forest management note

Note No. 10 Northern Forest Research Centre Edmonton, Alberta

FOREST FIRE INITIAL-ATTACK PLANNING WITH A PROGRAMMABLE HAND-HELD CALCULATOR

In recent years fire control costs have been rising at a dramatic rate. Major increases in fuel, aircraft, fire retardant, and labor costs have elevated both presuppression and suppression expenditures to unheard-of levels, particularly during the disastrous 1980 fire season.

In order to maximize returns on presuppression expenditures and ultimately to minimize both expenditures and forest resource losses associated with fire suppression activities, forest protection agencies are becoming increasingly concerned with the cost-effectiveness of their operations. Improved and intensified initial-attack capabilities are receiving close attention and have called for modern planning processes and techniques that will optimize the allocation and utilization of costly initial-attack resources. One such process involves the development, testing, and application of initial-attack simulation models.

Until recently, the development and operation of simulation models required the use of large, costly, and centralized computing facilities and a level of programming and operating knowledge not generally available to fire management agencies. Today, however, because of significant technological advancements in the development of microprocessors, greatly increased levels of computing capability have been compacted into inexpensive, easy-to-use, and readily available hand-held or desk-top calculators. For example, it is now possible to perform computations and simulation exercises with a pocket calculator (Albini and Chase 1980, Cohen and Burgan 1979) that 5 years ago would have required a complex computing system.

As an aid to improved presuppression and initial-attack planning, a simple fire containment model programmed for the Texas Instruments Model 59 (TI-59) hand-held calculator[1] has been developed at the Northern Forest Research Centre. The model was derived in part from a fire operations simulation study conducted in central Alberta (Quintilio and Anderson 1976). This model has been developed with the user in mind, and its complexity has been minimized accordingly. It is assumed that the user has at least a basic knowledge of the TI-59 or a comparable programmable calculator.

As with most simulation routines, several assumptions must be made. In this model the following assumptions apply: 1. fire shape is in the form of an ellipse (Van Wagner 1969); 2. the backfire rate of spread is maintained at a constant 1 metre per minute; 3. all the fire line constructed is held and requires no further or follow-up action; and 4. fire containment occurs when the fire line has been constructed along 40% of the perimeter of the fire at the head and adjacent flanks. The user may wish to continue to operate the model beyond this 40% containment criterion simply by repeating the appropriate steps even though the containment flag (1.00 on the calculator) is displayed.

Use of the fire containment model simply requires input of the variables outlined in the operating instructions in Appendix I. In this manner the user can determine the fire behavior circumstances (rate of spread), the resource allocation opportunities (fire-line construction), and the

[1] The exclusion of certain manufactured products does not imply rejection nor does the mention of other products imply endorsement by the Canadian Forestry Service.

time factors (elapsed time between events or activities) to be considered. The only other user options are 1. initial fire size at discovery (e.g., 0.1 ha) and 2. head-to-flank spread ratio (e.g., 4:1) for the elliptical fire growth subroutine. Model output is presented in terms of whether (1.00) or not (0.00) a fire is contained based upon the input information, the size (area and perimeter) of the fire after any given period of action, and the ratio of fire line constructed to total perimeter.

It is intended that qualified fire control personnel within a given forest protection organization have access to and are able to operate the model, on the understanding that they are knowledgeable of the factors influencing fire behavior and control. These are the people who can best assess the presuppression and initial-attack circumstances unique to their area of responsibility. For example, this model may be used to assess the following: 1. resource requirements under high-demand circumstances; 2. fire-line construction capabilities under various fuel and fire conditions; 3. resource readiness and dispatch rules; and 4. resource allocation alternatives. Users will no doubt identify a number of other possible applications as they gain familiarity and experience with the model. As a precaution, however, it should be recognized that this model is not intended as a decision aid for use on active fires but should serve as a presuppression planning tool only.

The model can be readily programmed by the user in accordance with the listing provided in Appendix II. Documentation of the storage registers used is presented in Appendix III. In order to verify the program listing and to become familiar with the performance of the model, the user may wish to run the initial-attack example problem outlined in Appendix IV.

A forthcoming publication will be devoted to specific applications of the model to presuppression and initial-attack planning. This report will provide expected levels of productivity for hand crews, air tankers, and helitankers and will also assist the user in assessing fire behavior situations that may be modeled from a range of expected fire spread rates based upon defined fuel and fire weather circumstances. Until input information of this sort is assembled or published, it is expected that the user will be the person most familiar with the specific fuel, fire, and resource productivity conditions that will serve as model input variables for a given region.

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CONVERSION FACTORS

Hectares (ha) × 2.471 = acres
Metres/minute (m/min) × 2.982 = chains/hour
Metres/minute (m/min) × 3.2808 = feet/minute
Metres (m) × 0.04971 = chains
Acres × 0.4047 = hectares (ha)
Chains/hour × 0.3353 = metres/minute (m/min)
Feet/minute × 0.3048 = metres/minute (m/min)
Chains × 20.117 = metres (m)

Appendix 1. Operating instructions

Step	Procedure	Enter	Press	Display
1	Turn calculator on			Ignore
2	Clear memory		2nd CP	0.
3	Read program Side 1	1	Insert card Side 1	1.
4	Read program Side 2	2	Invert and insert card Side 2	2.
5	Initiate simulation		A	1.
6	Enter initial fire size (ha)	n[1]	R/S	n
7	Enter head-to-flank ratio	n	R/S	n
8	Enter headfire spread rate (m/min)	n	R/S	n
9	Enter fire line constructed (m)	n	R/S	n
10	Enter elapsed time interval for time period (min)	n	R/S	Flickering C
11	Fire containment flag displayed[2]	n	R/S	0.00 if not contained 1.00 if contained
12	Display total burned area		R/S	n = area (ha)
13	Display perimeter of fire		R/S	n = perimeter (m)
14	Display ratio of fire line constructed to total fire perimeter		R/S	n = ratio
15	Return to Step 8 if sustained attack for a subsequent time period is desired[3]		2nd LBL 2nd A′	0
	OR			
	To initiate a new fire simulation, return to Step 5.		CLR	0

[1] The label n refers to any user-defined number.

[2] Any given simulation exercise can be continued beyond the 40% (0.40) containment criterion even if the containment flag displayed in Step 11 is 1.00. To do this follow directions in Step 15 (note: Step 14 will display new percent containment).

[3] The user is cautioned that repetitive iterations over extended time intervals can result in output distortions, because the model assumes that the fire retains its original shape through time.

Appendix II. Programming the model

This model can be programmed or modified by the user with a basic knowledge of TI-59 programming requirements as described in the manufacturer's Personal Programming Manual. The user is referred to sections IV-10, IV-21, V-52, VI-4, and VII-2 for programming and editing instructions, program key locations and codes, program listing, and magnetic card writing. The model can be stored on two sides of a single magnetic card and should be labeled with permanent fast-drying ink. We recommend that one or more magnetic cards be prepared for each calculator used because of the incompatibility among some TI-59 calculators. The user should also note that magnetic cards can be damaged by the walk-through security scanners used at some airports; therefore, it is recommended that programmed cards be transported with checked or carry-on luggage.

To enter program, press 2nd CP LRN, and key in the complete program listed below.

Loc.	Key	Comments
000	76 LBL	Initiate simulation
001	11 A	
002	22 INV	
003	58 FIX	
004	47 CMS	
005	01 1	Set U, constant
006	42 STO	backfire rate
007	13 13	
008	91 R/S	
009	42 STO	Read initial fire
010	14 14	size, A_0
011	91 R/S	Read head-to-flank
012	42 STO	ratio, R
013	01 01	
014	91 R/S	

Loc.	Key	Comments
015	42 STO	Read headfire
016	12 12	spread rate, V_k
017	91 R/S	
018	42 STO	Read fire line
019	18 18	constructed, L_k
020	91 R/S	
021	42 STO	Read elapsed time
022	02 02	
023	53 (	
024	43 RCL	
025	14 14	
026	65 ×	
027	01 1	
028	00 0	
029	00 0	Calculate theoretical
030	00 0	distance from origin
031	00 0	to rear of fire
032	65 ×	at detection, Y_0
033	02 2	
034	65 ×	
035	43 RCL	
036	01 01	
037	55 ÷	
038	89 π	
039	55 ÷	
040	43 RCL	
041	12 12	
042	55 ÷	
043	53 (	
044	43 RCL	
045	12 12	
046	85 +	
047	01 1	
048	54)	
049	54)	
050	34 $\sqrt{X}$	
051	42 STO	
052	10 10	
053	53 (	
054	24 CE	Calculate theoretical
055	65 ×	distance from origin
056	43 RCL	to head of fire at
057	12 12	detection, X_0
058	54)	
059	42 STO	
060	09 09	
061	71 SBR	Calculate initial
062	34 $\sqrt{X}$	flank length, Z_0
063	71 SBR	
064	13 C	Calculate initial
065	43 RCL	perimeter, P_0
066	08 08	
067	42 STO	
068	15 15	

Loc.	Key	Comments
069	42 STO	
070	16 16	
071	43 RCL	
072	14 14	
073	42 STO	
074	17 17	
075	00 0	Set no containment
076	42 STO	flag
077	04 04	
078	76 LBL	Set headfire and
079	15 E	backfire incremental
080	43 RCL	distances
081	02 02	
082	49 PRD	
083	12 12	
084	49 PRD	
085	13 13	
086	76 LBL	Commence free burn
087	17 B′	
088	43 RCL	
089	12 12	
090	44 SUM	Calculate length
091	09 09	of headfire, X_k
092	43 RCL	
093	13 13	
094	44 SUM	Calculate length of
095	10 10	backfire, Y_k
096	71 SBR	Calculate flank length,
097	34 $\sqrt{X}$	Z_k
098	71 SBR	
099	13 C	Calculate P_k
100	71 SBR	
101	14 D	Calculate A_k
102	71 SBR	
103	18 C′	Calculate actual
104	71 SBR	perimeter, C_k
105	19 D′	Calculate actual area,
106	43 RCL	S_k
107	07 07	
108	42 STO	
109	14 14	
110	43 RCL	
111	08 08	
112	42 STO	
113	15 15	
114	43 RCL	
115	18 18	
116	44 SUM	Total fire line
117	19 19	constructed, F_k
118	53 (	
119	43 RCL	Fire containment test:
120	16 16	Is total fire line
121	65 ×	constructed greater
122	93 •	than 40% of actual

Loc.	Key	Comments
123	04 4	perimeter?
124	54)	
125	32 X≷T	
126	43 RCL	
127	19 19	
128	22 INV	
129	77 GE	
130	99 PRT	If so, set contain-
131	01 1	ment flag
132	42 STO	
133	04 04	
134	76 LBL	
135	99 PRT	
136	58 FIX	
137	02 02	
138	43 RCL	Display containment
139	04 04	flag
140	91 R/S	
141	53 (	
142	43 RCL	
143	17 17	
144	55 ÷	
145	01 1	
146	00 0	Display burned
147	00 0	area (ha)
148	00 0	
149	00 0	
150	54)	
151	91 R/S	Display fire
152	43 RCL	perimeter (m)
153	16 16	
154	91 R/S	
155	53 (	
156	43 RCL	
157	19 19	
158	55 ÷	
159	43 RCL	Display ratio of
160	16 16	fire line constructed
161	54)	to fire perimeter
162	91 R/S	End Main Program
163	76 LBL	Subroutine to
164	34 $\sqrt{X}$	calculate length of
165	53 (	flank fire,
166	43 RCL	$Z_k = X_k/R$
167	09 09	
168	55 ÷	
169	43 RCL	
170	01 01	
171	54)	
172	42 STO	
173	11 11	
174	92 RTN	(Press INV SBR)
175	76 LBL	Subroutine to
176	14 D	calculate A_k, the

Loc.	Key	Comments
177	53 (	theoretical burned area
178	89 π	
179	65 ×	
180	53 (	
181	43 RCL	
182	09 09	
183	85 +	
184	43 RCL	
185	10 10	$A_k = \pi(\frac{X_k + Y_k}{2})Z_k$
186	54)	
187	55 ÷	
188	02 2	
189	65 ×	
190	43 RCL	
191	11 11	
192	54)	
193	42 STO	
194	07 07	
195	92 RTN	(Press INV SBR)
196	76 LBL	Subroutine to
197	13 C	calculate P_k, the
198	53 (	theoretical fire
199	53 (	perimeter
200	53 (	
201	43 RCL	
202	09 09	
203	85 +	
204	43 RCL	
205	10 10	M (intermediate value)
206	54)	$= \frac{(X_k + Y_k - Z_k)}{2}$
207	55 ÷	
208	02 2	$\div \frac{(X_k + Y_k + Z_k)}{2}$
209	75 -	
210	43 RCL	
211	11 11	
212	54)	
213	55 ÷	
214	53 (	
215	53 (	
216	43 RCL	
217	09 09	
218	85 +	
219	43 RCL	
220	10 10	
221	54)	
222	55 ÷	
223	02 2	
224	85 +	
225	43 RCL	
226	11 11	
227	54)	
228	54)	
229	42 STO	
230	06 06	
231	53 (	
232	53 (	
233	89 π	
234	65 ×	
235	53 (	
236	53 (	
237	43 RCL	$P_k = \pi\frac{(X_k + Y_k + Z_k)}{2}$
238	09 09	
239	85 +	$\times (1 + \frac{M^2}{4})$
240	43 RCL	
241	10 10	
242	54)	
243	55 ÷	
244	02 2	
245	85 +	
246	43 RCL	
247	11 11	
248	54)	
249	54)	
250	65 ×	
251	53 (	
252	01 1	
253	85 +	
254	43 RCL	
255	06 06	
256	33 X^2	
257	55 ÷	
258	04 4	
259	54)	
260	54)	
261	42 STO	
262	08 08	
263	92 RTN	(Press INV SBR)
264	76 LBL	Subroutine to
265	18 C′	calculate actual fire
266	53 (	perimeter,
267	53 (	$C_k = C_{k-1}$
268	01 1	
269	75 -	$+ (1 - \frac{F_{k-1}}{C_{k-1}})$
270	53 (	
271	43 RCL	$\times (P_k - P_{k-1})$
272	19 19	
273	55 ÷	
274	43 RCL	
275	16 16	
276	54)	
277	54)	
278	65 ×	
279	53 (	
280	43 RCL	
281	08 08	
282	75 -	
283	43 RCL	
284	15 15	
285	54)	
286	54)	
287	44 SUM	Store C_k
288	16 16	
289	92 RTN	(Press INV SBR)
290	76 LBL	Subroutine to
291	19 D′	calculate actual
292	53 (	fire area,
293	53 (	$S_k = S_{k-1}$
294	01 1	
295	75 -	$+ (1 - \frac{F_{k-1}}{C_{k-1}})$
296	53 (	
297	43 RCL	$\times (A_k - A_{k-1})$
298	19 19	
299	55 ÷	
300	43 RCL	
301	17 17	
302	54)	
303	54)	
304	65 ×	
305	53 (	
306	43 RCL	
307	07 07	
308	75 -	
309	43 RCL	
310	14 14	
311	54)	
312	54)	
313	44 SUM	Store S_k
314	17 17	
315	92 RTN	(Press INV SBR)
316	76 LBL	Initiate sustained
317	16 A′	action by resetting
318	01 1	variables
319	42 STO	Initialize backfire
320	13 13	rate, U
321	25 CLR	
322	91 R/S	
323	42 STO	Read new headfire
324	12 12	spread rate, V_k
325	91 R/S	
326	42 STO	Read new fire line
327	18 18	constructed, L_k
328	91 R/S	
329	42 STO	Read new elapsed
330	02 02	time
331	61 GTO	Branch back to
332	15 E	continue simulation

Appendix III. Documentation of variables by storage register location

Upon completing a simulation exercise, the input and output data are contained in the following storage registers and can be recalled simply by pressing RCL followed by the appropriate two-digit register number.

Register number	Contents
00	Not used
01	R, head-to-flank ratio; user input
02	Elapsed time interval for the time period (min)
03	Not used
04	Fire containment flag: 0.00 if fire is not contained 1.00 if fire is contained
05	Not used
06	M - Intermediate value in perimeter calculation
07	A_k - Theoretical area at end of current time interval
08	P_k - Theoretical perimeter at end of current time interval
09	X_k - Theoretical distance from head to origin of fire
10	Y_k - Theoretical distance from rear to origin of fire
11	Z_k - Theoretical distance from flank to origin of fire
12	V_k - Rate of spread (m/min); user input variable
13	U - Backfire spread rate set constant to 1 m/min
14	A_{k-1} - Initial area burned; accrued theoretical area burned at end of previous time interval (ha)
15	P_{k-1} - Initial perimeter of fire; accrued theoretical perimeter of fire at end of previous time interval (m)
16	C_k - Actual perimeter (m); note that $C_0 = P_0$ and $C_1 = P_1$ in sustained simulation
17	S_k - Actual area of fire at end of current time interval (ha)
18	L_k - Fire line constructed during current time interval (m)
19	F_k - Total fire line constructed at end of current time interval (m)

Appendix IV. Initial-attack problem

In order to verify the program listing and to become familiar with the performance of the model, the user may wish to run the initial-attack problem outlined below. Figure 1 is a pictorial representation of the problem and solution.

Fire situation:

Distance from initial-attack base = 60 km
Fire size at time of reporting = 0.3 ha
Fuel type = lowland black spruce
Fire severity = extreme (suggesting potential head-to-flank ratio of 4:1)
Potential forward rate of spread = 8 m/min

Resource availability and productivity:

One group of three B-26 air tankers
Elapsed time from reporting to initial attack including getaway = 20 min
Net effective retardant fire line constructed per two-door string drop = 105 m
Time interval between second and third retardant drops (events) = 3 min

Appendix IV. Initial-attack problem, continued

Step	Input/output from operating instructions (see Appendix 1)
1-5	Follow steps as instructed in Appendix 1
6	Input initial fire size = 0.3 ha
7	Input head-to-flank ratio = 4
8	Input headfire spread rate = 8 m/min
9	Input fire line constructed = 105 m
10	Input elapsed time = 20 min
11	Output fire containment flag = 0.00
12	Output burned area = 2.60 ha
13	Output fire perimeter = 641.63 m
14	Output ratio of fire line constructed to total perimeter = 0.16
15	Press 2nd LBL 2nd A′ and return to Step 8
15-8	Input headfire spread rate = 8 m/min
15-9	Input fire line constructed = 105 m
15-10	Input elapsed time = 3 min
15-11	Output fire containment flag = 0.00
15-12	Output burned area = 3.13 ha
15-13	Output fire perimeter = 694.76 m
15-14	Output ratio of fire line constructed to total perimeter = 0.30
16	Press 2nd LBL 2nd A′ and return to Step 8
16-8	Input headfire spread rate = 8 m/min
16-9	Input fire line constructed = 105 m
16-10	Input elapsed time = 3 min
16-11	Output fire containment flag = 1.00
16-12	Output burned area = 3.72 ha
16-13	Output fire perimeter = 739.09 m
16-14	Output ratio of fire line constructed to total perimeter = 0.43

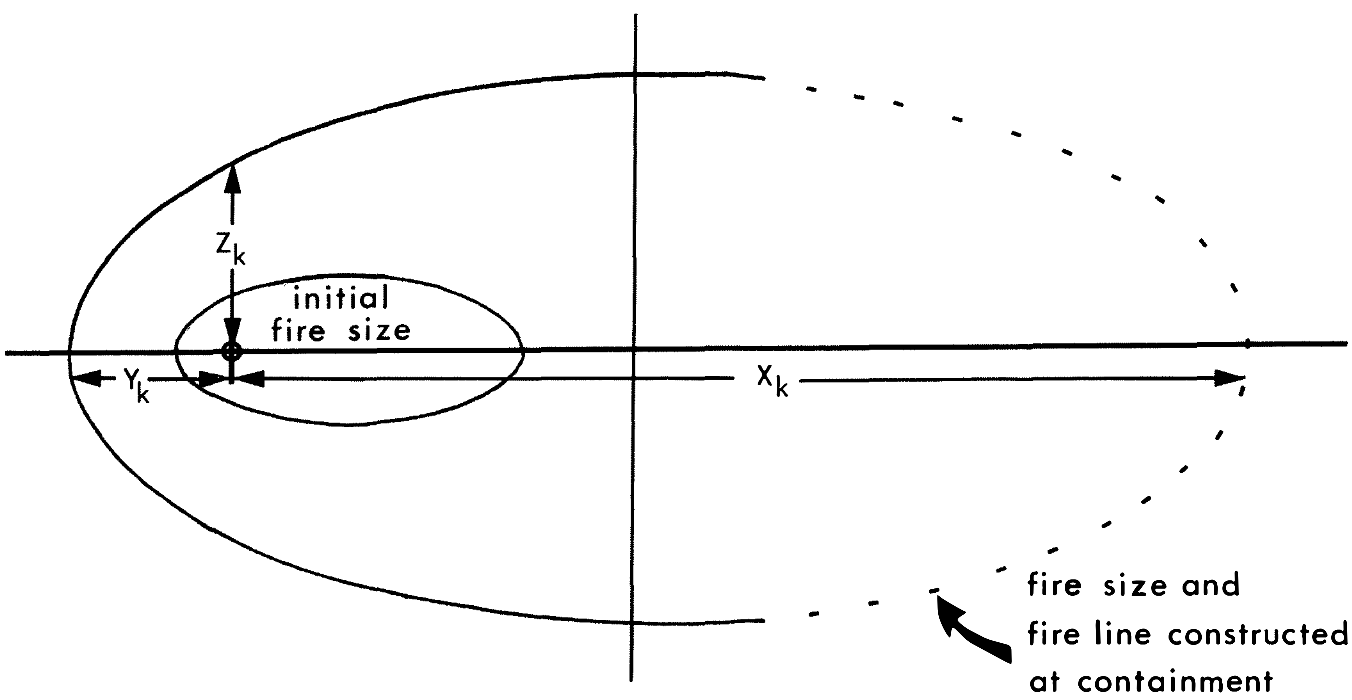

Figure 1. The initial-attack problem and solution.

Canadä

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