacturing the hose out of stronger material but this solution would not compensate for the fact that the outflow rate through the perforations exceeds the internal flow capacity. In general, there is not enough water in the soaker hose to service more holes. Hence, hose lays using garden-type soaker hoses in a "series" configuration could never be extended unless hoses with larger internal diameters were manufactured.

The width and height of fuelbreak needed to stop wildland fires varies by fuel type and fireline intensity (Wilson 1988). Work by Orr and Dell (1967), Johnson (1970), Quintilio et al. (1971), and Martin et al (1977) have shown water can be used to contain prescribed wildland fires. The results of this study, other garden-type soaker hose delivery configurations should be tried, because these hoses do have superior water delivery characteristics in close proximity to the pump where an ample water supply exists. Further, these systems will be less expensive, and less water demanding than the most commonly used a sprinkler systems.

2.5 LITERATURE CITED

Henderson, R.C., and R.K. King. 1968. Sprinkler system eases control of prescribed fires. The Truck Logger 24(9): 16 - 17.

Johnson, V.J. 1970. A water curtain for controlling experimental forest fires. USDA For. Serv. Res. Pap. NC-48.

Martin, R.E., S.E. Coleman, and A.H. Johnson. 1977. Wetline technique for prescribed burning firelines in rangeland. USDA For. Serv. Res. Note PNW-292.

Orr, W.J. and J.D. Dell. 1967. Sprinkler system protects fireline perimeter in slash burning. Fire Control Notes. 28(4): 11 - 12.

Quintilio, D., R. Ponto, and I.B. Frew. 1971. A sprinkler system for use in prescribed burning. Can. For. Serv. Rep. A-X-41.

Wilson, A.A.G. 1988. Width of firebreak that is necessary to stop grass fires: some field experiments. Can. J. For. Res. 18: 682 - 687.

3. THE GARDEN-TYPE SOAKER HOSE USED IN A "PARALLEL" CONFIGURATION TO CONTAIN WILDLAND FIRES

3.1 INTRODUCTION

Water is frequently used to contain wildland fires, and various "wetline control techniques" (Pyne 1984) have been documented. Martin et al. (1977) describes a "wetline technique" that was used to contain prescribed grass fires in Lava Beds National Monument, California. A "water curtain" technique described by Johnson (1970) was used successfully to contain a experimental forest fire in northern Minnesota. In Alberta, Quintilio et al. (1971) advanced work reported in Orr and Dell (1967) and Henderson and King (1968) when they described the cost and feasibility of using sprinkler heads to contain prescribed slash burns. In all three cases, water was the principal method of containing the fires, and large amounts of water were required to achieve desired results.

Water is not always available in the volumes required by most conventional fire fighting systems. In addition, even when water is plentiful, money may not be available to purchase pumps and hoses required to hydrate fuels along the containment perimeter. In an attempt to solve these problems, the common garden-type soaker hose used in a parallel configuration (Figure 1) was tested under field conditions because it was felt this hose type would enable

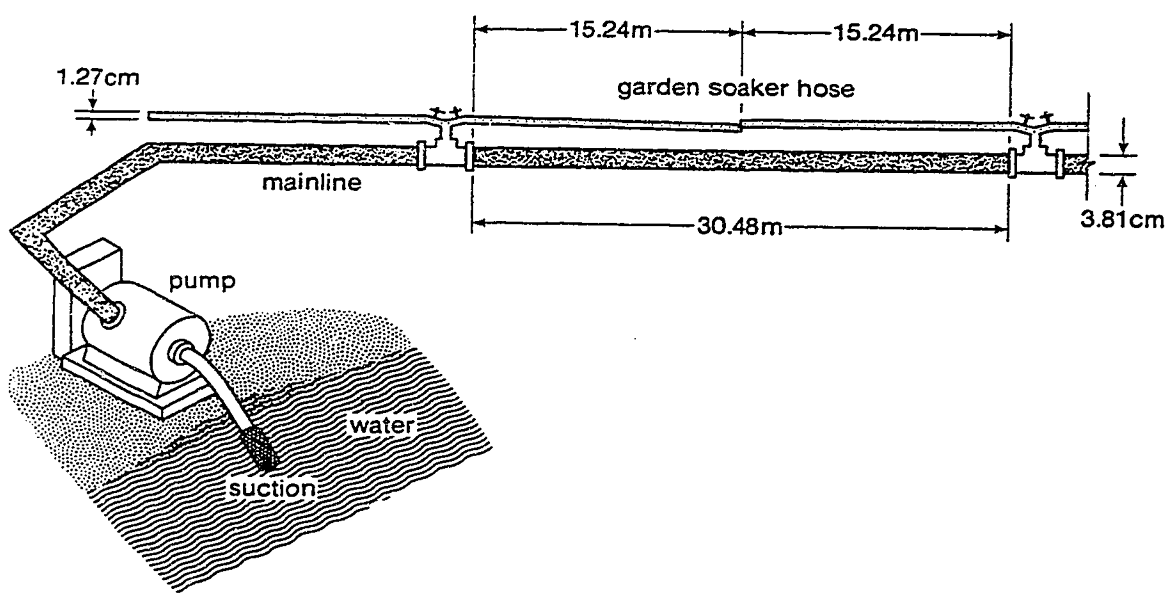

Figure 3.1 A garden-type soaker hose laid in a "parallel" configuration.

protection agencies to overcome the above stated limitations.

Garden soaker hoses are relatively inexpensive, water efficient and durable. Previous work by Kanjanakunchorn et al. (1991) suggested this hose type showed much promise as a forest fire fighting tool, but it could not be used successfully in a "series" configuration, when containment distances exceeded 50 m from the pump. However in theory, this hose type should work very well in a "parallel" configuration because the probably of experiencing bursting pressures from this system should be low. Also, there should be enough water volume to maintain even discharge rates along the hose lay when a 3.8 cm diameter mainline hose lay is used.

The objectives of this study were to determine the performance characteristics of garden-type soaker hoses used in a "parallel" configuration. As part of this work, I determined the effect of distance from the pump on water pressure and its affect on water discharge height, and volume of water delivered at a specific locations along the hose lay. In addition, I use commonly accepted engineering principles and equations to determined the design of the optimal hose lay when these materials and configurations are used.

3.2 METHODS

All experimental work was conducted on level terrain in Elk Island National Park, Alberta, Canada. Also, all tests were performed along 25-m wide trail in an aspen stand > 9 m tall. Therefore, these tests were not affected by terrain or wind. Local beaver ponds served as water sources.

The water delivery system included: a Wajax Mark III[1] (centrifugal) pump (Figure 2), which is commonly used in fire control operation in Alberta; lined fire hose (3.8 cm [1.5"] in diameter and 22.9 m in length) served as the mainline; and vinyl soaker hoses (RCR-strata). The RCR-strata soaker hoses were used in all tests because of their known performance characteristics (Kanjanakunchorn et al. 1991).

Soaker hoses were attached to the mainline at approximately every 22.9 m using 'T' connectors (Figure 3). The T connectors were adapted with quick couplings for easy assembly with mainline fire hoses. One leg of the "T" was throttled down to accept a 2.54 cm (1.0 in) diameter threaded plastic "Y" (siamese) valve with two shut offs. Garden soaker hoses were attached to these valves.

Laboratory calibrated Bourdon-type gauges were used to measure the water pressure at various points along the

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[1] Trade names are provided scientific purposes and are not intended to serve as endorsements.

Figure 3.2 The Wajax Mark III pump was used in all trials.

Figure 3.3 The T-type connecting pipe was used to connect garden-type soaker hoses to the mainline.

system. Gauges were located at the pump outlet, at each 'T' connector, and at the inlet to each soaker hose (Figure 4). All tests were conducted while a serviceable Mark III pump was operated at full throttle. Pump pressure at the discharge nozzle of the pump ranged between 620 kPa and 550 kPa.

Water spray heights were determined at 3-m intervals along each of the 15-m long soaker hoses. The spray height was measured with a graduated pole while standing in the water spray. The discharge rate (l/sec) and water distribution pattern were determined at 3-m intervals along both sides of the 15-m long soaker hoses (Figure 5). Plastic collection cups (3.0 cm diameter by 6.0 cm tall) placed flush with the top of the soaker hose and secured in an upright position using a wooden frame were used to collect the water. The first container was placed immediately adjacent to the soaker hose and successive containers were placed at 10-cm intervals from the hose to a distance of 2.5 m from each side of the hose. Measurements were taken immediately after a 15-minute period of hydration.

Field measurements of water pressure, height and volume were restricted to a distance of 228.6 m due to availability of materials needed to completely instrument all trials. This information was used to develop an equation that modelled pressure losses as distance from pump increased. Also, using standard engineering equations and principles

(a)

(b)

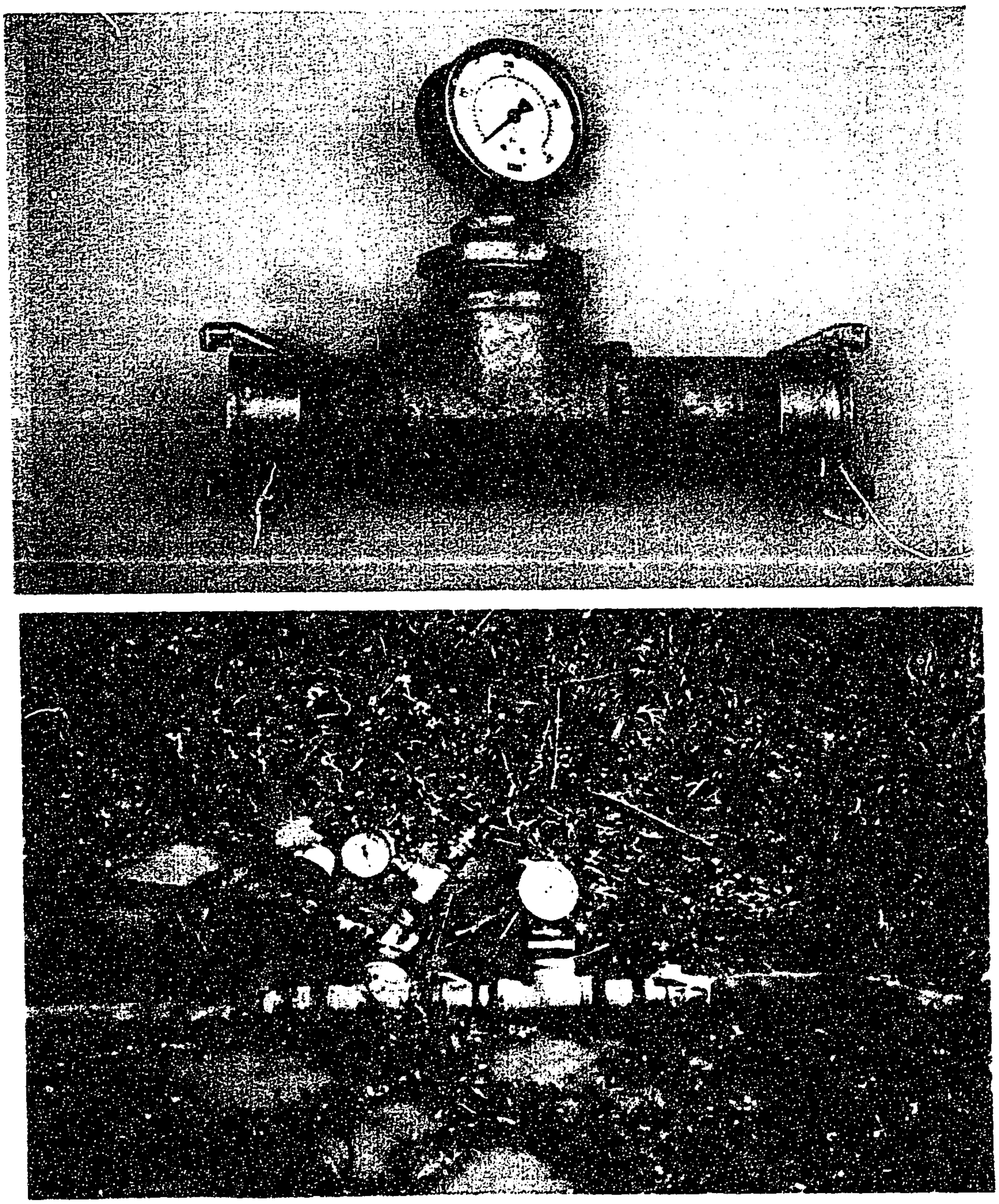


Figure 3.4 The Bourdon-gauge (a) and where it was located along the mainline and at the start of each soaker hose (b).

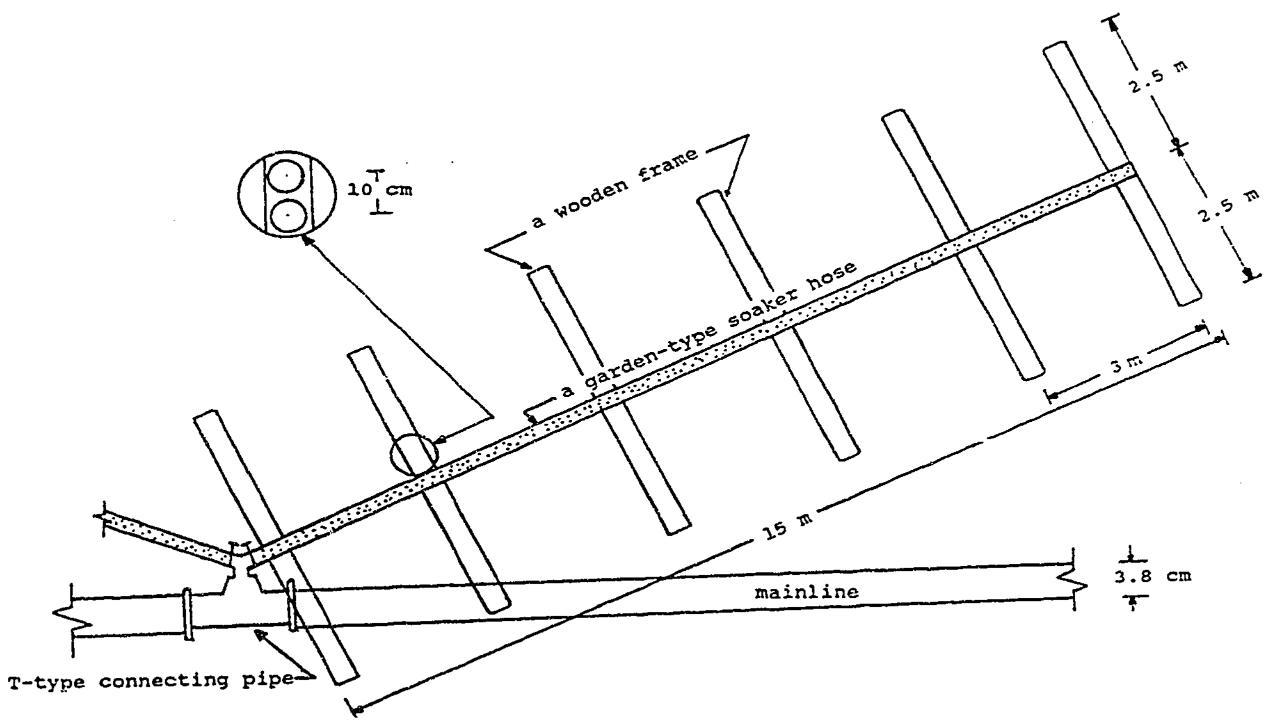


Figure 3.5 Method used for determining the water dispersal pattern along both sides of the garden-type soaker hoses.

and performance characteristics for the Wajax pump, I calculated the maximum hose lay possible on level terrain when a Wajax Mark III pump is used to pump water through RCR-strata laid in a parallel configuration.

3.3 RESULTS

The water pressure in this system varied from 620 kPa (90 psi) at the discharge valve on the pump to 207 kPa (30 psi) at the start of the last soaker hose, which was 228.6 m from the pump. As expected, the pressure along the mainline decreased exponentially as the distance from the pump increased (Figure 6). A third-order polynomial equation accounted for 86% of the variation in the data. This equation was highly significant ($p<0.001$).

$$P_m = 538.74 - 5.527d + 0.035d^2 - 0.000007d^3 \qquad (1)$$

The water spray height within this particular system configuration varied from 3 m at the inlet of the soaker hose adjacent to the pump to 1 m at the distal end of the hose furthest from the pump. From these data (Figure 7) the relationship between pressure at the soaker hose inlet and spray height can be expressed as:

$$h = 0.088\ P^{0.61} \qquad (2)$$

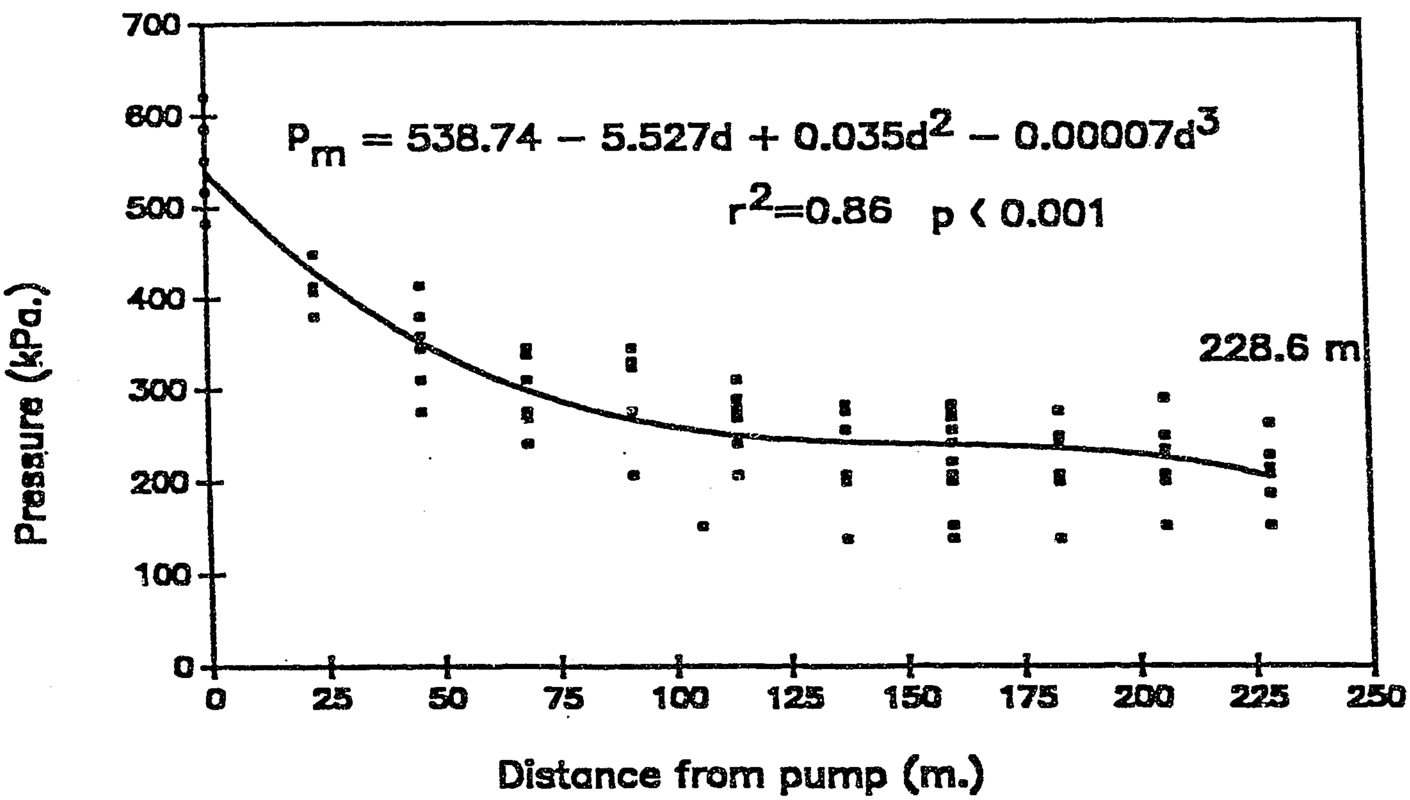


Figure 3.6 The change in water pressure along the length of the mainline for a garden-type soaker hose lay tested in a parallel configuration (n = 18).

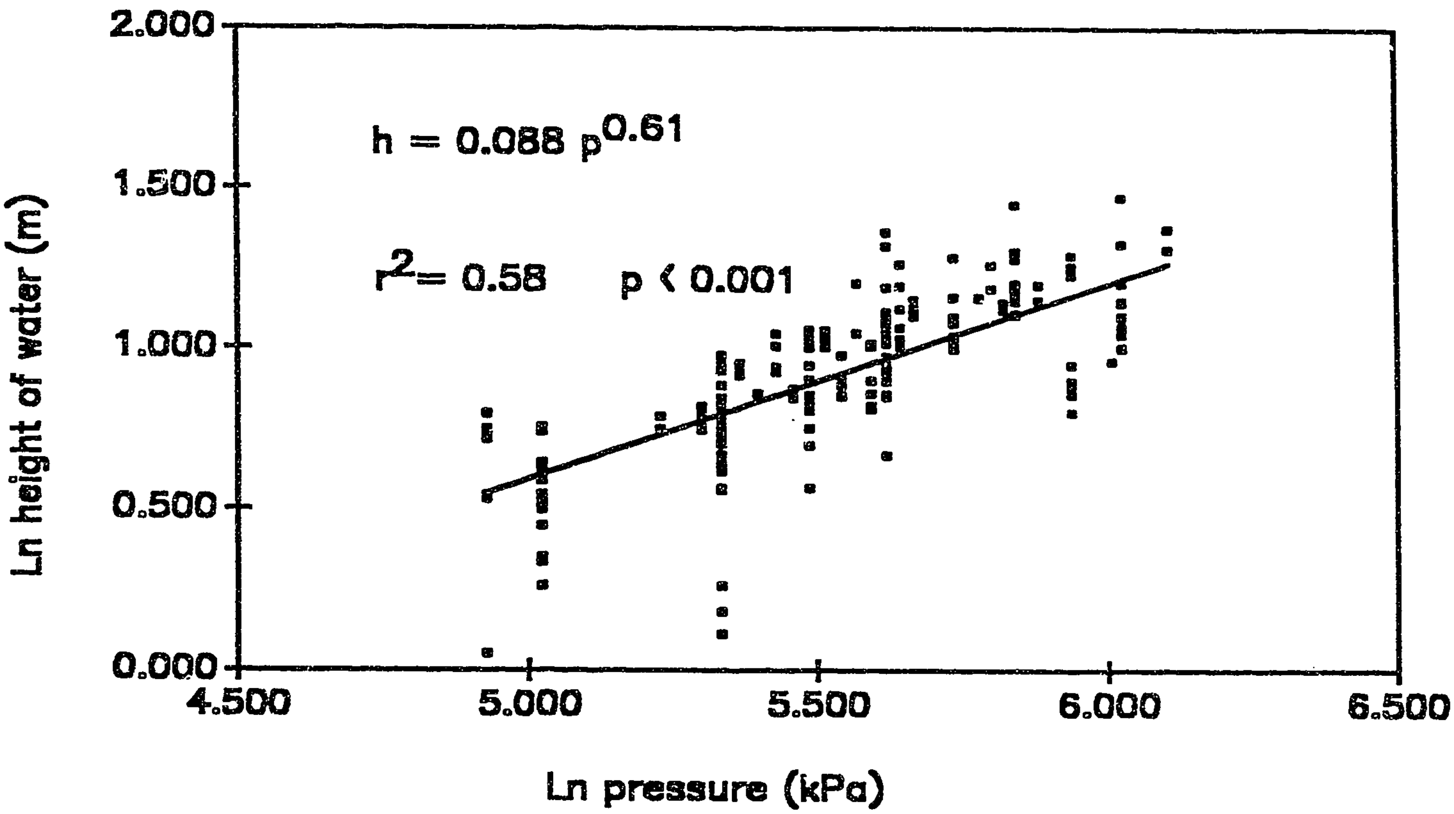


Figure 3.7 The relationship between the height of water spray and pressure along the length of garden-type soaker hose tested (n = 15 trials).

where h is the height of water spray (m), and P is the pressure (kPa).

The discharge rate also varied from 0.62 l/sec/5-m length of soaker hose at the inlet to the soaker hose near the pump to 0.12 l/sec/5-m length at the end of soaker hose furthest from the pump. The relationship between pressure and discharge rate is shown in Figure 8 and is best described by the equation:

$$q = 3.024 * 10^{-6} P^{2.03} \qquad (3)$$

where q is the discharge rate (l/sec/5-m length of soaker hose), and P is the pressure (kPa).

The water distribution pattern was most adversely affected by distance from pump and distance from the start of the soaker hose. The distribution pattern fluctuated greatly along the hose lay and at specific positions along specific hoses. The expected bell-shaped distribution pattern was only evident for the two hoses closest to the pump. Generally, the water is evenly distributed up to a distance of 2.5 m along each side of the soaker hose, and the amount of water falling at a specific location is most affected determined by distance from the pump and the distance from the start of a soaker hose. Nevertheless, even after water is pumped for a distance of 225 m the width of area hydrated is almost 4 m (2 m per side of hoses) (Figure 9).

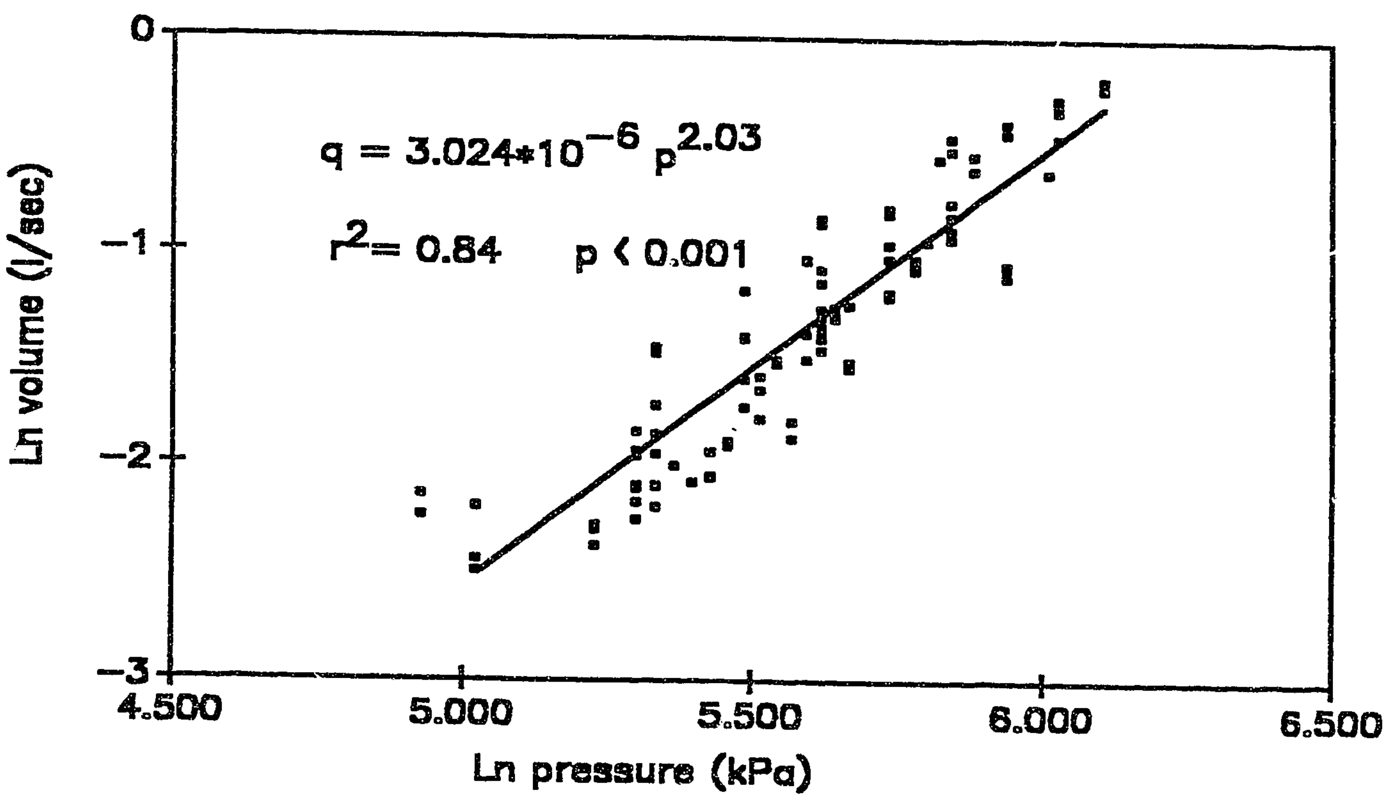


Figure 3.8 The relationship between discharge rate and pressure along the length of garden-type soaker hose tested (n = 15 trials).

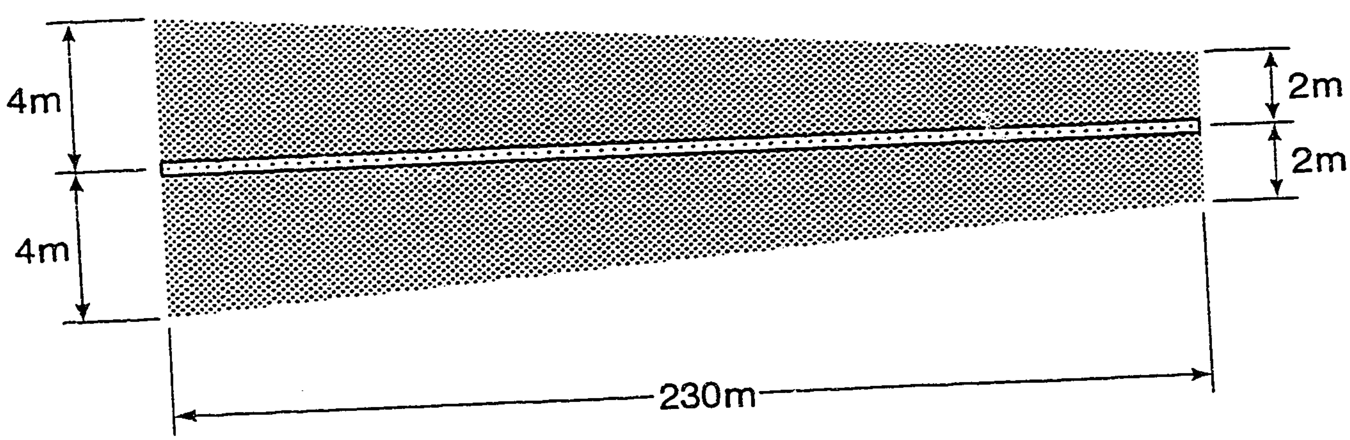


Figure 3.9 The water dispersal pattern for a garden-type soaker hose system used in a parallel configuration.

3.4 DISCUSSION

The RCR-strata garden-type soaker hose is well suited for wildland fire fighting and containment situations when employed in a parallel configuration. The tensile strength of this soaker hose was never exceeded when used in a "parallel configuration", unlike when the "series configuration" is used (Kanjanakunchorn et al. 1991). The highest water pressure measured anywhere along this hose lay was always lower than the instantaneous bursting strength of this hose type, even when the Mark III pump was operated at full capacity for long time periods. Hoses did occasionally rupture but the failure rate was not high (approximately 0.01%). Clogging of the soaker hose orifices due to water borne debris was a problem that was occasionally encountered. This type of material is common in water pumped from beaver ponds and sloughs.

Knowledge of how internal water pressure changed as distance from the pump increased, and further how these pressure changes affected the height of water sprayed and discharge rate was used to understand the limitations of this system. This information was also used in refining this system.

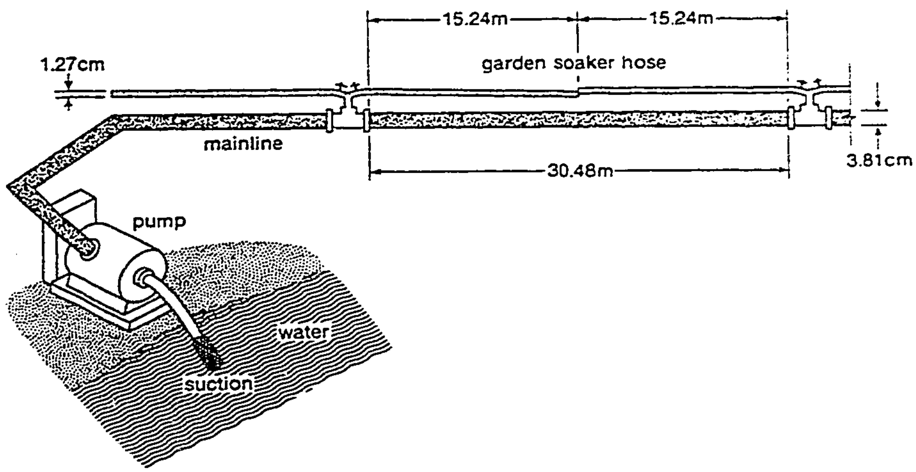
To design the most efficient system, one must identify acceptable performance characteristic and how the component parts of the system can be adjusted to meet those standards. I identified two acceptable performance standards, they were: (1) internal hose pressure must not exceed the strength of the soaker hose (620 kPa) when the pump is operated at full capacity, and (2) water pressure must be >207 kPa. because when the water pressure is <207 kPa then discharge rates and spray heights are 0.08 l/sec and 1 m, respectively at the end of each soaker hoses. These characteristics were judged to be the minimum unacceptable.

The Wajax Mark III pump (centrifugal), and the standard 3.8 cm (1.5 in) diameter unlined hose, which served as a mainline were integral parts of the system tested. Two design configurations were considered for the parallel soaker hose system; a single pump (Figure 10a) and system that employed a pump on both ends of the mainline (Figure 10b).

The effect of distance from the pump on water pressure, height of water spray and discharge rate as related to the components used have been described in equation (1), (2) and (3), respectively. By solving these equations, I was able to determine the performance characteristics of this hose lay on level terrain as distance (d) from the pump was increased. The significant results of these simulation are summarized in Table 1.

When a single pump is used, the maximum length of the mainline is 240 m. Beyond that distance the performance characteristics do not meet the standards established. The maximum length of mainline for pumps on each end must be

(a)



(b)

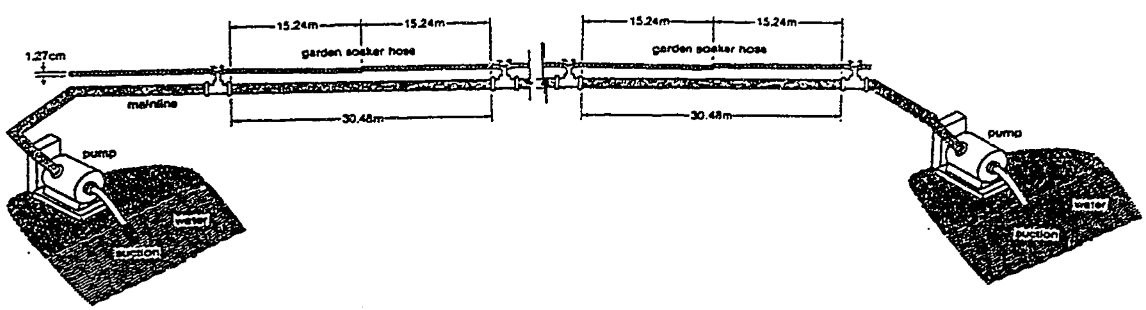


Figure 3.10 The potential system configuration: (a) a pump at one end of the line and (b) pumps at both ends.

Table 3.1 The relationship between pressure and distance, the height of water spray and the discharge rate

Distance (m)	Pressure kPa	Height of water spray (m)	Discharge rate (l/sec)
210[1/]	273 (40)[2/]	2.69	0.27
240	207 (30)	2.28	0.15
300	141 (20)	1.80	0.07
330	11 (2)	0.38	0.01
360	0 (0)	0	0

[1/] hoses are manufactured in 100 ft length (or 30 m)

[2/] numbers in brackets are the corresponding pressure in pounds/square inch (psi) less than or equal to 300*2 = 600 m because at the distance of 300 m both pump must provide at least 141 kPa of pressure if the minimum of 142 kPa, which is required to produce acceptable performance characteristics, are to be realized.

Once we know the maximum distance for maintaining the minimum pressure for the two-pump system, we can calculate the discharge rate for the pump to determine if the design can be accommodated based on performance characteristics of the Wajax III pump. The following is a discussion of how this analysis was accomplished.

The number of connections used in a two-pump system can be determined by solving the equation:-

$$N = \frac{L}{S_1} \qquad (4)$$

where : N = number of connections

L = pipe length (m)

s = a spacing of a garden soaker hose (m)

N = 300/30 = 10 connection

This information allows us to estimate fraction of the head loss (F) within our system. The flow rate in the pipe decreases with distance because water is emitted from the soaker hoses as it proceeds along the lay. Christiansen's (1942) equation defines a "F factor" that accounts for this loss in head pressure. This equation is written:

$$F = \frac{1}{(m+1)} + \frac{1}{2N} + \frac{(m-1)}{6N^2} \qquad (5)$$

where, F = fraction of the headloss under constant discharge conditions expected with the multiple outlet case

m = 2 for the Darcy-Weisbach equation

N = number of outlets along the pipe

If there are 10 connection (outlets) along a 300 m hose lay then the fraction of head loss equals:

$$F = \frac{1}{3} + \frac{1}{2(10)} + \frac{\sqrt{2-1}}{6(10)^2} = 0.385$$

The frictional head loss (F_l) can be calculated by solving the equation;

$$F_l = F.H_f \qquad (6)$$

where: F_l = the accepted friction head loss in the mainline (21.1 m)

F = fraction of the head loss under constant discharge conditions expected with the multiple outlet case

H_f = frictional headloss (m)

If we know F_l = 21.1 m which was determined by knowing the pressure losses from the start (60 psi) to the end (30 psi), and F = 0.385 then H_f, the frictional headloss equals 54.81 m.

It is well known that the friction coefficient (f) is a function of the Reynold's number and the relative roughness of the pipe. Assuming the inside surfaces of all hoses used in these tests are approximated by smooth pipe, then the smooth pipe relationship in the Moody Diagram can be used to estimate the friction factor (Watters et al. 1978). The first step in these calculations is to compute the Reynolds number (R_e):

$$R_e = 1.26*10^{-6}\frac{Q}{D} \qquad (7)$$

in which,

R_e = Reynold's number;

Q = pipe discharge, (m^3/s)

D = inside pipe diameter, (mm)

Hence, the Reynold's number for this solution is:

$$R_e = 1.26*10^{6}*\frac{3.01*10^{-3}}{0.0381} = 99543.31$$

Then the friction factor (f) can be computed using the formula:

$$f = \frac{0.32}{R_e^{0.25}} \qquad (8)$$

when: the R_e is >3000 and < 10^5.

Hence, the friction factor equal 0.018 in this situation.

In a closed pipe, the friction loss can be expressed by the Darcy-Weisbach equation (Watters et al. 1978). I also used this equation to find the flow rate.

$$H_f = 8.2627 * 10^7 fL \frac{Q^2}{D^5} \quad (9)$$

Where, L = pipe length (m)

D = pipe diameter (m)

f = friction factor

H_f = frictional headloss (m)

Q = pipe discharge (l/sec or gal/min)

$$\therefore \quad 54.58 = 8.2627 * 10^7 * 0.018 * 298 * \frac{Q^2}{38.1^5}$$

Q^2 = 9.89 or Q 3.14 l/sec or 50 gal/min

The performance characteristic of the Wajax Mark III pump (Figure 11) suggests a two-pump system will deliver sufficient amounts of water to maintain flow demands required by 10 connections or 20 garden-type soaker hoses. This type of analysis was also applied to a one pump system. From that analysis we determined that successfully over a distance of 229 m.

The system described and tested as part of this thesis work shows good possibilities as an important forest fire control and use tool. Limitations in distance water can be moved are affected more by pump, hose and site characteristics than due to soaker hose demands or characteristics. Water demands required by soaker hoses can be satisfied with the equipment used in these tests. In general, these small diameter, inexpensive, lightweight hoses have very little impact on the distance water can be

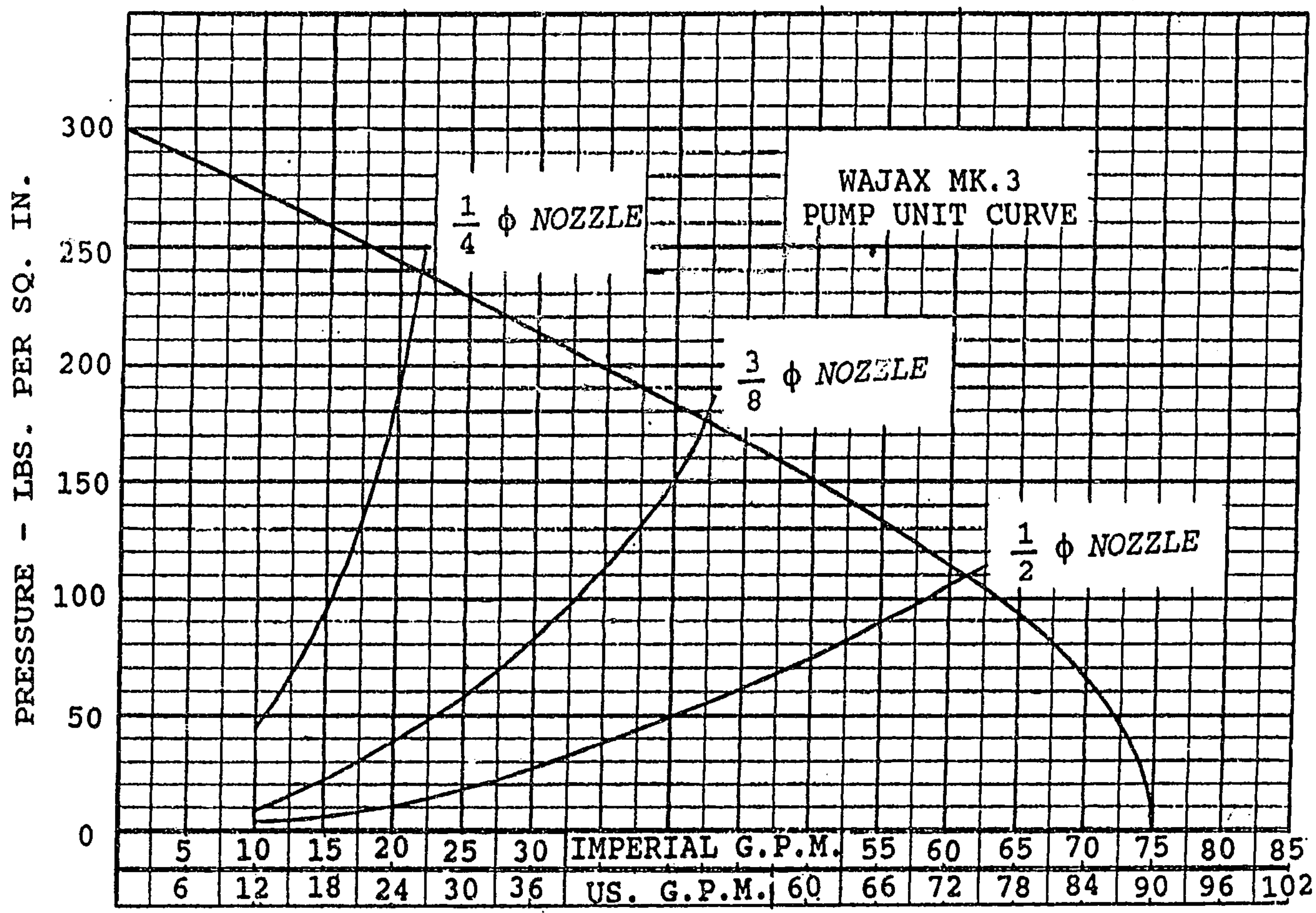


Figure 3.11 The performance characteristics of the Wajax Mark III pump (extracted from Wajax Manufacturing Limited 1990).

moved.

I believe fluctuation in hose pressures between tests were likely due to pump condition. This interpretation was developed after field test were preformed. While analyzing my data, it became obvious to my committee that these fluctuation could not be due to hose configurations or the system design. Therefore, it is recommend that these tests be preformed again using a new or well-serviced pump. It is likely internal water pressure will rise but the rate of change in pressure over distance will probably remain the same.

Based on the results of these experiments, I believe this system should be field tested. The ability to produce a 600-m long firebreak might be an advantage in some situations. Knowing how to do this might enable the fire boss to change to a more efficient strategy. Also, by knowing the effectiveness of this control system, one would be able to contain prescribed burns that were at least 2.5 hectares in size. At times, I anticipate many advantages could be realized by using this system. Therefore, I believe this system, if used properly, could contribute to more efficient forest fire control and use operations.

3.5 LITERATURE CITED

Bittinger, M.W., and R.A. Longenbaugh. 1962. Theoretical distribution of water from a moving irrigation sprinkler. Trans. Amer. Soc. Agr. Eng. 5(1): 26 - 30.

Christiansen, J. E. 1942. Irrigation by sprinkling. California Agricultural Experiment Station Bulletin No. 670. Berkeley, California.

Henderson, R.C., and R.K. King. 1968. Sprinkler system eases control of cribed fires. The Truck Logger 24(9): 16 - 17.

Johnson, V.J. 1970. A water curtain for controlling experimental forest fires. USDA For. Serv. Res. Pap. NC-48.

Kanjanakunchorn, S., P.M. Woodard, and H. McDonald. 1991. The garden-type soaker hose used "in series" to contain wildland fires. In Proc. 11th Conf. Fire and For. Meteor. April 16 - 19, 1990, Missoula, MT. Edited by P.L. Andrews and D.F. Potts. Soc. American Foresters, Bethesda, MD, USA.

Martin, R.E., S.E. Coleman, and A.H. Johnson. 1977. Wetline technique for prescribed burning firelines in rangeland. USDA For. Serv. Res. Note PNW-292.

Orr, W.J. and J.D. Dell. 1967. Sprinkler system protects fireline perimeter in slash burning. Fire Control Notes. 28(4): 11 - 12.

Pyne, S.J. 1984. Introduction to Wildland Fire. A Wiley-Interscience Publication, John Wiley & Sons, Toronto.

Quintilio, D., R. Ponto, and I.B. Frew. 1971. A sprinkler system for use in prescribed burning. Can. For. Serv. Rep. A-X-41.

Wajax Manufacturing Limited. 1990. Wajax Fire Control Equipment. Montreal, Quebec, Canada.

Walker, W.R. 1980. Sprinkler & Trickle Irrigation. Colorado State University. Engineering Renewal & Growth Fort Collins, Colorado.

Watters, G.Z., and J. Keller. 1978. Trickle Irrigation tubing hydrolics. The Summer Meeting of ASAE, Utah State University. Paper 78 - 2015.

Wilson, A.A.G. 1988. Width of firebreak that is necessary to stop grassfires: some field experiments. Can. J. For. Res. 18: 682 - 687.

4. ESTIMATING WATER AND TIME REQUIRED TO HYDRATE ORGANIC SOIL PROFILES USING GARDEN-TYPE SOAKER HOSES

4.1 INTRODUCTION

Water is frequently used to contain wild or prescribed fires. It is effective in creating fuelbreaks because water saturated fuels do not readily burn. The primary goal of a "wetline" (Pyne 1984) is to saturate the surface fuels and the underlying organic material to the depth of mineral soil or bedrock, thus breaking the fuel continuity in the horizontal plane.

The most common methods for establishing a wetline have been described by Orr and Dell (1967), Henderson and King (1968), Johnson (1970), and Martin et al. (1977). All of these methods are effective but all have the disadvantages of requiring large volumes of water, which may not always be available at the fireline and the cost of acquiring and installing the material required to deliver the water may be high. A Buckner 512M rocket-jet sprinkler can require between 7000 to 10000 litres of water, depending on the orifice sizes, to establish a fireline 16 m wide and 114 m long (Quintilio et al. 1971).

A possible alternative to these established methods was proposed and described by Kanjanakunchorn et al. (1991) who used a commonly available garden-type soaker hose to establish a wetline. There are advantages to using a garden-type soaker hose, particularly if these hoses are used in a parallel configuration (Kanjanakunchorn et al. 1991). These hoses are: inexpensive, durable, easy to transport in the field, and very water efficient compared to standard irrigation equipment.

Generally, the flow rate of these hoses are less than the infiltration rates for most soils in Alberta. For example, Singh (1983) reported the soil infiltration capacity was high for lodgepole pine forests (mean 14.20 cm), moderate for soils in aspen stands (mean 5.96 cm/hr), and low for spruce-fir stands (mean 2.08 cm/hr). This suggests most water that is applied at rates lower than those above would be absorbed by the organic materials and soil near the fireline until saturation has occurred. Hence, theoretically no water would runoff the site as overland flow.

At times managers need to know how much water is needed to construct a fireguard. This information would allow them to accurately forecast costs and the probability of accomplishing their goals. In situations involving prescribed burning, knowing the amount of water needed and the time required to fully hydrate surface and ground fuels could significantly reduce treatment costs. Therefore, in this paper I present the theory and methodology for calculating the water and time requirements to establish a wetline in forest fuels. For purposes of demonstration we have designed our system around the RCR-strata garden soaker hose used in a parallel configuration. The Wajax Mark III pump and 3.8 cm (1.5 in) dia. lined firehose serve as the basic method of moving the water.

4.2 THEORY

To calculate the amount of water and time required to fully hydrate surface and ground fuels in a forest stand, one needs to know six things: (1) the rate of water discharge (ie. the water delivery rate to the ground surface), (2) the initial volumetric water content (θ_{vi}) of the forest floor and soil, (3) the saturated volumetric water content (θ_{sat}), (4) the depth of the organic layer to be hydrated, (5) the length of fireline to be hydrated, and (6) the widths of spray discharged by the equipment used to delivery the water. The rate of water discharge and the width of spray are characteristics specific to the water delivery system used. The initial and saturated volumetric water content characteristics are peculiar to the fuelbed to be hydrated. All of these variables must be known before the water and time requirements can be determined.

For the purpose of this thesis, full saturation of the surface and ground fuel layers was [described] based on the assumption that the litter and duff layers are saturated before the mineral soil is hydrated. The wetting front is considered to be the boundary between the saturated and unsaturated zones in the litter-soil profile. The total volume of water at any instantaneous point in time would be equal to water volumes required to saturate that layer of fuel [the litter]; for example, the saturated water content of the duff layer would equal the amount of water required to fill the air space (free water) in this layer plus that directly absorbed by the organic material (bound water), which makes up this layer.

The infiltration rate (I) can be estimated when t is large with the Philip's equation (Hillel 1982), which is expressed as:

$$I = S_p t^{0.5} + Kt \qquad (1)$$

where: I is cumulative infiltration (cm), S_p is sorptivity or the unsaturated flow of water at the soil surface or wetting front in horizontal and vertical directions ($cm/sec^{0.5}$), K is saturated hydraulic conductivity of the litter and soil (cm/sec) and t is time (sec) of infiltration (Hillel 1982).

When t is small, the horizontal infiltration equation or sorptivity is described as:

$$S_p = \frac{I}{t^{1/2}} \qquad (2)$$

where S_p is sorptivity, I is depth of water infiltrated in horizontal, unsaturated flow, and t is time in second (Hillel 1982).

As a result of a field experiments reported in this thesis (Chapter 3), a garden soaker hose used in a parallel configuration will deliver water at a rate of 1.8 cm/hour to the ground surface. At that rate all water is absorbed by the soil and overland flow is nil. Hence, the solution to equation (2), the sorptivity (S_p) can be determined to be:

$$S_p = \frac{1.8}{(60*60)^{1/2}} = 0.03\,cm/\sec^{1/2}$$

This sorptivity value was used for both litter and soil layers, owing to the lack of information available on organic substrates.

An initial volumetric water content (θ_{vi}) of zero was assumed for both the litter and soil layers. This conservative estimate is used here to demonstrate the maximum time required to hydrate a soil profile of a given thickness. The saturated water content (θ_{sat}) of litter and soil were estimated separately from bulk density and particle density (Hillel 1982);

$$\Theta_{sat} = 1 - \frac{\rho_b}{\rho_s} \qquad (3)$$

where θ_{sat} is saturated water content (%), ρ_b is bulk density (g/cm^3), and ρ_s is particle density (g/cm^3).

The volume depth to saturate each layer was calculated using the relationship;

$$L_f = \frac{I}{\theta_{sat} - \theta_{vi}} \quad , \quad or \qquad (4)$$

$$L_f = \frac{I}{\theta_{sat}} \quad when \quad \theta_{vi} = 0 \tag{5}$$

in which L_f is the depth of wetline front (cm) produced by a cumulative volume of infiltrated water (I, cm), associated with a change in water content represented by $(\theta_{sat}-\theta_{vi})$. The cumulative infiltration was obtained by substituting each layer depth and water content change into the equation and solving for I.

Using the Phillip's equation for infiltration (equation 1), one can determine the amount of time required to saturate the soil and litter layers. If the thickness of each layer (L_f) is known, then when x is substituted for $t^{1/2}$ in equation 1, the resultant equation becomes: $I = S_p x + kx^2$ or $S_p x + kx^2 - I = 0$

The quadratic form of this equation is:

$$x = \frac{-S_p +- \sqrt{S_p^2 - 4kI}}{2k} \tag{6}$$

4.3 EXAMPLE AND DISCUSSION

These equations and known performance characteristics were used to determine the time and the volume of water required to hydrate a fireline constructed in the aspen parklands of the Elk Island National Park. The bulk density of litter and soil for aspen stands in the Park were determined to be 0.14 and 1.24, respectively (Samran 1991). The particle density for aspen litter was estimated to be 1.9 g/cm^3 (Radforth et al. 1977) and an estimate of the soil particle density of 2.65 g/cm^3 was obtained from Hillel (1982). The depth of litter and soil in the test area was 6.5 and 8.5 (Samran 1991). From this data, we calculated the time and the amount of water needed to fully hydrate this soil type.

These results (Table 1) indicate that it would take about 1.70 hours for a garden-type soaker hose delivering water at a rate of 1.8 cm/hour to fully saturate top 15 cm of soil in a typical aspen cover in the Parklands of Alberta. The volume of water required to achieve this condition was estimated to be 4802 liters. In contrast, the sprinkler system described by Quientilio et al. (1971) operating for the same period of time would require 7000 - 10000 liters of water of course a greater area will be hydrated by that sprinkler system. Also, this estimate assumes that all water discharged falls on the soil surface and is not absorbed by live plants. The volumes of water required to maintain this condition would be dependent upon the climatic conditions and fire conditions but the amount of water would be low because the soil profile would be at field capacity.

The garden-type soaker hose used in a parallel system could be used to efficiently construct a fire control lines. This system will give the highest "pay back" areas where small amounts of water are available, and when alternative methods of fireline construction such and manual or mechanical are not feasible. This system can saves more

Table 4.1 Example typical data and results of infiltration analysis when site conditions from the boreal forest of Elk Island National Park are used[1/]

	DEPTH (cm)	BULK DENSITY (g/cm^3)	θ_{SAT}	θ_{VI}	I (cm)	TIME (min)
LITTER	6.5	0.14	0.93	0	6.05	0.65
SOIL	8.5	1.24	0.53	0	4.52	101.40
TOTAL TIME:1.70 HRS (102.05 min)			WATER VOLUME:4802 LITERS			

[1/] Data on depth and bulk density are from Samran (1991) water when compared to the water/air curtain technique described by Johnson (1970) or sprinkler system presented in Quintilio et al. (1971). Also, this system reduces water loser due to overland flow because the water deliver rate is less than the infiltration rate in aspen stand (Singh 1983). Furthermore, it is not difficult to carry and assemble the garden soaker hose used in this system. Lastly, garden-type soaker hoses are less expensive than alternative systems (Kanjanakunchorn et al. 1991).

This theory can be applied to many areas if the infiltration rate, the bulk density, the particle density, and the depth of the fuelbed are known. This information will reduce fireline construction costs and the amount of water used. Both of these conservation measures can be of value to managers.

4.4 LITERATURE CITED

Crown, P.H. 1977. Soil survey of Elk Island National Park, Alberta. Alberta Institute of Pedology. Edmonton, Alberta. Report # S-77-38, 128p.

Henderson, R.C., and R.K. King. 1968. Sprinkler system eases control of cribed fires. The Truck Logger 24(9): 16 - 17.

Hillel, D. 1982. Introduction to Soil Physics, Academic Press, Inc. Harcourt, Brace Jovanovich, Toronto.

Johnson, V.J. 1970. A water curtain for controlling experimental forest fires. USDA For. Serv. Res. Pap. NC-48.

Kanjanakunchorn, S., P.M. Woodard, and H. McDonald. 1991. The garden-type soaker hose used "in series" to contain wildland fires. In Proc. 11th Conf. Fire and For. Meteor. April 16-19,1990, Missoula, MT. Edited by P.L. Andrews and D.F. Potts. Soc. American Foresters, Bethesda, MD, USA.

Martin, R.E., S.E. Coleman, and A.H. Johnson. 1977. Wetline technique for prescribed burning firelines in rangeland. USDA For. Serv. Res. Note PNW-292.

Pyne, S.J. 1984. Introduction to Wildland Fire. A Wiley-Interscience Publication, John Wiley & Sons, Toronto.

Quintilio, D., R. Ponto, and I.B. Frew. 1971. A sprinkler system for use in prescribed burning. Can. For. Serv. Rep. A-X-41.

Radforth, N.W. and C.O. Brawner. 1977. Muskeg and the Northern Environment in Canada, The Muskeg Subcommittee of the NRC Associate Committee on Geothechnical Research. University of Toronto Press, Toronto.

Samran, S. 1991. Ground fuel hydration in aspen stands of central Alberta. MSc Thesis, Dept. For. Sci., University of Alberta, Edmonton.

Singh, T. 1983. A proposed method for preliminary assessment of erosion hazards in west-central Alberta. Environ.Can., Can.For.Serv., Inf.Rep.NOR-X 251.

5. SUMMARY

This study was undertaken to find a better water delivery system for constructing fire control lines in prescribed burning or wildland fire situations. The objective was to analyze and evaluate the suitability of using the commonly available garden-type soaker hose to fulfil the goals of efficiently delivering water at a low cost.

The bursting strength of three different types of garden-type soaker hoses were tested and the strongest hose type, the RCR-strata, was further tested i "series" and a "parallel" configuration. All work was preformed under field conditions. Such information as rates of water discharged, height of water discharged and width of fireline hydrated was related to the water pressure inside the hose as distance from the pump was increased. All work was done on level ground.

1. The instantaneous bursting strength was significantly different among each type of the garden soaker hose tested. The bursting strengths ranged from 365 to 1207 kPa. The RCR-strata had the highest instantaneous bursting strength and the average was 1038.8 kPa (n=15).

2. In the "series" configuration, The water pressure decreased exponentially as distance along the soaker hose increased. At the start of soaker hose lay the water pressure, the height of water spray, and discharge rate

were: 565 kPa, 385 cm, and 30 l/hr, respectively. Yet by 75 m, the water pressure, the height of water spray, and the discharge rate had dropped to zero. The zone of wetted area was 8 m wide at the start of this configuration but was nil at 75 m. Internal water pressures were high with this configuration, because water flowing through 3.8 cm mainlines was forced into 2.5 cm diameter soaker hoses. Soaker hoses would rupture when the Mark III pump was operated at full speed. This system was not be judged suitable for most prescribed burning or wildland fire situation due to the limited distance water could be delivered with a one pump configuration.

3. In the parallel system, The Wajax Mark III pump could be operated at full speed. The average pressure, water spray height, and discharge rate changed from 620 kPa, 385 cm, and 0.62 l/sec at the inlet near the pump to 225 kPa, 228 cm, and 0.15 l/sec (228.6 m from the pump). The zone of wetted area was about 8 m wide at 22.9 m from the pump and 4 m wide at 228.6 m from the pump. The relationship between water spray height and pressure was determined to be: $h = 0.088p^{0.61}$. The discharge rate can be predicted from known pressure values using the equation $q = 3.024*10^{-6}p^{2.03}$.

From this data, I calculated the maximum length of fireline that could be constructed using one Wajax Mark III pump running at full speed and pushing water through a 3.8 cm (1.5 in) dia mainline to garden-soaker hoses arranged in a parallel configuration. I also show the maximum distance to be realized from using a pump on both end of a line. Also, the known discharge characteristic of this system can be used to predict the amount of water and time needed to hydrate fuelbeds if the thickness and sorptivity rates for that fuelbed are known.

6. FUTURE RESEARCH

The results presented in this study provide information on the feasibility of using the garden-type soaker hose to control prescribed and wildland fires. In this thesis, I have answered questions pertaining to the practical use of such a system, which will be of value to some forest managers. Also, I have supplied the information required to understand the theory behind this work. But a number of further questions were discovered as part of this inquiry. The following is a list of questions that require further study. Answers to these and other questions will enable scientists and managers to better identify and further test suitable systems and where necessary, to advanced technology or products required for even better systems.

1. The effectiveness of the water delivery system described in this thesis were never field tested with free burning fires. I believe this is the logical next step in assessing the feasibility of these systems. I believe these systems are best suited to containing wildfires burning in grass fuelbeds or containing prescribed burning in stand that have deep organic profiles. But these two recommendations need to be tested along with other possible fire control and use situations.

2. There are trade offs between efficient soil hydration for the purpose of constructing a fuelbreak and the

production of a fine mist to serve as a water-air curtain. I believe a high dense mist of water will not be as efficient in hydrating surface and ground fuels as a "weeping type" soaker hose because: (1) some water is evaporated in the air before it reaches the surface and ground fuels, (2) water sprayed high in the air has a greater chance of being blown off site thus reducing the amount of water available to construct a fuelbreak, and (3) aerial water if it falls on live plants may be absorbed before reaching downed and dead fuels. Therefore, if there is little benefit of producing this wall of water mist relative to the costs and water losses to ground fuels then perhaps a different type of soaker hose could be used, such as the lines of a "weeping hose".

3. There are probably some cost savings and efficiencies to be realized by combining the "series" and "parallel" hose configurations. It may be possible to reduce the number of T-connectors by connecting three or four soaker hoses in a series along the "parallel" hose lay. Hence, it may be possible to reduce the number of T-connection by 33 to 50%. The reduction in T-connectors would reduce costs.

4. Although I tested the performance of the RCR-strata hose over a long period of time, I did not determine the effects of natural conditions and time on hose longevity. It seems highly likely that soaker hoses subjected to field conditions for long periods of time may become

unserviceable. It is well known that some plastic dry and breakdown when subjected to sunlight over a long period of time. Currently, we have no data on the long term durability of the hose materials use in this study. These test should be preformed before large amounts of money are spent on purchasing this type of hose. These hoses may also be eaten by wildlife in certain areas. This would also reduce their value as a fire control tool.