Evaluating Sprinkler Efficacy for Wildland Fire Protection Programs in Fairbanks, Alaska

WESTERN PARTNERSHIP FOR WILDLAND FIRE SCIENCE

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A Wildland Fire Management Organization AFS Alaska Fire Service

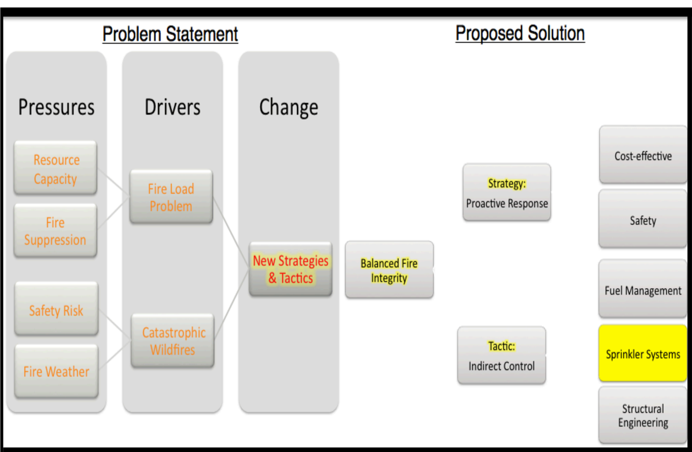


Figure 1. The problem statement and proposed solution.

The fire management pressures will drive change to new strategies and tactics. A balanced fire integrity uses a fire avoidance strategy allowing the fire to burn freely around values. A shift from a reactive to proactive fire strategy is safer and more cost efficient. A three-point approach is proposed for fire prevention. Fuel management modifies the fire type by removing, isolating, reducing, and converting the fuel hazard. Structural engineering solutions through building materials and architectural makes the value fire resistant. A sprinkler system raises the fuel moisture, insolating the defensible space and reducing the probability of firebrand ember cast.

Figure 2. A cabin protected by sprinklers (Lake Superior News 2011).

Sprinklers have proven to be an effective tool to protect Wildland Urban Interface (WUI). Johnson *et al.*(2008) writes "Sprinkler systems appeared to protect structures along with their surrounding vegetation regardless of fire behaviour, intensity, fuels, weather/wind, or Firewise status of the property". The Ham Lake and Gunflint Trail fire study recommended further research into the amount of water to needed for a 24-hour period. During drought situations, sprinklers could periodically water the area for perpetual protection.

Figure 3. Two bears in the woods cartoon (www.guy-sports.com).

The answer to the bear's conundrum is fuel moisture. The preheating phase of combustion is a limiting factor because it requires energy. If the fuel is sufficiently hydrated then it acts as a heat sink. How much water is needed to treat a given fire hazard? **This study evaluates sprinklers' watering effect on fuel moisture content in lowland Boreal spruce forests floors around Fairbanks, Alaska.** Field capacity is the maximum amount of water the soil can retain (Stocks 1970).

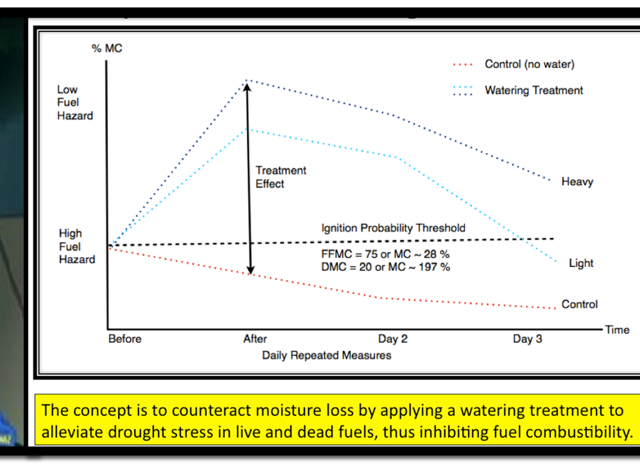


Figure 4. Hypothesis of sprinkler watering effect.

The hypothesis is more watering duration will result in longer protection period. Quantitative estimates will help firefighters decide the appropriate sprinkler watering application. A fire manager would want to maximize their protection period for a given watering treatment. Stocks (1970) observed duff moisture content changes with varying amounts of simulated precipitation, see Table 1 below.

Rainfall (inches)	Moist duff: Percent retained	Moist duff: Amount retained (inches)	Dry duff: Percent retained	Dry duff: Amount retained (inches)
0.5	10.24	0.051	19.52	0.098
1.0	9.00	0.090	12.73	0.127
1.5	7.24	0.109	10.92	0.164
2.0	5.09	0.112	10.83	0.217

Figure 5. Trees blocking the sprinkler spray.

The preliminary research was a study completed in 2012 in Fort Nelson, British Columbia. The preliminary project tested research methodology and watering treatment effect. The study found trees and other vegetation can block the sprinkler spray. This affects the distribution of water and the understory vegetation growth. The preliminary research made the sprinkler experimental design procedures easier to plan.

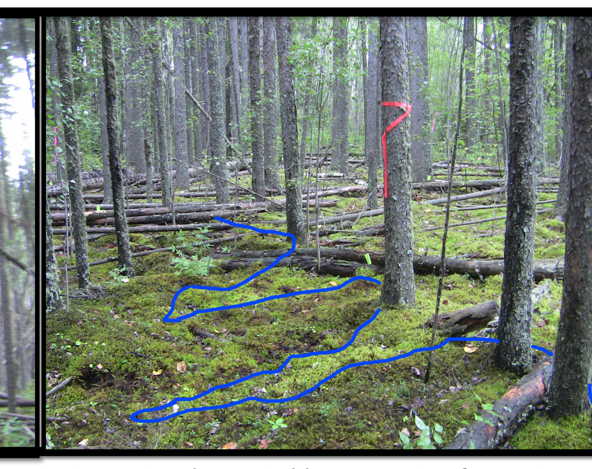


Figure 6. The sprinkler watering footprint.

There was an immediate change in moisture regimes evident. The blue line in Figure 6 highlight the difference in colour of the vegetation. The moisten vegetation was darker hue, while the water stressed growth was much lighter. When walking from the dry area to the wetter spots my footsteps changed from snap, crackle, pop to pitter-patter noise. This indicates the dry fuel would burn readily, while the wet fuel would not ignite. Notice the indents in the sprinkler water distribution from trees blocking the spray. The orange flagging marks the 10 metre radius of the sprinkler spray.

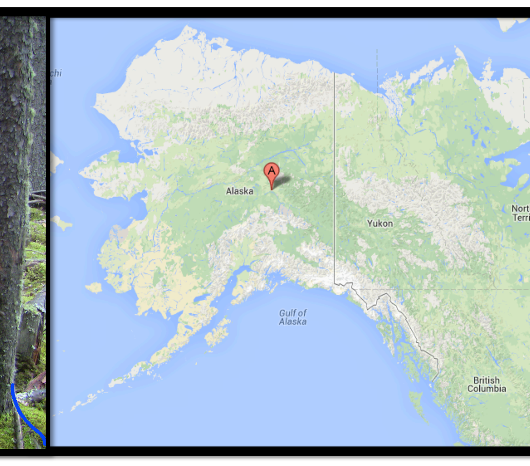


Figure 7. The study are for 2013.

I met the fire science community in Fairbanks, Alaska through my literature review. The Bureau of Land Management (BLM) had a lot of material written on fuel moisture such as The Measuring Fuel Moisture Content in Alaska: Standard Methods and Procedures by Norum and Miller (1984). I participated in the Fuel Moisture Sampling workshop and partnered with them to write my graduate thesis about sprinklers watering treatment effect on fuel moisture.

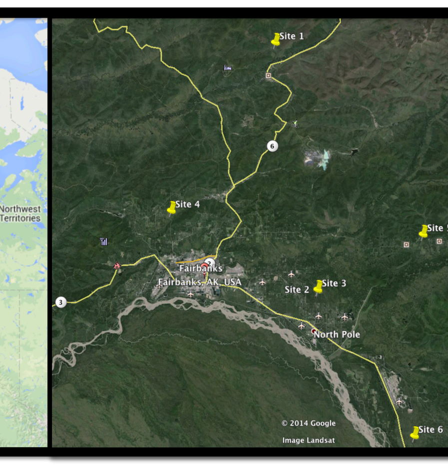


Figure 8. Research site locations.

The research site focused on lowland black spruce forests. This fuel type is known as Boreal Spruce (C2), a highly combustible vegetation community. The fire season for 2013 was very dry around interior Alaska with lots of fires burning. It was the perfect opportunity to test the watering treatment effect during extreme fire danger conditions. As shown in Table 1, dry duff has a higher water use efficiency than a moist duff.

Figure 9. Field photo during sampling.

The experiment measured the watering treatment effect using a before, after and control design. The litter layer (0-5 cm) and upper duff layer (5-13 cm) sample containers weights were measured in the field. These wet weights were later converted to fuel moisture content once laboratory studies were completed. Two water capture containers straddled the organic containers to measure the amount of water from the sprinkler spray. The amount of water received is the independent variable and the change in fuel moisture content is the dependent variable.

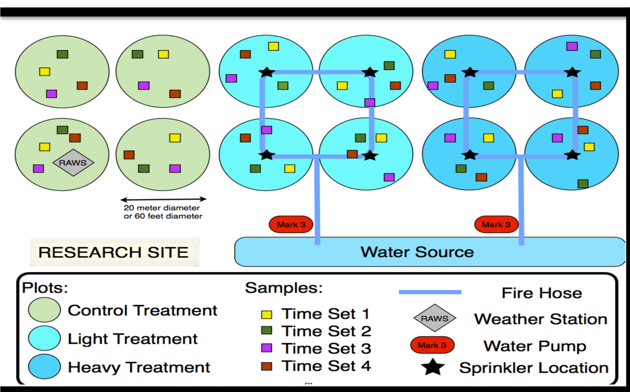


Figure 10. The research site experimental design.

The experiment tested a variety of sprinkler watering treatment levels at eight research sites. Each research site contained twelve treatment plots having four sample stations. The circular plots have a radius of 10 metres from plot center. Each plot has four sample locations to represent the diurnal gradient between 1300 and 1800. The plot averages demonstrate the sprinkler watering treatment effect. The samples explain the within plot treatment effect. The RAWS monitors the in situ forest weather conditions as atmospheric covariates.

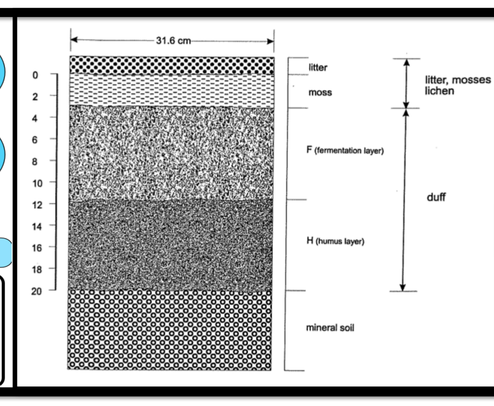


Figure 11. An organic soil profile (Unknown).

Deep organic LFH fuel complexes require analysis of the litter and duff layer. The litter layer is a mix of live and dead fuels.. Live moss fuels moisture follows the plant cycle. The dead litter fuels is governed by atmospheric conditions. The fermentation layer has partially decomposed material with white fungal hyphae intermix. Below is the humus layer. The humus layer is darker and denser humus layer. Water holding capacity is strongly linked to bulk density.

Figure 12. Target moss species.

The stair step moss is tiered with horizontal structure. The feather moss is similar to frond with more vertical alignment. These factors influence fuel moisture.

Figure 13. Each sample location setup was photographed.

There are many confounding factors that will affect the interpretation of the data. To explain the environmental variation site characteristics were collected as covariates for analysis. Below is the list of covariates categories and their measures.

Weather:
- Wind speed
- Wind direction
- Solar radiation
- Precipitation
- Temperature
- Relative Humidity

Research Site:
- Stand height
- Forest composition
- Site photos

Plot:
- Stocking density
- Basal area

Sample Location:
- Distance from the sprinkler
- Moss species identification
- Canopy closure
- Forest floor photos
- Nearest tree position

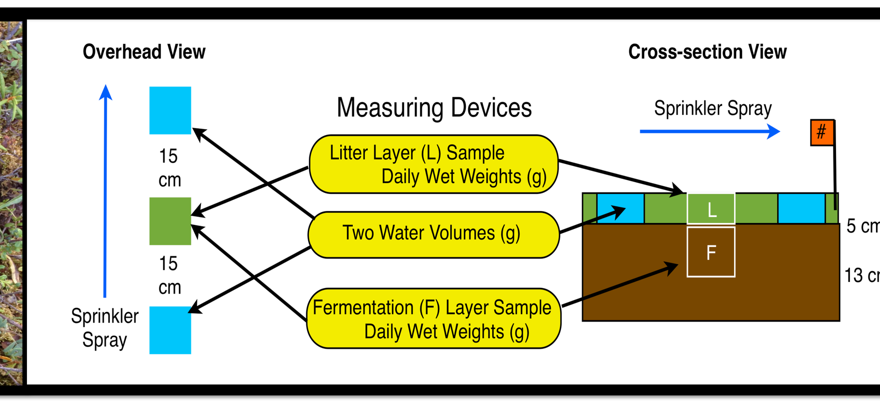


Figure 14. The measuring devices for fuel moisture and water.

The litter sample includes live and dead moss from the top five centimetres. The duff containers includes the upper duff located below the litter container. Empty water containers straddle the organic containers at fifteen centimetres apart inline with the sprinkler spray. A numbered flag is placed on the leeside of the sprinkler location to mark the sampling order. A map of sampling orders is drawn randomly from a bag of numbered markers, Table 2.

Time Set	Site Sample Order: 1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th
1	Plot 4	Plot 9	Plot 6	Plot 8	Plot 7	Plot 1	Plot 2	Plot 10	Plot 11	Plot 5	Plot 12	Plot 3
2	Plot 10	Plot 2	Plot 3	Plot 8	Plot 1	Plot 11	Plot 12	Plot 6	Plot 9	Plot 5	Plot 7	Plot 4
3	Plot 2	Plot 10	Plot 5	Plot 9	Plot 7	Plot 6	Plot 12	Plot 8	Plot 1	Plot 3	Plot 4	Plot 11
4	Plot 11	Plot 10	Plot 1	Plot 7	Plot 3	Plot 6	Plot 4	Plot 2	Plot 5	Plot 9	Plot 12	Plot 8

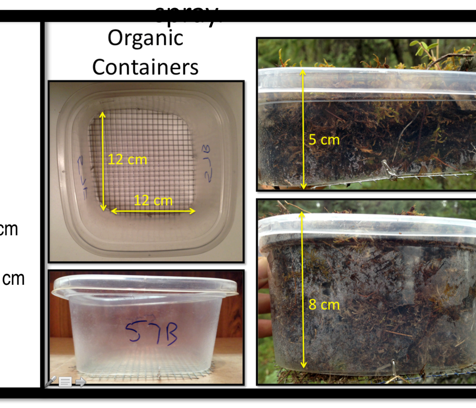


Figure 15. Organic containers.

The organic containers were constructed from Tupperware with the bottom replaced with ¼ hardware mesh. This enabled multiple measurements of the sample for before and after watering treatment. The hardware mesh kept organic matter inside and allowed for water movement. To capture the water at the same instant, water containers are imbedded into the forest floor in the direction of the sprinkler spray.

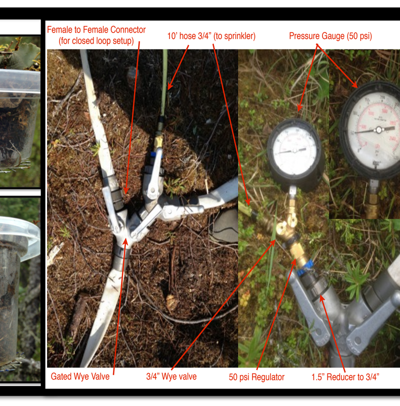


Figure 16. Water delivery system controls.

The sprinklers' water pressure was regulated. The amount of water consumed is a combination of pressure and duration. Since the water pressure was regulated the experiment treated watering duration. The precipitation duration and intensity controls the vertical integration or horizontal shift of fuel moisture levels

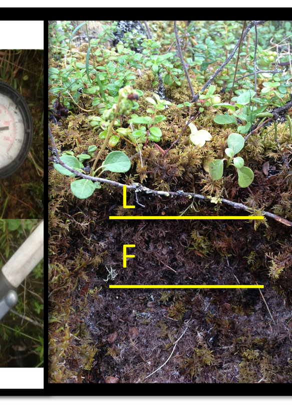


Figure 17. The water percolation.

The majority of the water is absorbed by the litter layer. Notice the moist upper vegetation is darker in colour. The hole is cut using fabric scissors to sever the organic cleanly to reduce soil structure disturbance.

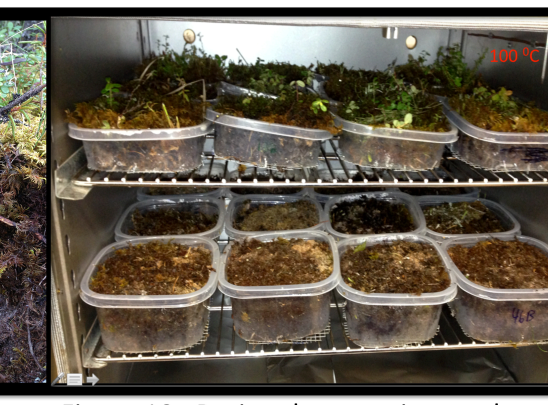
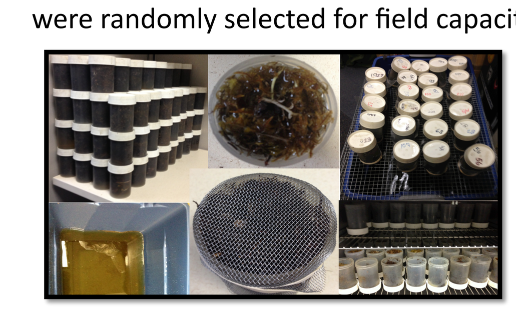


Figure 18. Drying the organic samples.

The organic samples were removed from the research site to be processed in the laboratory. The samples were dried in a temperature controlled oven at 100 °C for 24 hours. The samples are then removed for weighing. Then 30 of the 48 samples were randomly selected for field capacity.



Sample Equations

$$\text{Gravimetric Moisture Content (\%)} = \frac{\text{Wet Weight (grams)} - \text{Dry Weight(grams)}}{\text{Dry Weight (grams)} - \text{Tare Weight (grams)}} \times 100$$

$$\text{Volumetric Moisture Content (grams/cm}^3\text{)} = \frac{\text{Wet Weight (grams)} - \text{Dry Weight (grams)}}{\text{container dimensions (cm)}}$$

$$\text{Field Capacity (\%)} = \frac{\text{Saturated Weight (grams)} - \text{Dry Weight (grams)}}{\text{Dry Weight (grams)} - \text{Tare Weight (grams)}} \times 100$$

$$\text{Relative Moisture Content (\%)} = \frac{\text{Gravimetric Moisture Content (\%)}}{\text{Field Capacity (\%)}} \times 100$$

Dependent Variable:

$$\text{Change Between Repeated Measures} = \text{Moisture Content}_{t+1} - \text{Moisture Content}_{t}$$

Independent Variable:

$$\text{Water Treatment Applied (grams)} = \frac{\Delta\,\text{Water 1 (grams)} + \Delta\,\text{Water 2 (grams)}}{2}$$

Figure 19. Sample equations.

The fuel gravimetric and volumetric moisture content is measured. The field capacity uses the saturated weights from soaking the 30 samples after drying. The relative moisture is the ratio of fuel moisture content to field capacity. The change in fuel moisture content from before and after is the response variable. The predictor variable is the change in average water content caused by the sprinkler watering treatment. The water use efficiency measures the greatest change in fuel moisture content from the least amount of water.

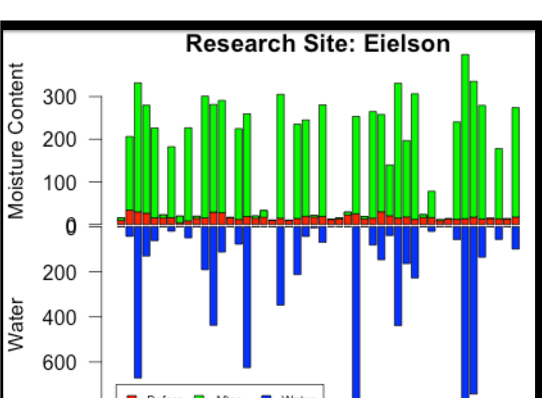


Figure 20. Before and after moisture content for each watering treatment.

Each research site had 48 samples. The bar graph shows the sprinkler watering treatment significantly changed the fuel moisture content. The graph demonstrates that a minimal amount of water changes the fuel moisture content. To measure water use efficiency the change in fuel moisture content graph is shown in Figure 21.

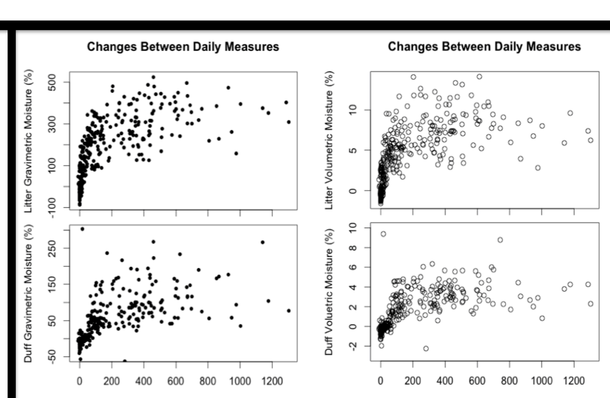


Figure 21. The change in fuel moisture content.

The changes between daily measures is the difference in fuel moisture content. The top and bottom graphs are the litter and duff moisture respectively. The left and right side graph is gravimetric and volumetric moisture content respectively. The litter layer had a higher water use efficiency curve. The duff layer requires more water because it is insulated by the litter layer. The negative moisture content on the graph represents control samples.

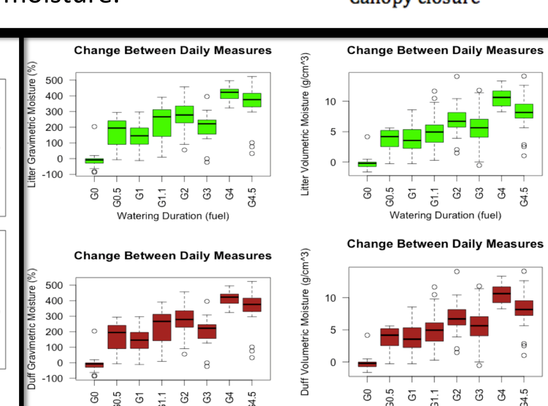


Figure 22. Watering treatment levels.

The water treatment levels were randomly selected to reflect the amount of fuel consumed by the water pump. The graphs orientation is similar to Figure 21. The graphs indicate the normal distribution and positive relationship between watering treatment levels and fuel moisture content.

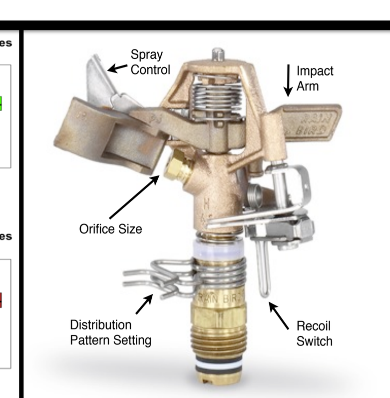


Figure 23. Impact sprinkler.

The impact sprinkler uses a recoil switch to control distribution pattern. The spray flap controls the spread and sprinkler spray distance. The orifice size affects the required water pressure and water output. The impacting arm equalizes the water distribution.

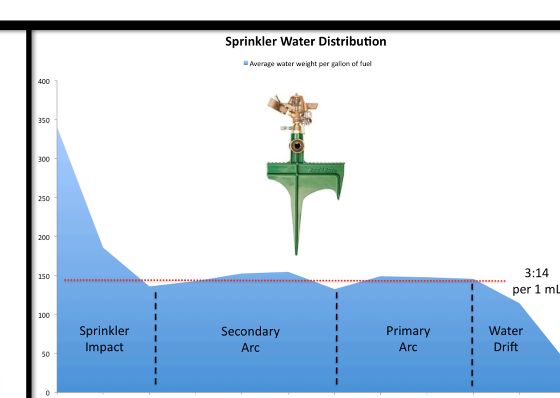


Figure 24. The sprinkler water distribution (Rainbird 2013).

To verify the water distribution of the sprinkler a open field study measured the spray distance and amount of water. The water is separated into four distribution zones. The greatest amount of water lands in the impact zone. The impacting arm creates a shorter distance secondary arc. The primary arc is caused from the non-impact spray. The water drift zone is uncertain due to wind variations.

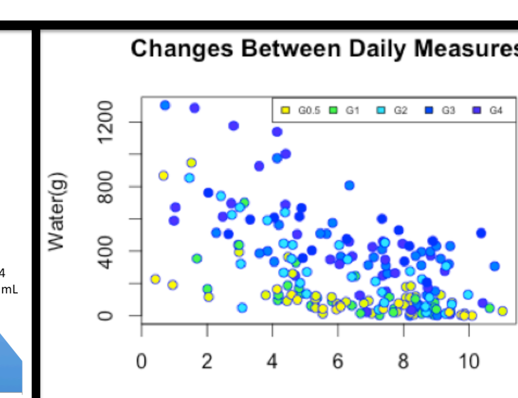


Figure 25. Sprinkler water distance.

The sprinkler watering distance was affected by the distance away from the sprinkler. Figure 25 graph indicates that a longer water duration increase the water captured. It is important to note that tree stocking density blocked and captured water. The further away from the sprinkler the greater the environmental variation in sprinkler watering treatment.

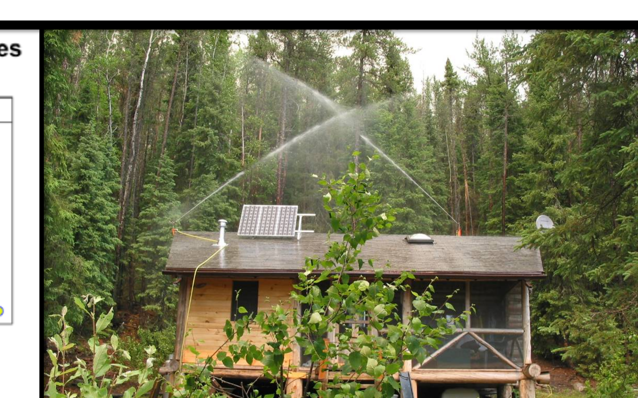


Figure 26. A isolated structure with sprinkler system (OMNR 2011).

The isolated structure was protected by the sprinkler system. The sprinklers are mounted on the roof to increase water spray distance. Notice the sprinkler spray overlaps to provide extra protection from the wind. It is important to follow a systematic approach when planning your sprinkler setup. Assign a water resource, setup a water delivery system, and test the sprinklers periodically to ensure proper operation.

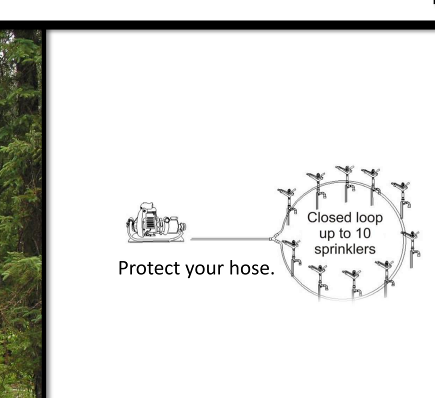


Figure 27. A closed loop system (modified OMNR 2011).

The recommended water delivery system uses closed loops to protect values. The close loop system equalize and raises water pressure throughout the hose. To get better water use efficiency from the system use low pump throttle to extend watering duration. For the experiment, the throttle was controlled.

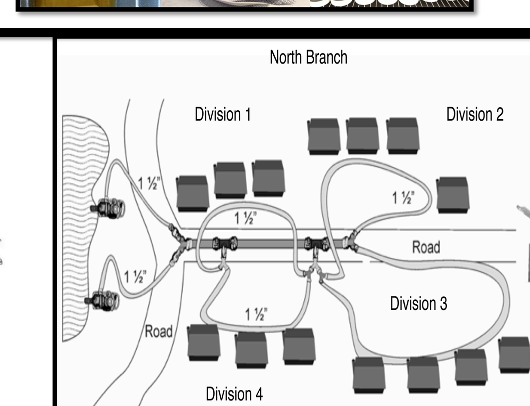


Figure 28. A structure complex system (modified OMNR 2011).

For complex value targets protect the perimeter area to stop the approaching fire. Draw the structure complex to prepare your structural triage plan. The structure complex in Figure 28 has been organized into divisions. This helps control the water delivery system if there is a malfunction. The tandem water pump setup incorporates redundancy in the system and increases water pressure.

Figure 29. Sprinkler safety culture (see copyright in top right corner).

Sprinkler protection programs are alighter hand on the land. Allowing fires to burn around values preserves the ecological integrity of wildland fire across the landscape. Sprinkler remove fire responders from the danger of extreme fire behaviour. Sprinkler help alleviate fire resource scarcity by enhancing the workforce productivity. Be creative in sprinkler implementation.

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