

Supplementary Material

A case-study of wildland fire management knowledge exchange: the barriers and facilitators in the development and integration of the Canadian Forest Fire Danger Rating System in Ontario, Canada

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Appendix: Supplemental Material

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Part A: Perspectives and supporting quotes for barriers and facilitators

The following summarize the Barriers and Facilitators (BF) elicited through semi-structured interviews. We recognize that there are dynamic interactions between BF that are highly context dependent (Nutley *et al.* 2007). While we consider these interactions in the determination of perspectives, we assigned the supporting quotes in the tables below to the most representative BFs instead of duplicating quotes where there are obvious interactions. It is also important to note these are select quotes and not an inclusive list. Quotes should not be applied outside of the context of this case study.

This section is important to provide the perspective and interpretation accounting for both the attributable quotes and consideration of interactions. These perspectives can be useful to consider knowledge exchange strategies but also to record historical context for an important period in development and implementation of the Canadian Forest Fire Danger Rating System (CFFDRS) in Ontario, Canada.

A1: Communication theme

Multi-way communication within the research group: It is important researchers understand one another and are comfortable discussing limitations and gaps in their own work to lead to deeper mutual understandings. Willingness to take a risk and discuss what you know, and what you don't know is important.

'You're constantly talking to each other and talking about priorities and things like that and arguing about things... You're active in that area [and so] you don't hesitate to have an idea or have a question and call each other and talk about it. So, you're

kind of working together on those things already and, ...things evolve when you do that, when you share that with each other...’

Researcher visibility and accessibility to practitioners: Fire management practitioners have a culture that places a high value on the shared “on the fire” experiences as the ticket to credibility. Researchers being involved and visible in the field operations helps with establishing that credibility through face-to-face communication and shared experience.

‘Particularly in places like Timmins and Chapleau and Sioux Lookout, where [there were opportunities] for that kind of collaborative work, we would try to get out and talk to folks about what was going to happen [and] what kind of help we needed... The researchers themselves ... were very visible - anybody above the crew leader level in Ontario knew [the researchers] because they had made their way through their district.’

‘These were all [researchers that fire operations personnel] knew and they've been on fires with them or they've been on prescribed burns with them and [socialize] with them and stuff like that so [the researchers] they weren't, [impractical and just] tucked away somewhere that [fire operations personnel] never saw; ... they'd be out there to and doing measurements and watching stuff and I think that helped a lot.’

Informal inter-agency (two-way) communication: The ability for researchers and practitioners to quickly access each other through informal and personal mechanisms was critical for that discourse needed to understand each other. These communications led to better research outcomes and buy-in overall. This also led to fire management practitioners buying into the implementation of research outcomes into ones’ set of “trusted tools”.

‘You need to have involved the people that you hope to use [the research outcomes] in the end involved early on. And you need to give them some kind of information along the way. ... You need to use some tool that brings the practitioners and the researchers together. Just so the people in the field don't think that everything's going on in a void and they're just going to get this thing dumped on their lap someday ... because that means it's not it's probably not going to work.’

‘Because [researchers] knew me personally ... we would toss around ideas or thoughts... It was very informal, and I thought very healthy ... because we had a lot of good discussion [and] I thought it helped me, but it also provided some thinking criteria for [researchers] to say [we] are steering this thing, where are we going with it.’

‘We had a lot of dialogue and back and forth [between agencies]. [CFS researchers] would be in our office all the time or [vice versa]. So, at that level ... we had a collective understanding of what each side was doing, and everybody understood ... the limitations.’

‘You want to build those relationships for sure. I think, lots of time, sitting at dinner you come up with an idea ... You talk about it a bit and, the next day, you're working on it and that's a way to get this message across.’

Formal inter-agency meetings: Regular formal communications were important as a baseline of structure. This happened at a broad interagency (and national) fire community level, at senior management levels, through to the local researcher and fire management practitioner levels. These types of meetings supported and encouraged the necessary informal communications by linking

upward to the organizational support. At a higher-level these helped with those broad mandate priorities and executive alignment.

‘At least annually, we would go to the ... CIFFC [Canadian Interagency Forest Fire Centre] directors meetings, where we had an audience of fire directors from across the country and talk about what was going on, and some of the research that was going on ...’

‘We did have more feedback and more regular meetings with people...we had those kinds of meetings on a regular basis. ... That was an opportunity to get everybody - the fire director, the region or the provincial director and a couple of other people from each province - to get together to talk about what their research priorities were.’

Communication products – suitable information, fit operational needs: Researchers delivered products to the fire management agency incrementally which built familiarity with both the researchers and the products. The products described the methods appropriately for the audience. Researchers invested considerable time engaging in discussions about research, the products, and their possible application in specific decision-making scenarios. There was mutual feedback to clarify questions during the development process. Simple products, like paper charts and tables, where practitioners could work through the Fire Weather Index (FWI) and Fire Behaviour Prediction (FBP) Systems inputs by hand were very successful. By working through these Systems by hand, practitioners would relate these to their own working experience and what they observed in the real-world. This led to the Systems being easier to understand and improved considerations how to operationalize them.

‘[About the interim FBP report/presentation,] the agencies could see the rates of spread they could see the basic stuff that didn't change in the final publication. And I think that was a really good idea, because it delivered a milestone, ... and then over the next five years they had a lot more wrapping up and analysis to deliver, and that was the final publication.’

‘By... chasing [researchers] around and bothering them something fierce about some of these things we got some help in terms of understanding the application of the codes and indices, and what they actually meant. And they were good enough to come and sit with us and talk about these things when they had time and I wouldn't call them training sessions, but that's what they turned out to be and so kind of an explanation... So it was, from that point of view, quite helpful.’

‘People wanted the Red Book when it came because they were struggling with [understanding FBP], they couldn't see the relationships and understand them. ... With the Red Book they'd sit around and look at it and understand the relationships better.’

‘I used [the Red Book]. When I was going to do fire behavior on special fires, I always had that in my pocket. I had that in my pocket before I had my computer packed.’

Messenger with effective communication skills: Interpersonal communication skills are important. Although you may be able to replicate the communication structure, the soft skills of those who hold those who are knowledge brokers are critical to ensuring success. They were

intermediaries and held a good understanding of both research and practitioner domains, but also had the skills to inspire, lead and encourage collaboration in KE.

‘[A specific researcher] had a lot of skills that maybe he was gifted - I don't know, but he could talk the talk at the level that was required.’

‘I don't think that everybody can do it. [Those leading the knowledge exchange] need to deliver it using language that colleagues [can understand]. If you get too conceptual or use too many technological terms, you're going to lose people. ... It has to be somebody who will put the information on the level of the people who are going to use it so that they can understand the principles.’

‘You really have to be a facilitator, and actually just as I say that, I can remember some of the early discussions around the fire intelligence role as being some of that: Being able to take the research piece or the more scientific piece and operationalize it or help communicate it in such a way that it works operationally.’

A2: Capacity theme

Financial capacity: Direct funding and in-kind contributions were necessary to support the research and associated activities; particularly the extensive field-based campaigns that provided the foundational data for the FBP System. Researchers had access to different funding mechanisms. The need to rely on alternative funding sources for researchers can steer research focus away from fire management needs, which some noted as occurring in later years. Fire management agencies have finite funds to cover many operational activities, and research and development may be seen as a risky investment without clear demonstration of cost and benefit.

Strong and continued executive support for funding was critical to the success of the FWI and FBP Systems.

‘So essentially all of the costs associated with ... an experimental ... fire ... would come back to the [provincial research and development] program in [Sault Ste. Marie] because the Feds didn't have any money. They had smart people, but they had no money...’

‘We were given a lot of money to do stuff compared to in more recent times. ... It seemed that back in the early days of the Ministry for me, if somebody was sold on it like a Fire Management Supervisor it was done. ... We had a lot more leeway in terms of getting things done because [of few administrative barriers] ..., at least [in how we were] spending this type of money.’

Capacity through organizational commitment: Higher-level management buy-in to invest money and people in the initiatives was very important. Despite the uncertainty associated with how very long-term research programs may turn out (i.e., the FBP System development), the higher level management understood the potential value of the research for fire management operations and maintained its investment in organizational capacity to see the result into use.

‘So there was a lot of support at the top and, in a way, we were just fortunate that we had progressive people in some higher positions ... we had progressive folks at the district fire level, there were progressive folks at the regional level that were willing to stick their neck out a little bit.’

Coordination and training capacity: Training did not just happen in the classroom or at designated times. Highly functioning communities of practice evolved with deep-rooted personal

commitment in sharing and enhancing their collective skills and knowledge. Listening to the advice of the fire management practitioner experts and involving them in training development was important. Ultimately the real majority of the 'learning' about how to use the FWI and FBP systems in early days, took place during the day-to-day conversations where mentorship happened.

'We developed that cadre of sort of fire behavior specialists, or officers out in the field. They became their own entity, where they did a lot of information sharing and tech transfer. ... [Training] took on a life of its own and they pushed it to the next level.'

'Having the research coordination role and the technology transfer role were critically important because there are not enough research people to go around in terms of trying to roll stuff out. ... When the FBP System first got translated onto the little handheld computers much of that was driven from within the program and not just [our] group, [also the] fire operations people. We could be more tuned in with what's going on in the program and we could provide the liaison to the research folks rather than them having to try to give a fire behavior prediction course or give briefings to 26 fire headquarters.'

'As I learned about the indices..., I found that, while they were useful to me, they were useless to my crew. ... I would sit with my crews and talk about the indices. And that led to, over the course of the year, is my crew would have to talk about the indices on their own, once I gave them to them, and share them back with me in a group. So, what we did is, collaboratively I was building a team that understood indices.'

‘I think it's often missing for new people coming online [more recently] that you sort of put under the wing of maybe a senior researcher, but you're not getting the exposure that I had in terms of developing my career.’

Social capacity through empowered champions: The ability for certain people to inspire, encourage, communicate, and bridge groups to mutual understanding was important. Learning from someone trusted encouraged working with them and had lasting impact. Not all scientists understood how to collaborate or communicate in an applied setting (nor were they expected to). Champions exist on both sides of the researcher - practitioner spectrum and in many cases both sides were working together for lasting impact.

‘We had certain people on the research side of it who were better at going into the field and talking to [fire management personnel] than others... We had some people who were really good researchers, but who really did not have any, any social skills ... These people could be really good researchers, but not necessarily really good at the interpersonal or the collaborative side of it ...’

‘Within our program there were some people who were pretty dedicated to trying to roll [the FWI and FBP Systems] out. They thought it was important to people and ... they pushed it. [I think it is important to] try and develop some real key champions within the field; people that will work hard all the time ... to show other people and won't give up. I think that's pretty key.’

‘The champion ... embedded in the organization is critical. ... They have to have certain skills for sure, but they have to be the champion for whatever it is that you want to be implemented; I think that role cannot be underestimated.’

Human resource capacity, personnel, expertise, experience: Maintaining those human resources and their long-term, iterative engagement was imperative. Not all research products will be developed at the “right time” for there to be a priority to implement them. Continued engagement, however, allowed products to be implemented when the time was right, but also focus research on emergent needs from a fire management agency. Personnel need the knowledge, experience and soft skills to successfully champion projects and support successful KE.

‘[A champion of the FWI/FBP systems] was smart enough and had the skill level to [participate effectively in knowledge exchange]. That's what you need from any of the people on research side and, on the user side, you need people who aren't afraid to actually say, “well, I don't quite understand that, can we get into that more?”’

‘There was a commitment by at least Ontario's program ... to put some money and effort into making it work. And so that created jobs for people like me to run around and try to make some of these things happen, and there was no blinking from the people above; they were on board, they wanted it.’

‘I often wonder how lucky we were to have [a number of researchers] all in the prime of their career at the same time. ... [And] they all had different skill sets. [Some researchers] were very, very good with the agencies and able to talk whatever level of talk was needed. They had a firm grasp on what the goal was and what they had delivered on.’

A3: Collaboration theme

Researchers and practitioners work together in the field: The field work that took place between Canadian Forest Service (CFS) researchers and fire management staff during the development of the FWI and FBP Systems was a good example of a collaboration where both parties felt like they belonged and were valued as part of the research and development process.

‘The Ontario program had a really close connection with the research community, with researchers in Ontario ... and those were people that weren't just sitting in Toronto, or Sault Ste. Marie, that we never saw - they did come out. They came out and did projects in the field, they worked with field staff, they came and sat in the Fire Centre for, you know, a week and observed what we were doing, and so there was a relationship there as well that, I think, we both learned from.’

‘[CFS researchers] weren't just in our office; I think they got around and ... back to those days, there was lots of field fire behavior research being done, either with the prescribed burn program or with wildfires. ... [Researchers] all worked for the feds, but they were all [seen as] part of the [Ministry Fire] program because they were around so much.’

Practitioners directly involved in developing the science: Collaborating led to situations where the operational priorities drove research directions and provided for teaching and learning opportunities as many operational staff participated in the data collection initiatives. Collaboration engenders a lot of ongoing engagement and support; this contrasts with the paradigm of research as “provider” and operations as a “client”. Putting in the time to build relationships, establish capital in trust, and relevance with the people in collaboration with was viewed as important by participants.

‘The district fire personnel and the fire crews were helping with the ignition and the control [and]... for the folks at the district level, they were exposed to some great opportunities to learn about fire behavior and all that good stuff and they took the opportunity to learn.’

‘This was one of [our] efforts to marry scientists with managers. ... We flew down to different locations and talked to the fire managers to see what their problems were. ... Folks were saying, ‘well, blowdown is one of our major issues and it's an emergent issue for the West Fire Region.’ The upshot from that was [to] establish a small team [to] get a quick and dirty solution. ... Let's bring a scientist and a practitioner and a group of people together to solve a problem [using a] semi scientifically rigorous method that meets the needs. So that's an example of really marrying the two groups together to solve a problem.’

‘That led to talking with [Ministry] people and ... trying to establish priorities. Working with [Ministry people] to see if there were commonalities in terms of what they thought the priorities should be. That's what eventually led us into the experimental burning program and a lot of it was just sitting around talking with people about what their priorities were.’

‘I know after those first couple years ... I didn't have any problems [finding support]. If I had to find research plots, needed crews, needed aircraft, it was right there because people knew me.’

Including all the necessary people in development: Buy-in from all involved was important to achieve successful outcomes. This required well-thought-out collaborative opportunities and the

establishment of genuine partnerships. This included researchers, management, and operations staff, among others. Such partnerships often emerged organically when working on a project. Creating a genuine collaborative partnership early on primed the pump for KE and implementation processes.

‘When you're trying to develop an experimental program to deal with something, you need the okay from your bosses and they're probably the persons to actually lead it ... But we still need the [fire operations personnel] because it's important for anybody involved in an experiment to understand the importance of it. ... It provides better cooperation, close to and during the burn ... they're behind you.’

‘If you're going to put on courses ... [it is important] that you get a diversity of people. And don't stop at just provincial people, there are people in other provinces ... that can probably help us out... I used to chat back and forth [with out of province contacts] ... and those kinds of lean-ons, we helped each other in our training and knowledge.’

‘Use the [end] users to help you promote your product. You can't just say, ‘Here's a nice thing we developed for you; aren't you glad?’ [End users] need to be [asked], ‘Hey, do you need this product, and do you want to help us develop it and test it and do all that kind of stuff?’ And then you've got that buy-in from the organization to say, ‘yeah, this is something we've agreed to, you know, right from the director, maybe the [senior executive management] right on down...’

‘The experimental [burning] program that we were conducting, it needed everybody's hand in it. We couldn't just pick a few people. We wanted everybody

to understand, basically, what was happening and how they were contributing to furthering the science in fire.’

Research agency support to build collaborative relationships: Ontario-focused work was being completed by CFS researchers because of the support to engage and collaborate. Researchers were not constrained in their ability to network with fire management staff (by either organization) which allowed them to build relationships and develop research questions together that directly addressed the needs of fire management.

‘At that time, our Centre was a provincial Centre concentrating our efforts on Ontario. I was given free rein to travel and talk to many individuals (locally, regionally, and provincially) that worked for the [Ministry] across the province in both fire and forest management. This led to lengthy discussions and on-site visits re: fire in forest management. This helped me on focusing on research needs at that time. The miles I put in to do this (up to 30,000 miles per summer) and associated expenses was worthwhile in building my personal experience and, maybe more importantly, allowed me to develop strong relationships with [Ministry] staff.’

‘Getting out and getting known and trusted was a really big advantage for me as it helped with trust that led to better collaboration, readiness to [participate] in projects, and, overall, better communication with all concerned. This collaboration also meant that I was often extended invitations to talk on fire and forest management during regional and provincial [Ministry] meetings, courses, and reviews, allowing for frequent exchanges on what I had found from my own research and what [the Ministry] felt they needed.’

Co-learning: On-site, in the field collaboration led to co-learning. The collaborative approach to “train-the-trainer” was also important as this does not always happen by design (i.e., formal classroom training) but was enhanced and made more effective by shared circumstances.

‘I learned how to do fuel plots with CFS staff. They taught us how to lay out a triangle and use go-no go gauges to measure forest fuels pre prescribed burn time. Subsequent to that, after the burn was completed, they came back and we went through the process again. It provided us and them with data measuring how much fuel in metric weight was consumed by the burn. Learned lots.’

‘A first step in any tech transfer is train the trainer. So, the researchers are the one champion and, I guess, initially it has to come from the developers because it hasn't been introduced yet. [But the researcher] has to choose his potential champions and train them. Then it flourishes from there.’

A4: Readiness for innovation theme

Organization ready for new tools/products to help conduct business: In the case of the FWI and FBP Systems, there was an identifiable gap recognized by fire management practitioners in what was available for fire danger and behaviour. The development of new products for this gap was critical given the high-risk environment where practitioners are motivated to use all information available to keep people safe. When the gap is less recognized at the operational level, or there was something that could somewhat do the job, (even if not well), that new innovation might be perceived as less important leading to greatly slowed (if any) uptake.

‘At least in Ontario, in my experience, and most of fire management across Canada, there's been a lot of time for people to get together with the science and research

community and work together on trying to sort these things. So, it's been an eager audience for the most part...'

'[Agencies] had a desire for this information, there was a gap that was being filled.'

'I think that there had been a hunger...within the agencies to better understand fire behavior... it [the FBP System] was very easily understood, and people could grasp it easily. And it meshed in with how they did things ... there was a demand for understanding fire behavior, so it worked well.'

Championing innovation: Supporting and clearly articulating the need for and added benefits of innovation to the fire management organization was important. This was especially the case with incremental improvement vs. a breakthrough innovation. From an operational perspective, a “need” was not always evident, and, when there is something perceived as good enough there are always other things competing for priority.

'at least in my experience... it's a matter of convincing [the] organization and people in it, that change is necessary and here's why.'

'You really have to have credible people and they have to get out and communicate and they have to talk to everybody basically and they also have to develop their own champions in the system.'

Support from organizational leadership: Support from senior managers to undertake long term, continued collaborative research engagement and to empower those who innovate, helps address many barriers. Top down support can strengthen readiness for innovation within the fire program.

‘We were fortunate that we had senior people in the program at the branch level..., you know, the directors we had were generally supportive of getting this kind of work done; they were supportive of these collaborative research efforts... and some of that was feasible because we had support from senior people at the branch level, and there were progressive managers, senior managers out in the region.’

‘There was a message that kind of came down from fairly senior reaches of the program that the Ontario fire program was in the business of supporting this type of innovative work. We're in the business of supporting science and technology improvement. And, within reason, ... we will work with research partners because we see a payoff. When we look at the tools we have now, they're in place because our predecessors did this kind of work, and there was a commitment to keep doing it.’

Step by step process or consecutive building of knowledge: Gradual innovation and building on a familiar methodology allowed people to understand and apply new products. The step by step process in the development, and in how the FWI and FBP Systems work supported this understanding. In these Systems the building blocks of knowledge could be logically understood and corresponded to what fire management practitioners saw playing out in the real-world. The gradual innovation meant organizations could develop an early understanding and interest in new products being developed which then served as a foundation for future innovation.

‘There was a staged implementation of a simple methodology that grew into a more complex methodology and people could see the progression. In the first implementation, the rough rates of spread, people said, ‘oh, they can figure out rates of spread,’ and then that evolved into a very simple system and they said, ‘okay,

this makes sense, we can apply it in a broader range.’ People can apply it... it just makes sense how it all falls together; it's very logical. ... If you just come out with the final system ... I think it would have been a lot less successful. People would have been very intimidated by it and just set it aside and said, ‘later, maybe.’ But the staged implementation, I think facilitated its overall acceptance.’

‘I think that [the FBP system] rollout there was instrumental again in its success because [agencies] had the previous tastes of the fire behaviour prediction system, and they had the interim system for several years. They were looking forward to seeing what [researchers were] going to do next.’

‘The rollout was instrumental in its success because [fire management practitioners] had the previous tastes of the fire behaviour prediction system; they had the interim system for several years and they were looking forward to seeing how it was going to get better ... I think if we, [researchers], had gone horribly wrong or we would have heard about it at that point. ... But I think we had things figured out well enough that it was a logical progression and not stepping too far. That workshop again stepped forward in a logical pattern from the interim session... it was a next steppingstone and having it predate the published version allowed us to just tweak stuff in the final form.’

A5: Trust theme

The importance of trust within fire management organizations: In high-stakes decision-making and working environment, where a lot of information must be processed quickly, there is little room for misunderstandings, especially from those in influential roles.

‘If you have individuals dealing with very stressful, risky operations you get a dynamic where..., trust is involved.’

‘One of the things that I was always concerned as a Duty Officer was having my Intelligence Officer, the planning section, somebody that looked at the information in detail, so that when I saw it, I knew that a lot of other things had been considered.

It’s about trust.’

Trust in researchers: Researchers tended to be trusted more when they had been out in the field with practitioners. It was felt they could more clearly understand the operational challenges that agencies are dealing with. In the case of the FWI and FBP Systems, having practitioners inform and participate in research helped build mutual trust. When that trust was built, there was far more buy-in when it came to participating and implementing the research products.

‘[Researchers] need to have currency in the agencies, however you do it, it doesn't really matter, but you need to have currency. And I mean they’ve got to trust you.’

‘Trust is an important thing you know if [certain researchers I trust are] doing the research ... I’m going to believe that stuff, no matter what comes up.’

‘[As a researcher] getting out and getting known and trusted was a really big advantage for me, as it helped with trust that led to better collaboration, readiness to assess in projects, and, overall, better communication with all concerned.’

‘What we built with people and what they built with us was sort of a common sense of trust ... from a research standpoint that was an important element. You know that you couldn't just set it up between regions, or between governments and have it necessarily work. I think you needed the interpersonal side.’

‘Get out there and talk to people and get different angles as I did, you know, from the fire people, from the forestry people, I mean, even Parks gets into it now ... From my experience, how it grew that trust between all of us and the eagerness for the ministry to help, it was really, really appreciated. I could not have done a lot of stuff without the help of a lot of good ministry people at that time.’

‘And part of that was because, again, the [researchers] were visible, they were credible and they weren't you know some remote ivory tower. ... They were out there, in jeans and bug jackets and charcoal covered boots, very visible with particularly the field people in the program.’

Broader fire management agency trust in the work: Agency personnel drew a linkage between their personal trust and that of their organization’s trust in research products and their own direct involvement in the research over a long period of time.

‘[Some researchers] were heavily trusted by the Agency ... there was a lot of trust from the agencies at that time, even when we were doing things that didn't pay dividends.’

‘The key for me is that I’ve got to trust that [researcher/research product], and not just me making a decision, whatever I decide to do. Other people have to be able to trust that person[/product]... [whether] you’re an initial attack fire boss, you're a crew member... they have that trust built all the way along.’

Trust in products developed to support fire management operations: The quick pace and high stakes of the fire program meant that there had to be trust in the data and tools being used to support decision-making. Products required building credibility through various avenues such as

demonstrations with case studies. Of upmost importance is demonstrating that the science could be applied and that it “worked” in the real-world (i.e., that it is demonstrably useful in helping inform their decision-making). Collaboration with practitioners on the development of tools/products was needed to ensure the outcomes (and their validation) are grounded in actual needs.

‘Nobody could figure out where the fire was. So I said, ‘where did you last see it and when you did see at the time before? How fast was it moving?’ I quickly looked at the tables of the diurnal effect on ISI in the air mass and did a quick calculation of hours and said, ‘Well in the morning it's going to be here’ and I put an ‘X’ on the map. And the [fire] manager looked at me like I had arrived from Mars... in the morning when they went out to look it was about eight feet from the ‘X’ and it had run a couple of kilometers. ... The issue is [the FBP system] worked and that [fire manager] came to me later and said, ‘you know, I suddenly believe the Canadian Forest Fire Danger Rating System (CFFDRS). The fire prediction behavior prediction stuff works.’

‘Members of the team always wanted to be able to take a piece of paper and work it out by hand to figure it out, so there had to be a, a process that you could actually hand-bomb the methodology through back in those days, so that, that lent a credibility to the process, so there would have been something from [that model] how to do this by hand.’

‘The key in a large organization like Ontario was the more you took these things out of people's hands the less people trust it.’

‘And we struggled, many the Duty Officers, it took them time to build that trust in the system to say ‘Okay, I understand it now and it's not just a black box it's what I'm putting into it matters’ so they, and sometimes you had to, I remember cases where we ran it four different times on one day just to have the duty officer understand what the value were, were going in and what the results were coming back out so.’

A6: Clear objective and alignment theme

Collaborative development of objectives: Priorities were developed iteratively and jointly among researchers and practitioners. This led to support on both sides for reaching common goals. The goals were considered more as evolving needs as opposed to a list of static priorities to choose from. There are long-term objectives but also more immediate objectives in response to an urgent or pressing needs.

‘You're not necessarily ... [collaborating] because your Minister has an MOU [Memorandum of Understanding] with the Ministry of Forestry in Ottawa, you're doing it because ... you agree on what the priorities are and you find a way to work together ... I can't emphasize that enough.’

‘A lot of our work was really based on interpersonal relationships with people. It wasn't just going out and saying, ‘we think you really need to do this, this should be a priority,’ or whatever; it was ... coming to that conclusion from talking to a bunch of other people who were like minded and developing a sense of collaboration. ... We were kind of all in this together.’

Aligned objectives: In the case of the FBP System, there was clear alignment of needs identified by both researchers and practitioners to be able to better predict fire in different fuels. For researchers it was important to understand the practical need that drove the research, and, for practitioners, it was to understand and use knowledge of fire behaviour.

‘At the time, we were very much aligned... Collectively, we were trying to develop a better understanding and better predictive tools for fire behavior in specific fuel types, in specific fuel complexes, because at the time ... all we had was the Fire Weather Index System and that was pretty generalized in terms of fire behaviour. ... CFS was looking at fire behavior predictions, fire occurrence prediction, and the idea of building a holistic system - driven by weather, driven by fuels, etc. – that would take what we knew about fuel complexes and out the other end would give practitioners better predictive tools for both the current fire and how the fire is going to behave once it gets going.’

Research products were developed with the clear objective of being appropriate to the end user: Researchers had success when the operational needs were understood and when there was desire to develop research products that were valuable to the end users. Having different options for research products was critical for uptake (i.e., hard copy tables and separate computer software). For example, researchers did not set out to make the set of simple look up tables that became the “Red Book”, however going through the KE process, realized that is what agencies needed. Recognizing the end user needs as an objective at the onset was critical.

‘People wanted the Red Book when it came because... they couldn't see the relationships and understand them as well with the computer; they put a number in and then they got a number out. ... If [those working in fire management] couldn't

see [the relationship between the inputs and the outputs], they put the computer away and didn't look at it again. With the Red Book, they'd sit around and look at it and understand better the relationships of what was happening.'

'I think ... [the Red Book is] pivotal and anybody can understand that, anybody who's got a fire background in FWI, FBP they can they can find their way through a book, but you can get hung up on a computer program.'

'The one thing that we noticed was that a lot of [research] was written for scientific use, not for operational use. It was important to go through that information and make it readable and usable for the Ministry.'

Objectives include a pathway to successful implementation: The KE process needed to be at the foundation of the research plan for uptake of that research. This necessitates researcher commitment, management support, and an understanding of the many parts of an organization and people who represent it. In this context, specific consideration of the design of a training program could achieve a pathway to successful implementation. Activities where there was a conscious objective to work with the intended end user was often viewed as an important factor, particularly at the onset of this applied research.

'As an end user, it's important you're not just getting the numbers on the piece of paper, but you understand where those [numbers] came from, whether it's through the science people at meetings talking to fire staff, or training courses, or ... facilitators sharing that. But that it's not just research and product, but that there's some kind of connection between where there's people overlapping and operationalizing the information. I think it's important.'

‘Part of my interaction with the research group was to make [training and implementation] happen. ... So there would be a fair bit of interaction [with the researchers] back then, just with a phone call or have someone come over to give us some guidance in doing those things.’

‘When you're introducing anything, it always pays to have an example or a demonstration of how it works ... [The researchers] would come down to the district and introduce us to this sort of stuff so we had the heavy hitters, the heavy artillery, doing it and they'd be able to say, ‘Remember that fire? ... Well the [FBP] system said it was going to do that and we had an intimate knowledge of that [fire]’ and everybody went, “yeah, we knew it could and ... should have jumped on it quicker.’

‘We didn't just roll the tables out and say, ‘okay, they're yours to deal with now.’ We were trying to also work on gathering data, thinking of the FWI, gathering weather information from stations and stuff like that and working on building a database to calibrate. We would hold training sessions with regional and district people. ... Even when we were developing the FBP system and, by then, we were starting to get the Hinton training course, and all this kind of stuff going.’

A7: Timing theme

Implementation of a new ideas and tools take time: Widespread and sustained change took time, even with great interest to move quickly. Acceptance of such change can occur more rapidly when the innovation can be directly and very clearly seen to help address a pre-existing need of the end-user.

‘Everybody's always looking for the shortcut, [but] it is just a matter of time and education... People are a lot more comfortable with things (FWI, FBP) than we were back when we started and the biggest gains or the best thing that happened from implementation was just time - as people get more comfortable with it. You could try to make it happen faster or make it smoother, but it still takes time to implement.’

‘If you ever look at an organization, I’ve always maintained that you get 2% of crazy people down there, we call them innovators, they'll try anything. And that's the only reason the system works is that you have innovators... The next half are early adapters and they'll see what these 2% are doing and, if they see something like, they grab it and run with it. Come on the other side, now... they wouldn't change [anything] if they didn't have to.’

Timing aligns with people, process and opportunity: In the case of the FBP System development and implementation, a number of factors aligned. There was fire management agency support and CFS researchers were encouraged to work on Ontario-specific research questions. There was funding available to support the needed work and there was a capable and credible group of local researchers committed to working on the program who brought pre-existing, well-established relationships with the fire management agency personnel who most needed the new research products.

‘Well, I mean I've looked back on you know in it, yeah just like that was fortunate those four [researchers] came together. Sometimes you hit something at the right time.’

‘there's a bit of a chicken and an egg thing I think happens around developing systems for operational use ... some of its driven by what's coming out on the research side, but some of it's driven by people right at the field level that are saying, ‘I'm trying to do this; I'm having trouble doing this; I'm seeing something out there on the marketplace or in another industry – why can't we do this?’ And it's a matter of bringing both of those pieces together and of looking at it from a whole bunch of different angles and seeing ... [if it] fits and [if it needs] to go on the back burner for five years because it's really immature technology and it's not ready for primetime yet.’

A8: Research motivation theme

Research motivated by operational need: Early on and consistently researchers worked closely with the fire management agency, which led to a better mutual understanding of operational needs. With continued success in collaboration for and adoption of research, motivation increased.

‘I was talking to forest managers, the fire supervisors, the districts ... just to get a real link into the program across the province. I think it built up a lot of trust with people; they would take me out to discuss things and it really improved my [knowledge] in terms of what the province wanted...it also helped me to understand ... the [objectives] that were higher priority for the Ministry.’

‘The [researchers] were engaged, they were making the effort and they could understand kind of where that work was eventually. You know not maybe not this year, maybe not next year, but eventually the things they were doing we're going to

pay off in the next generation of tools, whether it was information based tools or simple you know better understanding of fire behavior and fire processes.’

‘[As a practitioner], I understood intimately the process that the [fire managers] were going through. And [as a researcher], I understood intimately the science ... I knew the science, I knew what [the researchers were] trying to do and I knew how the system worked, so that the tool I created fit their need... Any question they asked, I really understood their problems, so I was able to build that bridge between the science and what their needs were and the real pressures of their job.’

Research motivated by fire management focused engagement: Though not all research motivation overlapped with practitioner motivations due to competing priorities. For example, researchers needed to produce research papers, but operational users place a higher value on straightforward applied products. However, in the case of the FWI and FBP Systems, the research was directly motivated by fire management needs, which were understood through collective engagement. Collaboration produced outcomes and products that were easier to apply for specific purposes and had real-world impact.

‘[As a researcher,] I think really if you're collaborating with each other with the idea that the sum is more than the parts you'll get something out of it collectively that makes it better. I think that's the important way to go at it and it requires trust... [As a researcher,] you're not collaborating on something ... because you're going to get a paper out of it; you're collaborating because you have common interests there and usually what that generates are some different ways of looking at things.

‘I can remember a couple of meetings in recent years where you would get agency people together and they would be talking about the fact that we never see the CFS folks anymore, in the field or whatever. They don't seem to be working on our problems; they're working on national problems or inter-disciplinary problems.’

Supporting fire management operations as part of the research process: There is a considerable investment in time for the applied researcher behind a successful implementation (e.g., the FBP System). Not all researchers can or will be able to support operational needs (e.g., developing interim products for use) given the tradeoff with other competing priorities. However, those products that assisted fire operations were important for fire management motivation.

‘The folks involved ... were easily accessible and were always available to talk ... I found quite helpful. I would say in my experience, every researcher I've encountered, whether it be in fire or forestry or something else, has been the same way.’

‘I think some of the most effective things I saw were when the research people talked with the operational people and maintained those relationships.... That was really important, in my time anyhow, because if both groups are off in their silos and there's no connection [they can't be as successful]. I think the transparency's helpful ...’

‘[A researcher] spent tons and tons of time trying to get people to better understand the fire behavior prediction system so that they would use it... He was a big driver of the advanced wildland fire behavior program and the fire behavior specialist course ... Tech transfer... When you look to the lengths [researchers] went to, to

try and get that information available, understood, yeah, a huge, huge amount of work on their part.’

‘[Agencies] were looking for more quantitative fire behavior prediction guidelines... There seemed to be growing interest... By the time FBP came out there seemed to be more awareness that we need better research products and ...[as researchers] we had the luxury of being able to conduct a field program to gather data over a number of years without any pressure.’

A9: Ownership and authority theme

Fire management agency commitment to implement co-developed tools: The desire for and subsequent feeling of ownership in the tools was well established within fire management prior to the product even being available.

‘There was a commitment from the program that we need to get better tools out for our folks - our folks needed better understandings of how they could relate to the outputs of these predictive type systems, how they could relate that [to] what they see on the ground, and how they could relate that to making better decisions.’

‘There was a push from some senior people in the program that this is a direction we need to go... we're not going to improve the mark very much; we're not going to build a better shovel... What are the things we need to push the program forward and make it more effective?’

‘I think you need that commitment from the organization that people wanted that kind of product so that as it arrives people are ready for it and eager for it.’

Financial commitment for fire management agency-driven outcomes: Financial support both direct and in-kind was offered while not being tied to specific pre-defined deliverables. There was a trust and commitment to invest in the shared objectives.

‘[Directors and Fire Management Supervisors] would spread the message out to the field managers that Ontario's in this business; we're going to try to support this kind of research work because it's going to pay off for us, we need you folks in the field to help them.’

Required ownership and participation from multiple levels within the fire management agency: In many cases the formal agreements came out of the established collaboration. These formal high-level agreements provided the levers of authority that enable others to get the necessary work done. The top-down and bottom-up ownership worked together in many instances.

‘We had MOUs [memorandum of understanding] or whatever, signed by the CFS and [the Ministry], to jointly do some of this stuff but really that was kind of at the management level. It was really at the researcher level where we needed to have people on the ground and a common understanding ... I think we had to build confidence in each other.’

‘The formal process is required at a certain point... especially when you start talking about funding allocations and management of a process... The informal is, to my mind, more efficient and effective, but when you get to a certain point in complexity or funding, then the formal becomes required in that you have to show some kind of management control, some kind of oversight type stuff. If you're working in a very large complex project, then there's a certain advantage.’

‘In any organization, there are, innovators, those that develop; early adopters, those that can understand and see the use of new techniques; late adapters that need a push or a policy directive to conform to the change; and laggards, you never win these individuals over. Best to put them in positions that do not require the use of new technology.’

Evidence of fire management agency authority in the research process: CFS and Ministry priorities were aligned which led to an ease in working together driven by authority under their respective mandates.

‘[as a researcher] you know spend a lot of time thinking about what, what Ontario might need and, and talking with the Ontario folks a fair bit, you know and that led us eventually into work on the FWI System, which was primarily for me and for the regional people, it was a lot of analysis of fire weather data and stuff like that and trying to calibrate the FWI System and the codes and indices, specifically for use in in Ontario.’

‘There was a fortuitous alignment between the interests of the research cadre and the operational interests of the program... The kind of work that the research people wanted to do and the things they were interested in were well aligned with what the program, for the most part, thought was important.’

Part B: Examples of potential applications

This work may inform the CFS in their continued and more recent efforts to update the core components of the CFFDRS for successful uptake in Canadian fire management in 2025 (Canadian Forest Service Fire Danger Group 2021). This need for continued KE is recognized in the report

“An overview of the next generation of the Canadian Forest Fire Danger Rating System” by the Canadian Forest Service Fire Danger Group where they state:

‘The operational implementation and use of CFFDRS involves more than just incorporating science into information applications; an understanding of the System and its limitations by users is critical. We also recognize the need to develop effective knowledge exchange and technology transfer to update existing fire management training material. Significant changes to the CFFDRS have far reaching impacts within organizations and that practical knowledge transfer and user uptake is a critical element of successful implementation of CFFDRS-2025.’
(Canadian Forest Service Fire Danger Group 2021).

This work may also support the WildFireSat initiative (also operationally led by the CFS along with the Canadian Space Agency, Environment and Climate Change Canada and the Canadian Centre for Mapping and Earth Observation) announced in 2019 which will be the first purpose-built satellite for operational fire management (Government of Canada 2022, Johnston *et al.* 2020). The rate and extent that WildFireSat will be integrated into fire management decision-making is an important consideration given the potential lifespan of the mission is five years of planned operations, launching around 2028 (Jackson and Johnston 2020). Recognizing the need for more than solely technical transfer, members of the WildFireSat User and Science Team concluded:

‘WildFireSat aims to deliver a purpose-built operational wildfire monitoring satellite to support wildfire managers as the primary users. To that end, despite the technical and scientific challenges of the mission, the key to operational success remains in the hands of the wildfire management community. In order to

achieve meaningful impact in wildfire management operations, the end-user engagement described in this study must continue for the duration of the mission to ensure that wildfire management needs continue to be heard and that wildfire managers develop a sense of ownership in the mission.’ (Johnston *et al.* 2020)

Enhancing the CFFDRS or improving fire monitoring with WildFireSat products are just two current examples where the innovations, which are in the process of actively being developed, can be supported through a sound KE approach (as described in McFayden *et al.* in press).

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