Wildland Fire Operations Research Group (WFORG)
1176 Switzer Drive
Hinton AB T7V 1V3
http://fire.feric.ca

An evaluation of handheld infrared cameras for ground initial attack crew use during wildfire mop-up operations

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Scott VanderMeer

Ray Ault

Steve Hvenegaard

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Introduction

Infrared technology is widely used by Canadian wildfire management agencies to achieve wildfire suppression objectives. The use of infrared technology to identify smouldering woody material during the final stages of fire mop-up is most commonly conducted using helicopters equipped with infrared cameras. This report documents the use of an infrared camera by firefighters on the ground on two separate fires in Ontario.

FPInnovations has completed several projects related to the use of infrared technology in identifying small, smouldering spots of burning organic material. This Ontario study is our first evaluation of handheld infrared cameras operated on the fireline by fire crews. The initial reaction to the project proposal was suggestion that widespread use of infrared technology on the ground would result in a reduction in cold trailing activities. This study found the use of an infrared camera on the fireline did not alter conventional cold trailing activities but generally complemented conventional patrol and mop-up procedures by enabling firefighters to locate more hotspots earlier in the day.

In part this study was initiated in response to improvements in infrared camera technology which have increased their applicability to ground patrol operations while reducing the camera acquisition and maintenance cost.

This project is a cooperative study between the Ontario Ministry of Natural Resources and FPInnovations.

Terminology

Initial attack is a term used widely in the wildland firefighting community. Initial attack crews in Ontario are usually the first to action a fire, and one of the last crews to leave. If the fire load is high, they may be replaced with a sustained action crew.

Infrared scanning is the physical act of scanning a surface with the aid of an infrared camera.

A thermographic camera or **infrared camera** is a device that forms an image using infrared radiation, similar to a common camera that forms an image using visible light. Instead of the 450–750 nanometer range of the visible light camera, infrared cameras operate in wavelengths as long as 14,000 nm (14 µm). Other terms commonly used include 'infrared scanner' and 'thermal imaging camera'. For the purposes of continuity, this report will use the term 'infrared camera'.

A **hot spot** is burning organic material of varying temperature and size. Identifying the location of these spots is crucial to the extinguishment of a wildfire.

For the purpose of this study, **mop-up** is considered the operational stage of a fire with an established wetline or control line around the perimeter of the fire. During mop-up operations, fire crews will systematically patrol the perimeter and interior of the fire to locate and extinguish hotspots.

Cold trailing is 'a method of determining whether or not a fire is still burning, involving careful inspection and feeling with the hand or by use of a hand-held infrared scanner, to detect any heat source.' *(CIFFC Glossary of Forest Fire Management Terms)*

Objectives

The objectives of the study were to:

- Evaluate the use of a handheld infrared camera (*Thermal Eye X50*) by Ontario firefighters in mop-up operations.
- Assess the ease of use and durability of the infrared camera.
- Develop a systematic approach to identifying potential benefits associated with the use of handheld infrared cameras on the ground by fire crews.
- Compare the effectiveness and shortcomings of two different hot spot identification methods (infrared camera scanning and conventional patrol methods) based on area covered, hot spots found and time of day
- Identify potential cost savings resulting from implementing hand held infrared technology during mop-up operations.
- Identify best practices for the operation of infrared cameras during mop-up operations.

Methods

Literature Review

In order to develop the methods for this study, previous research and background information were examined to understand handheld infrared cameras and their use. Sources included academic journal articles, agency documents, and unpublished studies.

Agency Review

Experts in the field of infrared technology were contacted, including those with experience in the use of infrared technologies on wildfire. Agencies were asked to comment on the advantages and disadvantages of using hand held infrared cameras for ground application.

Field Data Collection

Field data was collected between May 29th and June 8th, 2010. FPInnovations and the Ministry of Natural Resources of Ontario worked closely to maximize opportunities where firefighters could use the *Thermal-Eye X-50* infrared camera during the mop-up stage of a wildfire (*Figure 1*).

Figure 1. *Thermal-Eye X-50* infrared camera used during the study (See Appendix B).

Firefighters patrolled the fire perimeter and burnt area of two wildfires in the mop-up stage to locate hotspots using two different approaches. In the first approach, a two person team was equipped with an infrared camera and provided with an orientation in the operation of the camera equipment. In the second approach a two to four person team used conventional hotspot detection methods (sight and smell) in their patrol.

When an area of interest was identified the teams probed the suspect area with their hands to determine if the spot was, in fact, hot. The patrollers carried GPS units on track mode, marked the hot spots found, and flagged them for later extinguishment.

During the scanning and patrol operations, detailed notes and observations were recorded that could be used later to explain and elaborate results. Documentation of each hot spot included size of hotspot, hot spot temperature, and a digital image taken from the direction of detection

Additional documentation included the start and finish time for each team and number of patrollers on each team. After the scanning and patrols operations were completed, the GPS data was downloaded[1]. Using *ArcMap GIS*, maps were created of the scanning and patrol tracks, the hot spots marked by crews, and the fire perimeter. These maps were utilized in later analysis of the results.

Weather data and FWI values

A *Kestrel 4500 NV* weather station was deployed at each fire to collect weather data. (*Figure 2*). Weather data of primary interest for this study was temperature, relative humidity, and wind speed. Long term precipitation and Fire Weather Index (FWI) values from the closest OMNR weather station were recorded for the time frame of the study.

Figure 2. The *Kestrel 4500 NV* weather station on Sudbury 55 looking north.

[1] Natalie Belanger, GIS Specialist, Ontario Ministry of Natural Resources, assisted with the downloading of data and creation of maps.

Participant Questionnaire

An anonymous questionnaire was created for completion by the infrared camera operators. (*Table 1*) Additional relevant verbal comments were noted in the comments section. The purpose of the questionnaire was to determine if there were relationships between a participant's fire experience or previous infrared camera training with the operator's ease of use of the Thermal-eye X 50 and ability to identify hot spots using an infrared camera. The comments section was intended to collect ideas and opinions on potential best practices and gauge the receptiveness or support for the technology from firefighters.

Table 1. Infrared camera operator Participant Questionnaire

Participant Questionnaire

All participants in this questionnaire were involved in the scanning portion of the testing. They were selected based on availability. This questionnaire is voluntary and anonymous.

- How many years of fire experience do you have?
- What position do you hold on your crew? (i.e. Member, Sub-Leader, Leader)
- Have you had experience with infrared scanning? If so, explain.
- Have you ever received training in infrared scanning?
- How was the Thermal X50 as far as ease of use?
- Was it durable for ground scanning use?
- If you had access to an infrared scanner in the future would you use it?
- How do you see infrared scanning being used?
- Would you say that infrared scanning could replace cold trailing?
- If you see infrared scanning as being useful, what would you need to make infrared scanning effective? Is it time efficient?
- Did you have any issues with "solar gain" or solar reflection during the scan?
- Comments:

Thank you for your participation in this study.

Results

Literature Review

Few documents were found related to the use of handheld infrared devices in ground-based surveys or aerial application. The following are unpublished articles relevant to this study.

Johnson (n.d.) initiated a study in Saskatchewan to investigate the use of wand style infrared devices on wildfires to address some problems with aerial infrared scanning, specifically, crews receiving coordinates from the morning aerial scans too late to prevent flare-up, ambiguity in GPS locations, and the inability to create accurate and timely maps for mop-up crews. Handheld wand infrared devices may be able to deliver real-time information to crews, and achieve cost savings. Some of these concerns with aerial scanning continue for agencies across Canada and the United States (*Table* 2). This particular study was not carried through, but it points out the need for more research in this area.

In 2004, Wilde et al. (2004) examined wand-style handheld heat sensors in British Columbia to evaluate the application and possible uses for this technology in the field. Definite limitations to the device were found, however "users indicated that this technology does have value"[1]. The report recommended the development of a training package outlining infrared theory, limitations, and expectations to enable effective implementation of such a device.

Multiple instances show the successful use of ground-based infrared technology in other industries. Stateham (1973) reports on a successful test on combustible materials in dumps that spontaneously ignite. Using this "military night vision device," hot spots were found in areas with high organic matter. When the sites were scanned between 09:00 and 18:00, "thermal noise" or solar effects formed due to the daytime heating. Stateham also carried out tests between 21:30 and midnight. "At night the solar effects had dissipated and clear thermal images were obtained for data recording and for verification of earlier results"[2]. It is evident that solar reflection impacts infrared scanning operations results.

In 2001 United States Forest Service (USFS) Incident Commanders asked the National Infrared Operations Program (NIROPS) to develop a list of possible vendors for infrared scanning. They added information on factors and limitations in infrared usage and examined the forty year history of infrared technology in wildfire intelligence. The classification of systems available and associated limitations of infrared technology has made this document a useful resource (Zajkowski et al. 2004). "In the past, infrared systems have been used on fires without prior knowledge of the system's ability to meet the objectives of the fire managers"[3].

Agency Experience with Infrared Camera Technology

Fire management agencies were contacted and asked for their experience related to the advantages and limitations of ground based infrared camera use for wildfire mop-up and patrol. *Table 2* summarizes the responses

[1](Wilde et al., 2004) pg.3
[2](Stateham, R.M. 1973) pg. 6
3(Zajkowski et al. 2004).pg. 5

Table 2. Advantages and Limitations of handheld infrared scanning technology (as identified by wildfire management agencies)

Handheld ground infrared technology		
Applications	**Advantages**	**Limitations**
Alberta[1] Used for ground scanning of burn piles, problem areas on prescribed burns Seldom use IR handheld cameras on the fireline	• IR can penetrate through smoke.	• Ozone, carbon dioxide, and water vapour lessens IR signal. • Dense water vapour could result in masking signs of combustion. • Rainfall reduces heat signature due to cooling effect on hot spots • "Early morning ensures the best results. Scanning during the later part of the evening is acceptable as long as remnant or residual solar gain has subsided" (Simser, n.d, pg. 3). • There are limitations to finding hot spots due to having to be within the line of sight of a spot. • Indirect heating only detects surface energy of 1/1000 inch. • Temperature range of hot spots can vary which can change the heat signature color contrast
British Columbia[2] Useful in mop-up operations. Good for small fires with superficial, shallow burn, and fires that can't be cold-trailed	• Works best in the morning due to higher color contrast. • Works best under heavy timber (shaded area).- • Finds surface heat well. • Assists with cold trailing and finding residual fire.-	• Doesn't replace cold trailing. • Limited use in open canopy and sun. • Only detects residual heat that is exposed. • May not identify deep fire. • Limited full-day time use (solar reflection). • Limited use in wet, foggy, and rainy conditions.
United States Forest Service[3] **(USFS)** Is effective to target areas of concern	• Quick access to Raytheon Palm IR can make ground scanning more efficient than waiting for aerial scan. • Increased availability of scanner, almost every engine (fire truck) has access to one. • Can scan during the day, but early mornings and later evenings/nights are seen as optimal • Little training required	• Attenuation through water molecules. • Solar radiation can cause false observations. • Temperature can be too subtle for reading the heat signature. • Fuel type/canopy could block reflection of thermal energy preventing the sight of a hot spot. • Very hot objects may saturate sensors preventing a depiction of a hot spot. • Heavy reliance on interpretation by infrared analyst, which could be wrong.
Ontario[4] Can help secure perimeter and small islands within the inside of the fire, reducing the opportunity for re-burns.	• "Can generally be operated during the day with exception of very sunny and hot days" (Ward, 1982, pg.11). • Targets can be actioned by suppression crews which may not have been easy to otherwise locate	• Rain effect; deflects thermal radiation. • Saturation can cause problems identifying heat signature. • Only measures surface heat. • Reflection of thermal energy off of other sources of heat can give false results. • Line of sight affects the amount of area that could be covered.

[1] (Simser, n.d.)
[2] (Wilde, 2004)
[3] (Randy Herrin, Personal Communication, June 22, 2010)
[4] (Ward, 1982)

Infrared Technology Implemented and Equipment Utilized (by Agency)

Despite trying to contact most Canadian agencies, feedback was received from only three provinces and Parks Canada. The United States Forest Service's National Infrared Operations Program also provided information. A summary of handheld infrared cameras in wildfire operation can be found in *Table 3*.

Table 3. Agency infrared camera use and equipment type

Agency Review Chart			
Agency	**Approach**	**Handheld Infrared Camera Use (Y/N)**	**Primary Uses for Handheld Infrared Camera**
Alberta[1]	FLIR H Series 1) Handheld ground 2) Low altitude – handheld helicopter	Yes, but uncommon.	• Securing cat guards. • winter debris pile burning
British Columbia (BC)[2]	THERMAL EYE 250D 1) Ground level -hand held units, either wand style or camera. 2) Low altitude- rotary wing platforms. .	Yes	• Spot fires or areas of residual fire on wildfires or controlled burns. • Piles, windrows, priority burn edges. • Mop-up and patrol.
United States Forest Service (USFS)[3]	RAYTHEON PALM IR 1) Ground scanning done with a handheld *Raytheon Palm IR.*	Yes	• Used as a final check on larger fires along a perimeter (30 meters in), in areas of concern where land might border private property or structures. • Some situations require two scans with no signs of heat before being turned over.
Parks Canada (Banff)[4]	AGEMA 510 2)Low Altitude- rotary wing (IA staff as operators using handheld)	Yes	• Used for mop-up, piles, spot fires, prescribe burns. - Sometimes used to make resource requests on a fire. • Scan primarily in the early morning.
Ontario[5]	THERMAL EYE X 50 1) Ground level	Yes	• The last written document Ward (1982) suggests its use: • Primarily for mop-up use. • Perimeter Control; locating spots near perimeter. • Locating spots inside the fire in un-burnt green islands. • Looking at spot fires.

[1] (Simser 2008)

[2] (Wilde 2004)

[3] (Randy Herrin, Personal Communication, June 22,2010)

[4] (Matt Rance, Personal Communication, July 2, 2010) & (Dean MacDonald, Personal Communication, May 17, 2010)

[5] (Ward 1982) & (Robert Janser, Personal Communication, June 23, 2010).

Field data collection

We spent eight days capturing results from Sudbury 55 and Sudbury 92 which were 7.4 hectares and 1.5 hectares in size (respectively). Fuel types included dense black spruce and mixed wood (a mix of white pine, oak, and maple)

Sudbury 55

Sudbury 55 was started by a lightning strike. The fuel type was primarily mixedwood (mix of hemlock, oak, maple, and white pine). This fire was patchy and experienced wind gusts from the south, evident from the lean of the trees on the south aspect. Rocky terrain made ground movement challenging for firefighters.

We arrived to Sudbury 55 on June 1 at 1030. A weather station was set up on the south side of the fire to collect temperature, relative humidity, and wind speed. At the time of our arrival, the fire was too hot to scan so the Incident Commander (IC) suggested that we wait until the situation improved before infrared scanning the area. We walked the perimeter and found the fire to measure 7.4 hectares. At the time there were four crews (14 people) deployed on the fire.

We attempted to assess the capability of the camera to identify hot spots at midafternoon. At 1400 the temperature was 26ºC, relative humidity was 38%, and wind speed was less than 3 km/h. After several attempts by various crew leaders/members to use the infrared camera on the fire, it was determined that the fire was too hot to give useful results. Solar reflection from rocky quartzite was causing false positives even after the contrast knob was fully adjusted. Again, at 1600 we attempted scanning but had similar observations. At 1900, we again went into the burned area to test the limitations of the infrared camera. The temperature hovered near 20ºC, with a humidity 37%, and wind speed picking up a little at 4 km/h. Our goal was to locate an area that had been shaded for some time. The north side of the fire had forest cover of primarily hemlock, oak, and maple. After testing the infrared camera here, we were able to see the distinct heat signature of a hot spot. From the north aspect we walked around to the south side. At 2030 the infrared camera was providing good results with little influence from solar reflection. The IC made the decision to start ground scanning with the infrared camera early the next morning.

June 2, 0500. Two teams were selected from the IA Crew - one for infrared scanning operations and one for conventional patrolling. The IC and a crew leader decided to scan with the infrared camera on the north side of the fire in more difficult terrain. Neither of them had prior experience with infrared cameras but they were seasoned firefighters with combined experience of nineteen years. They understood the basic concept behind infrared and had the opportunity on the previous day to use the infrared camera. Within a short time the fire crew could recognize the heat signature of a hot spot. The perimeter of the fire was patrolled by three people, starting at 0745, approximately one hour and fifteen minutes after the infrared scan was completed

The start and end times of the scan and the patrol are shown in *Table 4*. The participants were asked to collect pertinent weather information to develop comparisons between spots that were detected with the infrared camera and ones that were found by the patrollers. Although the temperature was taken at the hot spots, time constraints did not allow for sufficient response time for the thermometer to adjust adequately. Two false positives were observed. A false positive for the purpose of this study is defined as anything that was sighted as a spot, verbalized, and then checked and confirmed as not a hot spot.

Table 4. Weather data for Sudbury 55 June 2, 2010.

Time	Wind Speed (km/h)	Temperature (C)	Relative Humidity (%)	Test Carried Out
5:00	1.8	16.2	74.8	
5:30	1.4	16.1	77.9	Scan Started 5:15
6:00	0	15.2	86.7	
6:30	1.7	15.5	88.6	Scan Ended 6:26
7:00	2.3	18.1	78.8	
7:30	0	23.8	54.0	
8:00	1.7	21.1	59.9	Patrol Started 7:45
8:30	4.2	19.8	65.5	
9:00	1.8	19.7	65.9	
9:30	0	24.7	48.2	Patrol Ended 9:30

The Fine Fuel Moisture Code (FFMC), Duff Moisture Code (DMC) and the Drought Code (DC) developed in the Canadian Forest Fire Weather Index (FWI) System (Van Wagner 1987) provide relative indicators of moisture content in the fine fuels, upper duff layer, and deep duff layer (respectively).

The majority of sustained smouldering of fuels will occur in the duff layer and fire crews focus their patrolling tactics and mop-up efforts on problematic fuel areas such as deep, dry duff layers or heavy accumulations of fuels in rain shaded areas. Hence, for this evaluation of handheld infrared cameras during wildfire mop-up operations, the moisture codes of primary interest are the DMC and DC.

DMC is a good indicator of the potential for 'landscape receptivity to ignition by lightning' with a DMC value of 20 used as a threshold value to expect fire starts from lightning strikes. (Wotton 2008) This threshold value can also be applied to the potential for sustained smouldering fire in duff layers. The DMC values recorded at Sudbury 55 (*Table 5*), ranging from 76 to 93, indicate a relatively high potential for sustained smoldering fire.

DC is used to indicate the moisture content of deep duff layers and the moisture content of large down and dead woody debris. (Wotton 2008) A DC value of 300 is accepted by fire crews as a threshold value to expect deep, sustained burning and difficulty in mop-up operations. DC values calculated at the Sudbury 55 fire (*Table 5*), ranging from 211 to 247, indicate a relatively high probability of sustained smouldering fire in the deep duff layers and heavy fuels. However, the DC value does not indicate serious difficulty in mop-up operations.

The burn characteristics in the photos of hotspots found on Sudbury 55 and 92 (*Figures 6 and 7*) are indicative of the anticipated burning associated with DMC and DC values calculated for these fires.

Table 5. *Fire Weather Index* (FWI) values and precipitation for Sudbury 55 from the nearest weather station during the time from fire detection date to scan date.

Date	Rain (mm)	FFMC	DMC	DC	ISI	BUI	FWI
May 28	2.0	85.5	76	211	4.2	80	15
May 29	0	89.7	80	217	6.1	83	20
May 30	0.4	89.7	84	224	6.9	87	20
May 31	0	88.6	87	231	6.8	90	23
June 1	0	88.6	91	239	6.5	93	23
June 2	**1.2**	**83.3**	**93**	**247**	**2.8**	**96**	**12**

Table 6 lists the hotspot details located during the infrared scan. The infrared scan was performed by a two person team, for a period of one hour and eleven minutes. Of the fifteen spots found, ten were found with the infrared camera. Out of those ten, three had visible smoke once spotted and all but one was larger than 30cm^2. The comments column indicates where the spots were found.

Table 6. Hot spots found by the infrared scan team on Sudbury 55 (Green highlight represents hotspots found by the infrared camera).

Hot Spot	Time Found	Smoke Visible (Y/N)	Size = or > 30cm X 30cm (Y/N)	Found with Infrared Camera (Y/N)	Comments
1	5:18	N	Y	Y	Leaf Litter
2	5:24	N	Y	Y	Could Smell
3	5:26	N	Y	Y	Undergrowth
4	5:40	N	Y	Y	Leaf Litter
5	5:41	N	Y	Y	Leaf Litter
6	5:41	Y	Y	Y	Leaf Litter-bottom of white pine
7	5:56	N	N	Y	Under rock-hard to see
8	6:00	Y	Y	Y	
9	6:01	Y	Y	N	
10	6:02	N	N	N	Beneath White Pine
11	6:06	Y	Y	Y	
12	6:09	Y	Y	N	
13	6:09	Y	Y	N	
14	6:09	Y	Y	N	
15	6:14	N	Y	Y	Edge of fire-underneath duff

Table 7 shows the results of the conventional patrol on Sudbury 55. During one hour and forty-five minutes of patrolling the perimeter, the three person crew found sixteen hot spots. The patrol overlapped a small area in the northwest corner of the fire which was covered by the two person infrared scan team. The patrollers and infrared scan team found different hot spots in the overlap area. *(Figure 3)*

Table 7 Hot Spots found by the patrollers on Sudbury 55.

Hot Spot	Time Found	Smoke Visible (Y/N)	Size = or > 30cm X 30cm (Y/N)	Found with Infrared Camera (Y/N)	Comments
Patroller 1					
1	8:51	Y	Y	N	Perimeter Edge
Patroller 2					
1	8:00	Y	Y	N	
2	8:10	Y	Y	N	
3	8:30	Y	Y	N	
4	8:35	Y	Y	N	
5	8:40	Y	N	N	
6	8:47	Y	Y	N	
7	8:48	Y	Y	N	
8	8:49	Y	Y	N	Hard to see
9	9:20	Y	Y	N	4 smokes in close proximity
10	9:27	Y	Y	N	
11	9:29	Y	Y	N	
Patroller 3					
1	8:06	Y	Y	N	Deep
2	8:23	Y	Y	N	Deep
3	9:00	Y	Y	N	Rock Crevasse
4	9:14	Y	Y	N	Under Story

All of the GPS tracks and waypoints were compiled on maps to show areas covered, hot spots found with the infrared camera, and hot spots found by the patrollers. The spots found by each patroller are differentiated on the map. For example, P01_001 represents hot spot number one found by patroller number one, correlating with the information in *Table 7*.

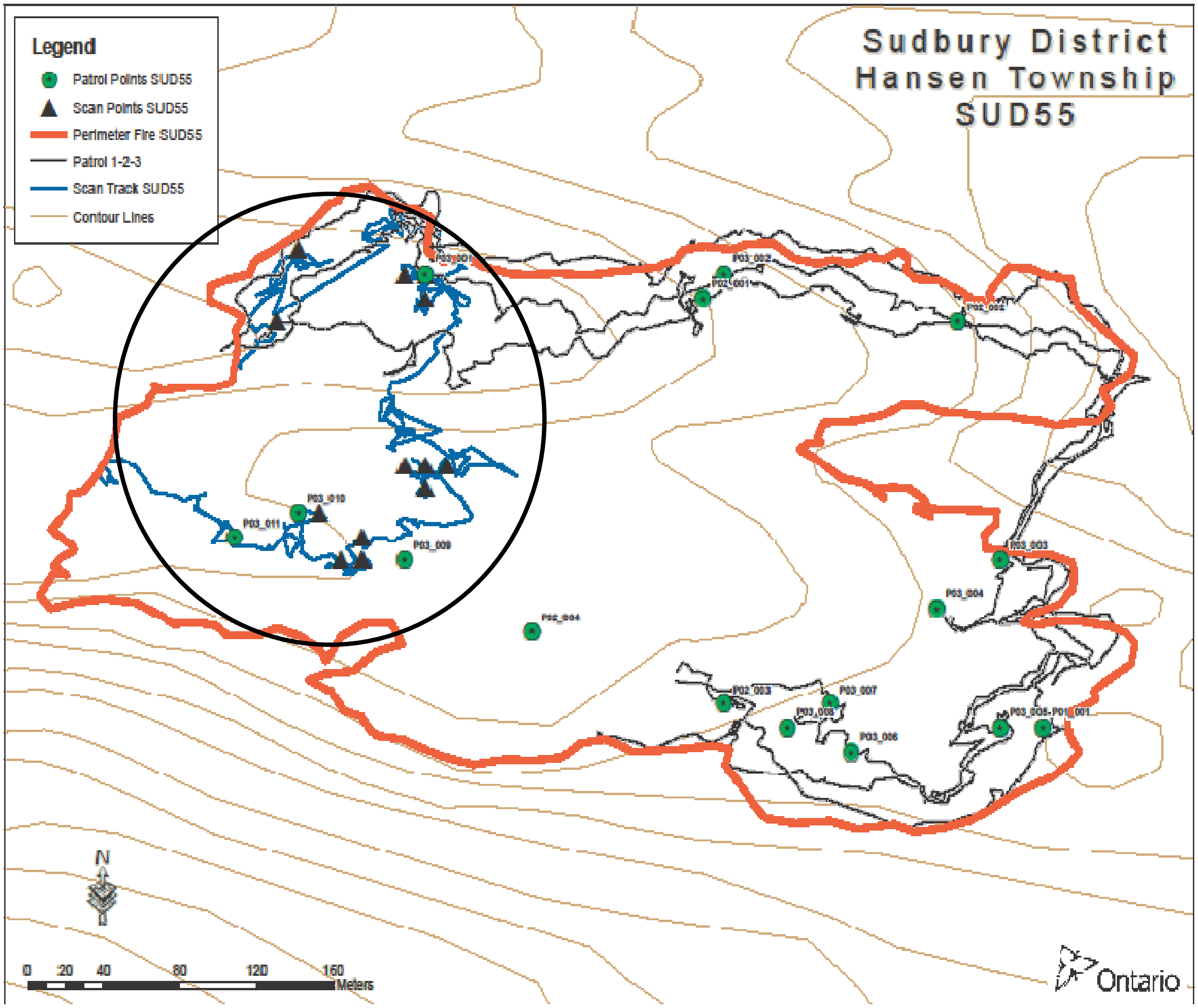

Figure 3. GPS tracks recorded by patrol and scan crews with marked hotspots found by each crew. The black circle indicates area that was covered by both crews.

Sudbury 92

The Sudbury 92 fire was burning in a C-5 fuel type with a southeast slope of less than five degrees. The site had significant rock features which made for a patchy burn.

Upon arrival at Sudbury 92 on June 4, 2010, we found the fire was not at the mop-up stage. Torching fire behaviour was observed and fire crews were still in the containment stage of fire suppression. Infrared scanning operations with the ground crews were postponed until the next day with intentions to use one crew for infrared scanning and the other for conventional patrolling. During a preliminary scouting, the fire was measured at 1.5 hectares. Attempts to use the infrared camera at 1300 in the shady, less sun exposed locations proved unsuccessful. Even with the contrast knob turned down, we could not distinguish between a hot rock and a hot spot, leading to many false positives. Poor conditions for infrared scanning in the afternoon at Sudbury 92 are similar to the observations at Sudbury 55.

On June 5, 2010 we arrived at the fire at 0500 to start an infrared scan of the fire. Only one crew was available as the second one had left due to internal changes. The fire crew scanned the fire with the infrared camera and did not follow-up with a patrol. The crew had limited fire experience with the leader having the most at five years.

A weather station was set up on the northeast side of the fire. Temperature was 15ºC with relative humidity of >95%. Winds were calm. *Table 8* represents the FWI values and precipitation observed at the nearest weather station. Appreciable dew was present in the grass around the fire during the early morning hours prior to the infrared scan. The sky was clear during the scanning period. There was no effective change in temperature, humidity, and wind for the duration of the infrared scan.

Table 8. FWI values and precipitation amounts recorded from the weather station nearest to Sudbury 92.

Date	Rain (mm)	FFMC	DMC	DC	ISI	BUI	FWI
June 2, 2010	0.8	80.9	80	239	3.9	87	15
June 3, 2010	0	85.2	82	246	3.0	90	12
June 4, 2010	0	87.2	85	253	5.5	93	20

The four person crew was given a twenty minute training session prior to starting the infrared scan operation. A hot spot was located and they saw how it looked through the infrared camera. The limitations of the camera and the importance of recognizing the heat signature of a hot spot were emphasized.

The scan started at 0531 and ended at 0656 for a total of one hour and twenty-five minutes. At 0559 the sun was over the horizon and starting to shine on part of the fire. Participants were asked to record information regarding the location of the spot as shown in *Table 9*. In total they found seventeen hot spots. Out of these, six were found using the infrared camera with smoke visible in five of those six spots. There were at least six false positives, resulting in more time required to complete the test track.

Figure 5 represents the GPS track of the infrared scan on Sudbury 92 and hot spots marked, with the blue triangles representing hot spots found with the infrared camera and black triangles representing hotspots found using conventional practice. The perimeter and the patchy burn areas where there was canopy coverage were the targeted areas of the scan. Most hot spots found without the infrared camera were in an open area exposed to wind and sun.

Table 9. Hot spots found on Sudbury 92 (Green highlight represents spots found with infrared camera).

Hot Spot	Time Found	Smoke Visible (Y/N)	Size = or > 30cm X 30cm (Y/N)	Found with infrared camera (Y/N)	Comments
1	5:33	Y	Y	N	
2	5:37	Y	Y	N	
3	5:40	Y	Y	Y	
4	5:45	Y	Y	N	Hard to spot
5	5:46	Little	N	Y	
6	5:48	Y	Y	N	Open canopy
7	5:49	Y	Y	N	Open canopy
8	5:51	Y	Y	Y	Closed canopy
9	5:51	Y	Y	N	Open canopy
10	5:53	Y	N	N	
11	5:56	Y	N	Y	Underbrush
12	6:03	Y	Y	N	
13	6:04	Y	N	N	
14	6:06	Y	N	Y	Base of tree
15	6:35	N	N	Y	
16	6:48	Y	Y	Y	Base of rock
17	6:53	Y	Y	N	Found in log

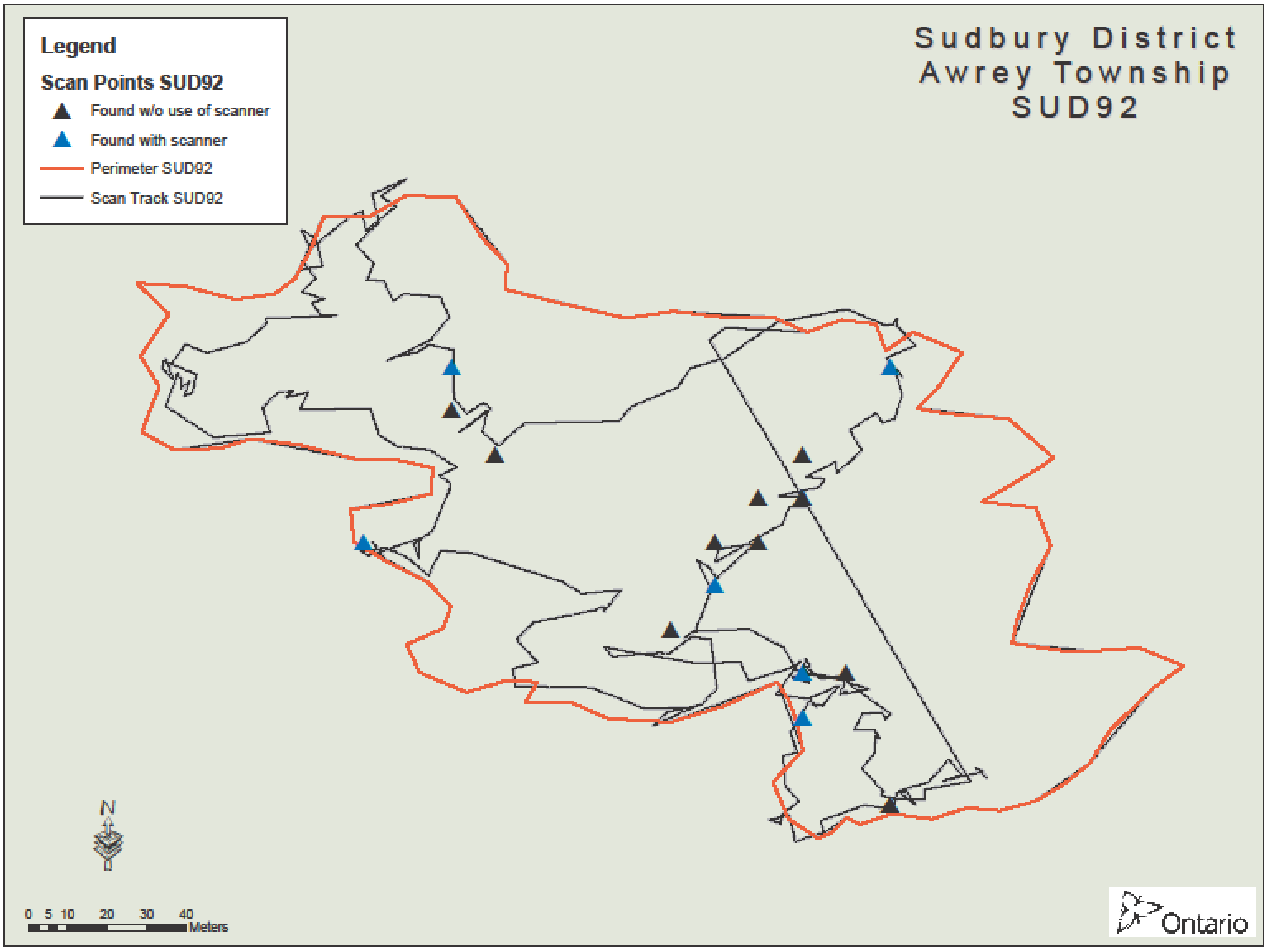

Figure 5. GPS track with marked hot spots during the infrared scan on Sudbury 92.

Questionnaire results

During the study we gathered written feedback using the questionnaire in *Table 1*. We also noted verbal feedback from many others during the tests. *Table 10* is a summary of the questionnaire responses received from infrared camera operators on Sudbury 55 and 92. Prior to this study, none of the participants had received training on infrared devices.

- "I could see how this would be useful… for guards and green areas within fire perimeter…"

Table 10. Summary of questionnaire responses for Sudbury 55 and 92.

11 Year Crew Leader
The Thermal-Eye X-50 was "easy to use but I may need to practice to be systematic and thorough in scanning".
Potential uses : deep burns, under shrubs, hard to reach places, inside burning trees, to double check small IA fires.
Not too many with solar gain due to early morning scan.
I would use it sometimes, but only for specific areas-situational.
8 Year Crew Leader
It was simple to use, contrast was useful.
I would use it if it was accessible.
Potential uses : deep burns, overlaying ground letter, ie. red rot under leaves.
I see the ground crew being cheaper and faster… "it would take a while before I trusted it".
"Every spot we found with the scanner I had smelled something already and smell isn't line of sight".
We had to wait till evening and early morning to reduce solar gain.
"It was an interesting test, but I think a skilled patrol with the entire crew would likely be faster and small fires could just be cold trailed".
5 Year Crew Leader
It was easy to use.
Potential uses : when you are close to calling the fire out…might be useful to narrow in where smoke is when it is smelled.
"Time efficient…can cover large amount of area in a small amount of time".
"No issues with solar gain"…(*Note; at least 6 false positive were observed*).
"I could see people becoming complacent/lazy and just scanning without bending over to cold trail".
5 Year Crew Boss
Easy to use once you learn to discern the difference between hot spots and other areas.
Potential uses: before an area is out as a double check, could compliment cold trailing.
To make scanning effective I would need "proficiency, practice-need some practical training on fires"
Scan was affected by solar gain- "need to choose the direction you face while scanning carefully"
"Useful tool if practical training is given."
3 Year Crew Member
It was easy to use.
I would use it if I had access to it.
"I would use it when smoke isn't visible and hot spots are apparent".
The size of fire it could be used on depends on how it is used/efficiency.
The solar gain during later parts of the scan
2 Year Crew Member
Gave very little insight into using the scanner.

Thermal-Eye X-50 Review

The *Thermal-Eye X-50* (*L3 Communications*) model was the only thermal infrared device tested. This model was chosen for a number of reasons:

- Light weight and small (See *Figure 1*)
- Durable
- Available (Ontario owns four of these including two X100 models)
- Easy to use
- Price (approx. $6000)

Complete product specifications can be found in Appendix B.

The *Thermal-Eye X-50* appears to be one of the more durable infrared devices available. The feedback received in the survey indicated it was easy to use. After receiving questions about its ability to withstand water, we confirmed, through the product specifications, that it is buoyant and submersible up to three meters. Battery life was identified as a concern. Although the manufacturer's specifications indicate two hours of use on two AA batteries our experience was about an hour and a half. When batteries are low the infrared camera operates intermittently until the batteries are replaced.

Discussion

Hotspot characteristics

At both Sudbury 55 and 92, the hotspots found by the infrared camera and those found by the patrollers had distinct characteristics. Those found by the infrared camera frequently were in closed canopy, either under heavy branches or in underbrush. The spots were burning in the duff layer, often creeping with little or no smoke (*Figure 6*.). One could infer that these spots are more definitive in their heat signature and therefore easier to locate due to less solar reflection.

Spots found with conventional patrol practices had one distinctive feature: the smoke exhibited by these spots made them identifiable by smell or sight. They were often in the open areas of the fire (*Figure 7*) and more exposed to wind and direct thermal energy from the sun.

Figure 6. Hot spot found using infrared camera on Sudbury 92.

Figure 7. Hot spot found using conventional patrol practices on Sudbury 55.

In order to establish a stronger relationship between burn characteristics, fuel types, weather conditions, and infrared camera / conventional patrol hotspot detection, it will be necessary to enhance the descriptors section. The expanded set of descriptors should include burn depth, extent of smouldering material, fuel type, and weather conditions.

Optimum conditions for infrared scanning operations

We noted solar saturation to be the primary factor influencing infrared camera effectiveness. Even with the contrast adjustment capability, saturation of the sun's thermal energy prevented us from performing effective infrared work during the day. As a result, infrared scanning in the late evening and early morning is preferred.

Scanning results from this study indicate that the *Thermal-Eye X-50* is most effective in the early morning before the solar energy heats the surface or later in the evening after solar energy has decreased. The weather on the days of infrared scanning was stable with clear sky and temperatures in the mid-20s. Future studies should study the effectiveness of the infrared camera under different cloud cover, temperature, fuel conditions and canopy cover.

There was no precipitation on Sudbury 55 or 92 during the time of the infrared scanning. Alberta SRD has developed a table for low level helicopter infrared scanning which provides guidelines for drying time after a precipitation event. This may be a useful resource for consideration during future studies.

Table 11. Precipitation guidelines for the use infrared scanning (Simser 2008, pg. 3).

Precipitation Rule of Thumb	
0.0-2.9 mm of moisture	Wait 1 good drying day
3.0-4.9 mm of moisture	Wait 2-3 good drying days
5.0-10.0 mm of moisture	Wait 4 + good drying days

Infrared Camera Operator performance

Observations made during this study suggest that infrared camera operators with greater fire experience demonstrated a better awareness of probable hotspot locations which translated to a more productive scanning operation. On Sudbury 55, we observed that experienced firefighters would scan the perimeter, patchy areas, or perceived "problem areas." On Sudbury 92, an inexperienced crew chased hot spots without a general plan for travel path (*Figure 5*). A systematic approach to scanning and patrol operations and an infrared camera operator with strong fire experience are contributors to effective use of the infrared technology.

Fire experience lends to increased knowledge and awareness of probable hotspot locations and experienced firefighters will focus their efforts more productively when patrolling or scanning for hot spots. This experience supplemented by training in infrared camera use and heat signature identification is needed to ensure this device is used to its full potential.

On Sudbury 55 the infrared scan team consisting of two firefighters found a total of 15 hot spots. Ten of the spots were located with the infrared camera and five where located using conventional sensory detection - sight or smell. These results suggest that infrared camera use and conventional patrolling can be complementary practices and combining these practices may increase the overall hotspot location performance of a crew.

Questionnaire responses

The questionnaire responses indicate consensus regarding the camera's ease of use. All of the users thought the infrared camera was easy to use however one senior crew leader pointed out "easy to use – but I may need to practice to be systematic and thorough". Given the Thermal-Eye's ease of use a formal training course is most likely unnecessary. Familiarity with infrared camera equipment and discussion around planning a systematic infrared scan would be useful elements in crew training. Questionnaire responses indicated the firefighters understood that this tool complements their patrolling activities rather than replacing the need for cold trailing.

All of the fire crews completed a comments section describing the hotspots found. Given the low number of hotspots identified and the minimal information provided, we were unable to develop conclusive results from this data.

Future hotspot detection with handheld infrared cameras will generate more discussion, questions and recommendations for best practices for infrared camera use and patrolling.

Cost Benefit Analysis

Conceptually, the value of implementing ground-based infrared camera technology in mop-up operations can be measured by comparing the total cost of different mop-up scenarios compiled from several fire events. Three scenarios were identified:

- Firefighters on the ground using conventional hotspot detection methods (smell / vision).
- Firefighters on the ground using conventional hotspot detection with an infrared camera.
- Helicopter-mounted infrared camera used to detect hotspots and direct firefighters.

Results from these scenarios were to be tabulated by examining comparative data:

- The number of hotspots found using the different hotspot detection methods.
- The time spent on the fire by crews working within each scenario. What will be the time savings benefit for hotspot detection for each method?
- The number of fire person hours saved by an infrared scan by fire compared to the cost of patrol only. The net benefit would represent less mop-up time for the crews and an earlier release date from the fire.

Table 12. Conceptual methodology for analyzing three approaches to wildfire mop-up operations.

	Standard patrol	Standard patrol operation aided by handheld infrared camera	Helicopter IR detecting hotspots and directing firefighters
Time to locate hotspots			
Spots found			
Time to extinguish hotpsots			
Crew size			
Crew cost			
Cost of patrol			
Cost of helicopter			
Cost to full extinguishment			
Opportunity cost of having crew committed			
Potential savings from releasing crew sooner			

To develop best practices and to compare the cost effectiveness of including an infrared camera in patrol operations with standard patrol practices will require a data collection mechanism (*Table* 12) that displays pertinent comparative data and demonstrates cost benefits for one patrol practice.

The limited data collected during the two scans on Sudbury 55 and Sudbury 92 was not sufficient input to this methodology and it was not possible to make solid conclusions or recommendations regarding cost benefits of handheld infrared scanning. Data should be collected from several fires over several days with a large number of hotspots detected in order to develop a reliable cost benefit analysis.

A few productivity and best practices questions that could be explored in future studies include:

- How much fire area or perimeter length can a crew scan/patrol under varying weather conditions, in different fuel types or rugged terrain with each of the scenarios?
- Is there an optimum fire size for handheld scanning? Is there a threshold fire size where handheld scanning would no longer be feasible and helicopter based scanning would be a more viable solution?
- What are the optimum conditions (fuel type, ground layer, canopy cover and weather) for each of the scenarios and what are the best practices to achieve mop-up objectives?

Conclusions

Most Canadian wildfire management agencies have handheld infrared cameras but, generally, do not use these on the ground during mop-up operations. With advancements in infrared camera technology, the cameras have become easier to use, provide good results and should be considered for more extensive use in mop-up operations.

Although this pilot study collected only two sets of data on two fires on separate days, there were some observations made that suggest that handheld infrared cameras are a viable technology for use in mop-up operations:

- The infrared camera is able to detect hot spots that are not detected by firefighters using conventional practices.
- The optimum time for handheld infrared scanning is in the early morning or early evening while conventional patrolling practice is most productive in midafternoon.
- Burn patterns and depth of burn were consistent with expectations for the given duff moisture code and drought code.
- With less than an hour for orientation and practice time, firefighters found the infrared camera easy to use and were able to detect hot spots. Experienced firefighters achieved good scanning results with minimal orientation and practice time.
- This study implemented useful methodologies on two fires documenting a comparison of patrol with infrared camera and patrol without infrared. During two separate scanning operations, a total of 32 hotspots were identified with 16 of these (50%) being found by the infrared camera.
- Working closely with the fire crews proved to be an effective way to assess the users' ease of operation and receive immediate feedback from the crews.

These observations and the documented results provide good opportunities to draw practical conclusions supporting the use of handheld cameras in wildfire mop-up operations.

Conventional patrolling and infrared scanning should be implemented as complementary practices rather than exclusive hotspot detection operations. Observations from infrared camera operators in this study provided support for this conclusion. Using the two hotspot detection methods under the respective optimum conditions will decrease the effective patrolling/scanning time and may increase production rates in mop-up operations.

On Sudbury 55 a small area of the fire was covered by both the infrared scanning crew and the patrolling crew with different hotspot detection results for each. Future research should involve both the infrared scanning crew and the patrol crew covering the same track, using a GPS to record the location of the hotspot and then comparing detection results from each hotspot detection method.

The study identified optimum infrared scanning times and limitations resulting from solar saturation during daytime heating. Overnighting and extended attack on fires is common practice for initial attack crews in Ontario. With crews camping close to the fireline, there is good opportunity to use the handheld infrared camera for extended periods under optimum conditions.

Assessing the impact of cooler or cloudy conditions on scanning operations will be important in determining best scanning practices.

FWI values are good indicators of the probability of sustained burning and extent of burn depth. The two fires under study had a high DMC and a moderate DC with smouldering burning limited to the upper duff layer. The handheld infrared camera should be tested under extreme drought conditions with deeper burn depth to evaluate its effectiveness with a varied fuel environment.

Even though a small data set was produced in this study and more investigation is needed to confirm these observations it appears that equipping a fire crew with an infrared camera during mop-up and patrol operations can result in fire crews locating more hotspots faster, therefore putting the fire out sooner and the fire crew being ready for redeployment to a new fire.

Experienced firefighters are able to learn basic operation of the handheld infrared camera in minimal time and combine this technology with systematic patrol practices and achieve good results. With best practices for patrolling and infrared camera operations guidelines, the camera should be easily deployable on fires on an 'as needed basis'.

Comparative methodologies developed for this study can be adapted for use in a cost benefit analysis of different mop-up operations under study. With a larger data set acquired from several fires, stronger cost benefit analysis and recommendations can be developed.

Direct observation of infrared scanning operations and patrol practices is critical in maintaining prescribed methodologies and control variables in the studies and achieving representative results. Observations of current patrol and scanning operations will help to evolve current mop-up practices to standardized best practices for handheld infrared camera and patrol operations.

Recommendations

Based on the results of this study please consider these recommendations:

- Good infrared scanning results and data produced from the comparative methodology warrant further ground based infrared camera study. This methodology can be applied to a cost benefit analysis to compare different mop-up and patrol practices and the time and cost savings associated with each practice.
- In order to compile sufficient data for a cost benefit analysis, more studies will need to be conducted on mop-up operations. To achieve reliable results, it is recommended that patrol operations and infrared scanning operations be studied on a minimum of 3 and max of 10 fires depending on the extent of operations and nature of the burns.
- Working closely with a committed representative from one or more of the wildfire management agencies will be critical to successful planning and completion of further studies. These personnel will be integral in preseason planning, organizing logistics, implementing studies and developing best practices for infrared scanning and patrol operations.
- Training is essential to effective use of the handheld camera and producing good hotspot detection results. Evaluating training requirements and developing training materials for best practices could be a focus in future research. Training materials should include a user's guide attached to the infrared camera carrying case for 'just in time' training and for pre-season crew refresher training.

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Appendices

Appendix A - Best practices for Infrared Scanning based on literature and discussions

Author(s), Date	Factors and Recommendations Presented
Johnson, n.d.	Study was incomplete, conclusions or recommendations.
Wilde et al., 2004 (pg. 3)	• Further testing/research will be conducted to determine if the temperature setting can be adjusted for potential daytime use. • A training package will be developed for users regarding this technology. (theory, limitations and expectations). • The Protection program will continue to source other models for possible evaluation.
Stateham, 1973	• Between 09:00-18:00, there were significant solar effects. • Between 21:30-midnight, solar effects dissipated, and clear thermal images were observed.
Zajkowski, et.al, 2004	• A guide was developed to assist Incident Commanders in making the right choice of infrared device for specific conditions in order to save time, energy, and money. • Four elements of IR sensing were established: 1) the source (fire); 2) attenuation-interference with the radiation of thermal energy; 3) the sensor detector (handheld, airborne, or space-borne); 4) the remote sensing analyst and/or image interpreter. • See infrared imitations in Agency Review section.

Appendix B - Thermal-Eye X-50 Product Specifications

(Retrieved June 22, 2010 from http://www.morovision.com/thermal_imagers/X50.htm)

Thermal-Eye X-50 Product Specifications		
Focal Plane Array	Type & Material Pixel Count (Resolution) Spectral Response Thermal Sensitivity	Amorphous Silicon Microbolometer 100 X 80 Less or equal to 150 mK
Thermal Imaging Performance	Start-up Time Detection Range for Human Activity Contrast/Brightness Susceptibility to Blinding Visible Light Infrared Polarity	5 seconds Up to 305 meters Fully Automatic None White = Hot, Black = Cold
Optics	Lens Focal Length Field of View Minimum Focus Distance	16mm 11” x 8” 1 meter
Video	Output Format Viewfinder display View Dimming	Analog Monoshrome LCD (320 X 240 pix.) Integral to power on/off switch
Power	Power Source Operating Time Auxiliary Power	Two AA batteries 2 hours with alkaline, 5 with lithium 9 to 12 VDC input on rear outlet
Environmental Characteristics	Operating Temperature Storage Temperature Water & Shock Resistance IP Rating EMC Compliance	-10 to 50 Celsius -20 to 80 Celsius Waterproof to 3 meters submersion, buoyant in fresh water, & shock proof to 2 meters IP-6x FCC Part 15 & CE Mark
Physical Characteristics	Size Weight Eye Cup Mounting	13.4 X 11.4 X 5.1 cm 381g including batteries Integral to camera body with 2” eye relief ¼-20 Tripod Mount