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Optimising Multimolecular Film Performance on Water Surfaces

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ABSTRACT

As evaporation represents the primary source of water loss in dams and reservoirs in Australia, it is critical to improve the efficacy of evaporation mitigation technologies (EMT's) (Craig I 2005; Baillie 2008). Chemical suppressants such as monolayers and multimolecular films have been a key focus of evaporation mitigation research, however their adoption has been limited largely due to their highly variable efficiency (Schmidt et al. 2020; Abdallah et al. 2021; Barnes 2008).

The primary aim of this research project was to investigate multimolecular film behaviour at variable doses, quantifying relationships between dose and spreading rate and an optimal dose recommendation. The secondary aim was to explore the potential to detect multimolecular films using remote sensing techniques.

The methodology utilised in this project was primarily drawn from existing research paper investigating the spreading and dispersive properties of monolayer. In these research papers the position of the leading edge was tracked and plotted against time to determine the spreading rate (Brink et al. 2017; Wandel et al. 2017).

Findings indicate a significant relationship between applied dose and the film behaviour, emphasising the importance of understanding the applied dose when trying to maintain the integrity of the multimolecular film. Improvements in the effective use of multimolecular films in practical applications may be achievable by applying a recommended dose of 0.60ml/m^2 every 8 days. While the development of a film detection system was not successful, the study underscores the need for further research in this area.

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ABBREVIATIONS

ESE .... Evaporation Suppression Efficiency

PDMS.. Polydimethylsiloxane

MFR .... Manufacturer Recommendation

MFRH .... Manufacturer Recommendation (Harsh)

EMT.. Evaporation Mitigation Technology

R-square .... Root Mean Square

CHAPTER 1: INTRODUCTION

Freshwater availability plays a critical role in global agricultural production. Across the world 23% of croplands are irrigated and experience substantial yield reductions in periods of water scarcity (Caretta 2022).

Currently, the agricultural industry consumes almost 70% of Australia's freshwater resources (ABS 2020-21). For many of Australia's key agricultural regions, the climate is trending towards higher temperatures and lower rainfalls, placing a growing importance on improving water management practices (Pittaway et al. 2023). Throughout Australia water used for agriculture is primarily stored in open storages such as dams and reservoirs (Baillie 2008; Schmidt et al. 2020). While the precise volume and surface area of water stored across the nation is difficult to quantify, it is generally agreed upon that evaporation represents one of the largest sources of water loss in open storage (Craig et al. 2005; Baillie 2008; Schmidt et al. 2020; Pittaway et al. 2023). For this reason, the development and adoption of evaporation mitigation technology (EMT) is an essential factor in improving water use efficiency.

EMT's can be broadly classed into 4 types: structural, floating, chemical and biological (Abdallah et al. 2021a). When considering these options, chemical evaporation suppressants can appeal for several reasons: they are available at a relatively low cost, require no additional equipment to apply and are appropriate for use on open storage. The two main types of chemical suppressant are monolayers and multimolecular films.

Monolayers have been the subject of extensive research beginning in the 1960's. They are a single molecule thick film applied to the surface of the water that reduce evaporation through changes to surface tension and capillary wave dampening (Barnes 2008; Christofferson et al. 2014; Brink et al. 2017) Early research primarily focused on insoluble fatty alcohols however the high variability in efficacy and requirement for frequent reapplication limited their adoption (Brink et al. 2017). There has since been a reuptake of research utilising different chemical formulas however high variability still presents a significant issue; this is largely due to the difficulty maintaining the films coverage over the water surface under field conditions (Barnes 2008; Brink et al. 2017; Abdallah et al. 2021).

In contrast to monolayers, multimolecular films have been researched to a significantly lesser extent. There is still some uncertainty as to the mode of evaporation suppression with multimolecular films (Schmidt et al. 2020). Multimolecular films are a thicker film that significantly reduce turbulence at the water's surface and are more durable than a monolayer, requiring less frequent reapplication (Schmidt et al. 2020; Pittaway et al. 2023). When applied to water the thicker films are highly reflective creating a colourful surface (thin film interference) and making them visible to the naked eye. The significant drawback of multimolecular films is the increased thickness may have unknown impacts on the water ecology with researchers such a Pittaway stating that water column and microlayer testing must be completed prior to widespread adoption (Pittaway et al. 2023).

This project will focus on a commercially available multimolecular film called WaterGuard. Waterguard is a biodegradable, siloxane-based product blended with a polymer to improve its self-spreading and self-repairing properties. When applied to the water surface WaterGuard is highly reflective which may be of significant assistance when utilising multispectral sensing equipment to detect the coverage on a water surface. This research will focus on improving the understanding of the films spreading and dispersive properties and investigate the potential to use remote sensing tools to detect the film on the water surface.

1.1. Aim

The aim of this research project was to investigate multimolecular film behaviour at variable doses, quantifying relationships between dose and spreading rate and determining an optimal and a minimum dose recommendation. The secondary aim of this research is to explore the potential to detect multimolecular films using remote sensing techniques.

1.2. Objectives

1. **Suppressant Properties**

   Investigate the properties of WaterGuard. Draw from previous research methodologies to find the spreading rate of the film at various doses.

2. **Application Guidelines**

   Determine the minimum dose of WaterGuard that can be applied per square meter while maintaining full cover of the water surface. Recommend an application rate in ml/m^2 and a reapplication frequency for effective use of WaterGuard.

3. **Film Detection**

   Explore methods of multimolecular film detection using remote sensing techniques. Draw from similar applications of sensing techniques utilising properties such as spectral signatures, thin film interference and reflectance.

CHAPTER 2: LITERATURE REVIEW

Over the past 60 years there have been numerous investigations into the efficacy of monomolecular films in evaporation reduction. Within these publications an ongoing theme is the high evaporation suppression efficiency (ESE) recorded under laboratory conditions, followed by incredibly variable ESE when tested in the field (Schmidt et al. 2020; Abdallah et al. 2021). This literature review will investigate the sources of high variability in performance, the methodology used in previous studies and the gap in literature that this project will address.

The first section of this literature review will provide background information surrounding what monolayers and multimolecular films are, how they work and what impacts their efficiency. This will be followed by a summary of current research investigating any themes in limitations and future recommendations. The next section will address the methodologies of previous research and their relevant applications. Finally, a detailed summary will highlight the identified gap in knowledge and provide justification for this project.

1.3. Background Knowledge

The following section of the literature review establishes background knowledge necessary for understanding the aim, rationale, and methods of this project. This will include developing an understanding of the structure and function of monolayers and multimolecular films, the factors that impact their ESE and themes observed in recent literature. While this project investigates multimolecular films, past research of monomolecular films (monolayers) is both relevant and applicable in experiment design and the identification of limitations.

1.3.1. Monomolecular Films

Monomolecular Films (Monolayers) are single molecule thick films that form at the air-water interface (Barnes 2008; Prime et al. 2012). These films are comprised of amphiphilic molecules, making them both insoluble and capable of attaching to the water surface (Barnes 2008). Monolayers self-spread and self-repair (within limitations) due to a concept called the Marangoni effect (Brink et al. 2017). This effect occurs when the monolayer chemical is applied to the water surface creating a difference in surface tension between the water and the film, inducing a rapid mass transfer or spreading (Barnes 2008; Brink et al. 2017). The resulting monomolecular film provides resistance to evaporation for 2-3 days before requiring reapplication (Schmidt et al. 2020). Since the 1960's there have been many theories surrounding how monolayers supress evaporation. Notable publications from Barnes (1986) and Saylor (2000) proposed that there are two primary mechanisms through which this is achieved:

1. The tight packing of the molecules forming the monolayer inhibits the ability of water molecules to pass through the air-water interface.
2. The wave dampening effect reduces the surface roughness and natural convection.

Evaporation reduction resulting from the use of monolayers is challenging to quantify, especially outside of laboratory conditions (Craig I 2005). Schmidt et al.'s 2020 report synthesised data from 11 field trials of different monolayers and determined an evaporation reduction ranging from 0-71%. Similarly, Abdallah et al.'s 2021 review of 16 monolayer trials revealed an ESE varying from 3-99%. While some of this variability can be attributed to the nature of monolayers degrading, there are also significant and reoccurring limitations in research methodologies, explored in Table 1. Ultimately, the inability to demonstrate repeatable evaporation reduction utilizing monolayers has severely limited the uptake of the technology.

Table 1: Issues contributing to variability of ESE in monolayer research (adapted from (Seton 2023a))

Issue	Description	Relevant Research
Duration	When trials are too short in duration efficiency can be overestimated as film degradation due to climatic and biological factors may not occur. In Abdallah et al.'s review eliminating trials with duration <24hrs reduced variability from 96% to 32%. In contrast, trials that involve continual application for greater than 3 months can impact the heat flux of the water storage.	(McJannet et al. 2008; Hancock et al. 2011; Schmidt et al. 2020; Abdallah et al. 2021)
Scale	Small scale monolayer trials are not often repeatable at an on-farm storage scale. Bucket/pan/tank trials provide researchers with more control for data collection. However, factors such as exaggerated heat fluctuation and wind shadows can generate unrealistic results.	(McJannet et al. 2008; Hancock et al. 2011; Brink et al. 2017; Schmidt et al. 2020; Abdallah et al. 2021)
Climatic Conditions	Trials conducted in a lab setting do not factor in the impact of wind and solar radiation on monolayer performance.	(McJannet et al. 2008; Brink et al. 2011; Gallego-Elvira et al. 2013; Wandel et al. 2017; Mozafari et al. 2019; Schmidt et al. 2020; Abdallah et al. 2021)
Water Quality	Some monolayers are susceptible to attack from microbes found in the water, contributing to variability arising from degradation of the film.	(La Mer et al. 1965; Pittaway, P. A. et al. 2010; Pittaway et al. 2015)
Measurement of Water Loss	In on-farm trials it can be difficult to isolate water loss due to evaporation because of factors such as seepage.	(Craig I 2005; Baillie 2008; McJannet et al. 2008; Hancock et al. 2011; Schmidt et al. 2020)
Dose	The addition of bulking agents can cause error in determining the dose of the active ingredient being applied, especially on a small-scale low dose application.	(Hancock et al. 2011; Schmidt et al. 2020)

1.3.2. Multimolecular Films

Multimolecular Films share some similarities with monolayers although there is significant difference in the film thickness and composition, the mechanisms of spreading and evaporation reduction, and the durability and limitations of the film. Current publications indicate that there are only two multimolecular films being trialled in Australia (Pittaway et al. 2023). One product is marketed as a silicone oil polymer blend (polydimethylsiloxane (PDMS)) and the other is a liquid paraffin. The primary appeal of multimolecular films is the greater resistance to wind and solar radiation offered by the thicker, more reflective films (Christofferson et al. 2014; Schmidt et al. 2020). Multimolecular films require a higher dose than monolayers and spread less readily, imposing limitations on the maximum size of water storage they can be used on (Schmidt et al. 2020). Spreading properties are improved when film forming materials such as siloxane oil are combined with polymers to form polymeric amphiphiles (Barnes 2008; Christofferson et al. 2014). Research investigating how multimolecular films reduce evaporation is limited however three potential factors have been identified:

1. The thick film interferes with the ability of gas and water molecules to pass through the air-water interface (Schmidt et al. 2020).
2. Significant wave dampening effect reducing surface roughness (Hancock et al. 2011; Schmidt et al. 2020).
3. Increased Reflectance (observed in trials of siloxane oil-based products) contributing to decreased surface temperature (Hancock et al. 2011).

Barnes (2008) and Christofferson (2014) suggested that the use of multimolecular films could be a viable alternative to monolayers to endure the Australian climate. The potential for improved durability is desirable, however several papers have highlighted significant ecological concerns (Pittaway, P. A. et al. 2010; Schmidt et al. 2020; Pittaway et al. 2023). While PDMS products are food safe and inert in soil, the impacts on gas exchange specifically dissolved oxygen content have not been quantified (Schmidt et al. 2020; Pittaway et al. 2023) . Additionally, in the context of the film being applied to water reservoirs used in irrigation, any impacts that the film has on crop health, soil infiltration rates or wildlife such as birds and amphibians needs to be needs to be evaluated prior to use.

Pittaway, who is an expert in microlayers and water ecology, has emphasized the need for extensive testing of the impacts on the natural microlayer, water quality and surface ecology prior to the application of multimolecular films on water of ecological significance (Pittaway et al. 2023). Prior to undertaking lengthy ecological investigations, it is necessary to evaluate the viability of the multimolecular film by developing a deeper understanding of their properties surrounding spreading and response to climatic conditions.

Similarly to monolayers, trials of multimolecular films face the same challenges listed in Table 1. There is, however, a lack of published research quantifying spreading and dispersive properties, the impact of solar radiation or the impact of wind on film integrity (Schmidt et al. 2020). This information is critical to developing any smart or autonomous system designed to reduce variability in ESE (Brink et al. 2011; Brink et al. 2017).

1.3.3. Factors Impacting Film Efficiency

Evaporation mitigation techniques be it floating, suspended or chemical all work with the same key principle; the efficacy at suppressing evaporation is directly related to the percentage of the water surface that is covered (Lehmann et al. 2019; Schmidt et al. 2020; Pittaway et al. 2023). While this concept is relatively easy to apply to floating and suspended covers, it is more challenging when considering chemical coverage. Chemical films used in evaporation suppression are designed to be biodegradable (Pittaway et al. 2015). While this is essential to the environment, it imposes limitations on how durable the film can be, contributing to breakage and beaching under field conditions (Barnes 2008; Brink et al. 2011; Christofferson et al. 2014; Wandel et al. 2017).

Wind not only impacts the integrity of an existing chemical film, but also the spreading and dispersive properties when trying to apply the film (Barnes 2008; Wandel et al. 2017). Gallego-Elvira's 2013 paper investigated the impact of wind on monolayers determining that they were most effective under light wind conditions (1.5ms^{-1}). Once wind speeds exceeded 3ms^{-1} the monolayer efficiency steeply declined (Gallego-Elvira et al. 2013). The mechanism of wind disrupting monolayer performance involves both the impact of the wind on the surface velocity of the water and the formation of capillary waves as a result (Wandel et al. 2017). Figure 1.3.1 demonstrates how capillary waves cause changes in the density of a monolayer on the surface and induce Marangoni flow (Barnes 2008). This results in the film drifting across the surface and becoming beached on the edges of the reservoir.

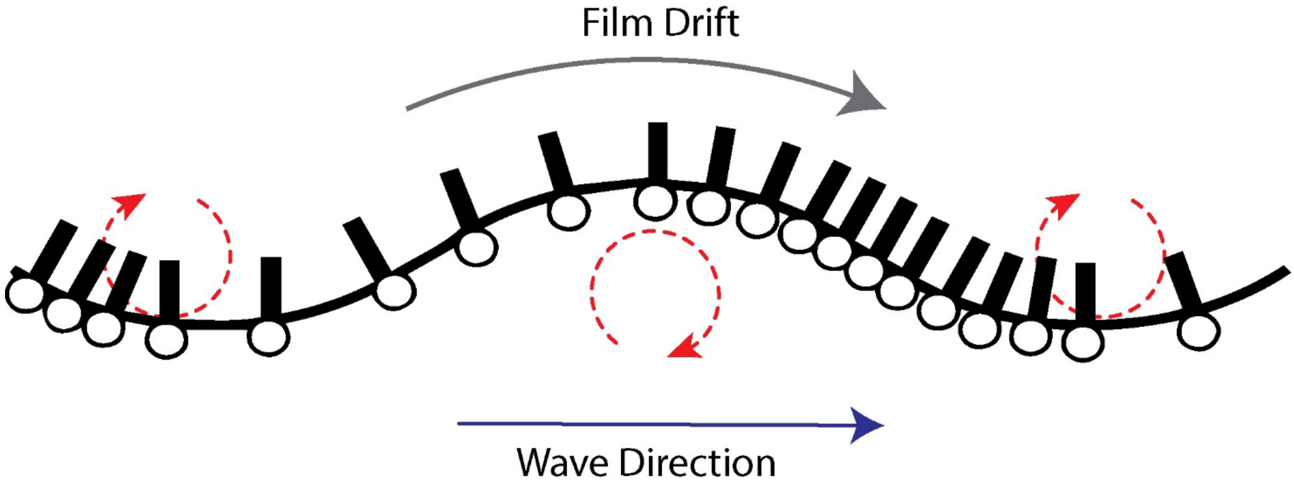

Figure 1.3.1 Impact of capillary waves on monolayer molecules leading to Marangoni Flow and film drift (Adapted from Barnes 2008)

As wind speeds increase between 3-5.5ms^{-1} monolayer drift renders it ineffective rapidly (Wandel et al. 2017). Wind speeds exceeding 5.5ms^{-1} induce significant water roughness that can cause the film to break apart or become submerged (Wandel et al. 2017). Research quantifying multimolecular films resistance to wind is currently limited to early trials of a siloxane product called Aquatain, which has since been reformulated (Gallego-Elvira et al. 2013). While it is theorised that multimolecular films such as PDMS will have greater durability under wind stress, there are no supporting publications to the authors knowledge.

Solar radiation can also contribute to degradation of monolayers through chemical volatilization occurring as a result of increasing surface temperature (Gallego-Elvira et al. 2013). Again, there has been extensive research to quantify this effect in monolayers, however the same cannot be said for multimolecular films. It has been theorised by Hancock (2011) and Schmidt (2020) that solar radiation will cause less degradation in PDMS films due to the surface reflectance (albedo effect) limiting increases in surface temperature. Overall, it is evident that there are significant gaps in the knowledge surrounding how multimolecular films interact with climatic conditions.

1.3.4. State of the Research

Drought is one of the primary drivers behind the research and adoption of evaporation mitigation technologies within Australia (Schmidt et al. 2020). Specifically, during the millennium drought, there was a resurgence in monolayer and multimolecular film research as the entire country faced significant water scarcity issues with no end in sight. Research from this period surrounded the ESE of different monolayers and the mechanisms through which they supressed evaporation. Common themes in research recommendations from publications 2000-2010 were:

1. A need for improved monolayer forming materials better able to withstand field conditions (Craig I 2005; Baillie 2008; Barnes 2008; McJannet et al. 2008; Brink et al. 2009).
2. Improved application techniques, understanding of appropriate dose rate and cost benefit analysis (Barnes 2008; McJannet et al. 2008; Brink et al. 2009).
3. Impacts on water quality and ecological concerns (McJannet et al. 2008; Pittaway, P. et al. 2010; Pittaway, P. A. et al. 2010).
4. Impacts of climatic conditions such as solar radiation and wind on the film integrity (Craig I 2005; Barnes 2008; McJannet et al. 2008; Brink et al. 2009) .
5. Reducing the variability of the monolayers for adoption on large scale water storage (Baillie 2008; McJannet et al. 2008).

In the following decade the focus of the research turned towards improving monolayer materials and understanding the factors limiting the adoption of the technology. Research investigated the impacts of wind on the film efficiency and spreading properties and developed model-based smart application systems.

The themes in research recommendations from 2010-2020 were:

1. The need for a smart application or decision support system in conjunction with a cost benefit analysis (Brink et al. 2011; Coop 2011; Hancock et al. 2011; Palada et al. 2012; Gallego-Elvira et al. 2013; Brink et al. 2017; Wandel et al. 2017; Schmidt et al. 2020).
2. Multimolecular films as a more durable alternative and potential ecological impacts (Christofferson et al. 2014; Schmidt et al. 2020).

After 2020 the number of publications on monolayers and multimolecular films has diminished. This could be attributed to many factors including the impacts of the pandemic on research, the shift into La Nina bringing record high rainfalls and interest in alternative evaporation mitigation technologies. Despite this, the improvements in drone technology and sensing equipment that have taken place over the last 5 years could be what is needed to bridge the gap between theoretical application of chemical films and smart autonomous applications.

1.4. Applications and Methods

Section 2.2 investigates the methodologies applied in previous research, highlighting common practice for experiments, their limitations, criticisms, and application to this research project.

1.4.1. Spreading and Dispersion

To address issues related to maintaining cover percentage of a chemical film the spreading and dispersive properties must be investigated and quantified. This section will examine the methodology used to achieve this in previous research without the influence of wind. The issue with centimetre scale experiments is the shear amount of extrapolation required to adjust the results to be comparable to real-world applications (Brink et al. 2017; Schmidt et al. 2020). To combat this issue, while remaining in a climate-controlled environment, researchers such as Brink (2017) and Gallego-Elvira (2013) have conducted their experiments on water troughs and tanks varying from 0.3m-6m diameters.

When investigating the spreading properties of a monolayer the standard approach involves determining the following:

1. Spreading Force (S) – derived from measurements of surface tension taken at the air-water, water-monolayer and monolayer-air interfaces (Saylor et al. 1971)
2. Spreading coefficient (K) – calculated from the relationship between dynamic viscosity, density and spreading force outlined by Dussaud and Troian (1998).
3. Spreading Rate (distance travelled by leading edge over time) – calculated with aforementioned coefficients and a scaling constant *n* or measured in a frame by frame analysis (Dussaud et al. 1998; Brink et al. 2017).

One paper of significance to the experiment designs for this project is Brink et al.'s 2017 paper '*Spreading rate and dispersion behaviour of evaporation-suppressant monolayer on open water surfaces: Part 1 – At zero wind stress.*' In this paper Brink determines the spreading rate of selected monolayers by both following the above procedure and measuring the position of the leading edge with a video camera and talc trace. He performs this experiment with a variable dose on 3 scales to investigate the scaling coefficient required to extrapolate data, and the impact of dose. The main limitations identified within the paper involve the accuracy of the data when extrapolating over long periods of time (scale) and the precise drag caused by using a trace. Brink's paper provides valuable insight into the setup and analysis of leading-edge based spreading experiment which can be utilised in this research.

1.4.2. Wind Stress

When developing a system to maintain film coverage it is essential to understand the spatial distribution and movement of the film under variable wind conditions (Wandel et al. 2017). This has been achieved in previous research by examining the relationships between drift velocity, spreading angle and spreading shape with a controlled source of wind (Wandel et al. 2017). Like the previous section, the smaller scale required to conduct controlled experiments does limit the certainty of the results when being extrapolated. Studies of the interaction between wind and monolayer performance predominantly use either wind tunnels or fan-based systems to simulate controlled airflow. Wind tunnels can provide more consistent airflow across the whole water surface however they impose significant limitations on the scale of the experiment (Mozafari et al. 2019). Comparatively, fan systems can be more applicable on a larger scale, however the wind speed must be measured from several locations across the water surface to determine the workable wind area (Wandel et al. 2017).

In Wandel et al.'s 2017 paper the impact of wind on the surface drift velocity and spreading angle of monolayers was investigated. Wandel used a fan-based wind delivery system demonstrated in Figure 1.4.1. Windspeeds were then measured at 88 points in a grid pattern over the water surface to determine the size and shape of the area where wind speeds were uniform (Wandel et al. 2017). To find the drift velocity of both clean water and a monolayer under wind stress a trace was required that could both withstand the water turbulence and be clearly visible in footage used for analysis (Wandel et al. 2017). 7mm polystyrene balls were applied by hand to the water surface at various wind speeds and the time they took to cross the workable area of water was used in finding the drift velocity (Wandel et al. 2017). A significant limitation of this method is the underprediction of the surface speed caused by the drag of the trace. While the additional drag could be accounted for in data processing, there was some difficulty in determining accurate results for both high and low wind speeds (Wandel et al. 2017).

The use of a trace was unnecessary when determining the spreading shape and angle of the monolayer due to the visible wave dampening properties (Wandel et al. 2017). Frame by frame analysis of the shape and angle of the monolayer spreading when applied under wind force revealed an inverse relationship between the spreading angle and wind speed (Wandel et al. 2017). Monolayer spreading occurred in a tear drop shape, the edges of which became more liner as wind speed increased (Wandel et al. 2017). The primary limitation of this experiment was quantifying the impact of water circulation in the tank caused by the directional wind force (Wandel et al. 2017). When adapting this research to multimolecular films, it could be expected that wind speeds will more severely impact the spreading properties of the PDMS film as it has already been well documented that multimolecular films do not spread as readily as monolayers (Schmidt et al. 2020). While the scale limitation remains inherent to this project's constraints, there is the potential to harness the visible qualities of multimolecular films such as the thin film interference in developing a means to monitor surface drift.

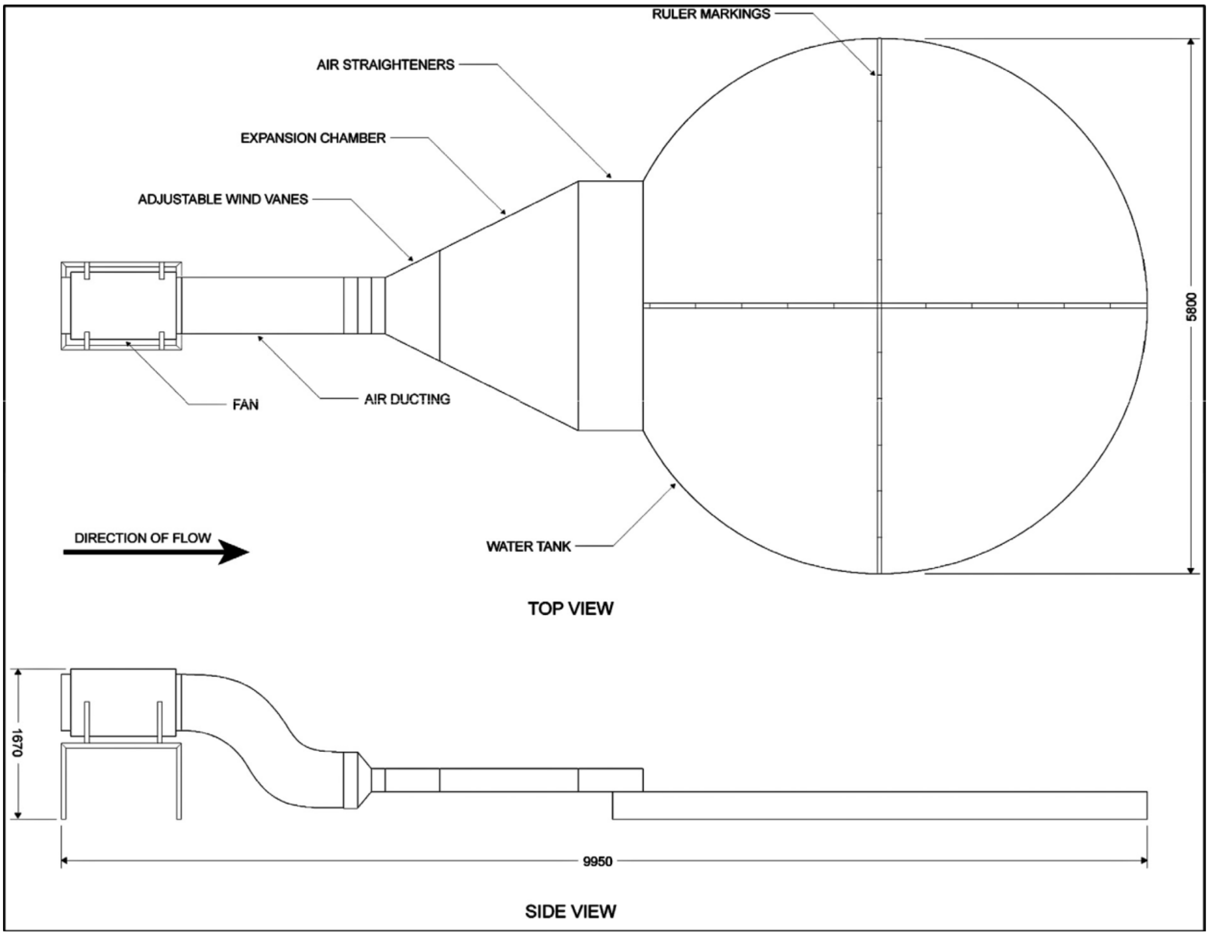

Figure 1.4.1 Wind Delivery system used by Wandel et.al (2017) to simulate controlled wind conditions.

Other approaches to quantifying the impact of wind speed on monolayers involved monitoring trends in ESE as wind is applied (Palada et al. 2012; Gallego-Elvira et al. 2013). These trials involve exposing the monolayer to wind and measuring the evaporation reduction over an extended period. This method is useful in identifying the threshold where the wind speed is too great for the film to effectively retard evaporation (Palada et al. 2012; Gallego-Elvira et al. 2013). However, once a method involves the measurement of evaporation the issues such as scale, duration, and dose (discussed in Table 1) must be considered.

1.4.3. Sensing and Detection

Throughout this review, the methods used in monolayer experiments have been both relevant and applicable to multimolecular films. However, when considering using remote sensing techniques to detect multimolecular films, the different visual properties such as high reflectance and thin film interference (Figure 1.4.2) may support the use of different detection systems. After performing a search for literature using Scopus, Science direct and Google scholar and key terms such as remote sensing, detection, multispectral, hyperspectral and multimolecular film, surface active film, surfactant, Polydimethylsiloxane there were no relevant publications covering the remote sensing of multimolecular films. Because of this, some degree of trial and error will be required when developing a sensing system. A starting point to this investigation involves examining sensing methods utilised in oil slick detection and thin film detection.

Thin film interference has been observed in the use of multimolecular films as pictured in Figure 1.4.2. This phenomenon occurs when light waves are reflected by the upper and lower limits of the film and interfere with each other creating an iridescent sheen (NOAA 2016; Alpers et al. 2017). The thickness of the film impacts the wavelength of light reflected (NOAA 2016). This feature could help not only identify the spatial distribution of the film, but potentially the thickness.

Figure 1.4.2 PDMS Film in bucket (left) and trough (right) trial showing thin film interference and reflective properties. (Source Sarah Seton 2023)

Oil spill detection has been extensively researched with a wide variety of sensors used including synthetic aperture radar (SAR), multispectral and hyperspectral (Alpers et al. 2017). Of these sensors, multispectral is the most readily available for application in this project. The multispectral camera can be used to isolate different bands of light including RGB, red edge, near infrared (NIR) and thermal infrared (Micasense 2022). By capturing imagery of clean water next to water with a multimolecular film and isolating and manipulating the bands of light film detection may be achieved. While the development of a sensing system may be challenging and require some trial and error, the potential for real world application is vast. Technological advances are making the use of drones in remote sensing increasingly popular expanding the potential methods available to smart application systems.

1.4.4. Smart Applications

A 'smart' application system for monolayers or multimolecular films can be defined as a system with the ability to autonomously make decisions based on current or predicted conditions in relation to where, when and how much of the film forming chemical should be applied (Brink et al. 2011). Currently, methods of smart or responsive applications of monolayers are based upon a Universal Design Framework (UDF) and modelled film response to applied wind force. Brink et al.'s 2009 and 2011 papers develop a set of rules to govern the decision to re-apply a monolayer based on inputs such as wind speed and direction, precipitation, solar radiation, last application etc. While this approach is well reasoned, technology has come a long way in the 13 years since the development of Brink's smart application system. The use of drones capable of carrying sensors and payloads there is untapped potential to develop an autonomous system that can both detect drift and breakage of the chemical film, run through a series of decisions, and apply an appropriate dose of film forming chemical.

1.5. Summary and Justification

This literature review has identified that the performance variability of monolayers and multimolecular films has created a significant barrier to their adoption. It has been repeated over decades of research that without repeatable ESE of at least 30% and a decision support tool for film reapplication the use of chemical films in evaporation suppression is not viable (Baillie 2008; Schmidt et al. 2020). By applying methods established in monolayer research in combination with a multimolecular film more suitable to harsh field conditions this project could determine means to reduce the variability of multimolecular film and begin breaking down the barrier to adoption. The significance of achieving a method of detecting and maintaining film integrity is the potential future application for smart drone-based detection and application systems on large water storages.

CHAPTER 3: METHODOLOGY

2.1. Scope

The scope of this research included reducing the variability in ESE of a multimolecular film through an investigation of properties vital to maintaining film integrity. The study was comprised of a small scale indoors trial designed to determine the relationship between spreading rate and dose applied. The aim of the experiment was to define the minimum dose required to form a complete film and determine the spreading rate of the film at variable doses. The secondary objective of this research involved investigating whether the film was detectable using available spectral sensors, with the overarching goal of being able to identify areas of degraded film.

The study was limited to small-scale indoor trials conducted on troughs with a surface area of $0.503m^2$. The reduced scale has significant implications on the results, primarily the extent of extrapolation required to adapt any findings to an applicable scale. As outlined in section 2.1.1, scale is a reoccurring issue in chemical EMT research. This is largely due to the need for controlled climatic conditions and the impracticality of repeatedly emptying and refilling large water tanks for each repetition. While field-based evaporation trials present an opportunity to validate data collected in small indoor experiments, this option was not viable within the time constraints of the study. Similarly, delays in project progress resulted in the film detection experiment being limited to a preliminary trial, still requiring significant further exploration in future research.

The experiments were carried out within the Centre for Agricultural Engineering at the University of Southern Queensland in Toowoomba. When working in the laboratory, a risk management plan was used to minimise danger arising from working in a potentially hazardous environment. Data was collected from August to October and recorded both digitally and in an official laboratory notebook. This data was stored and processed in line with a detailed data management plan.

2.2. Experiment Designs

This project consisted of two key experiments followed by data processing and analysis. An approved Risk Management Plan (RMP) and Data Management Plan (DMP) are attached within the specified appendix.

Experiment 1: Spreading and Dispersion
Experiment 2: Film Detection
APPENDIX A: Risk Management Plan
APPENDIX B: Data Management Plan

2.2.1. Spreading and Dispersion

Objectives and Justification

The objectives of this experiment were as follows:

1. Determine the spreading rate of WaterGuard under controlled conditions.
2. Investigate and quantify any relationship between dose applied and spreading rate.
3. Determine at the minimum coverage of WaterGuard (i.e. the point where the applied dose fails to fully cover the water surface).

Objectives 1 and 2 were achieved by drawing from and adapting previous research methods, primarily from Brink et al.'s 2017 paper: *Spreading rate and dispersion behaviour of evaporation-suppressant monolayer on open water surfaces: Part 1 – At zero wind stress.* In this paper Brink utilised several methods to determine the spreading rate, coefficient, and force of different monolayers at variable scales. The method used to determine the spreading rate involved measuring the position of the leading edge in relation to the application site over the time taken for the film to near the edge of the water surface (Brink et al. 2017). In Brinks experiment a trace was required to determine the position of the leading edge; this was unnecessary in this experiment as the leading edge is visible and easily recorded on a GoPro camera provided that the water trough is dark in colour and there is overhead lighting.

Objective 3 inevitably required some degree of trial and error, however the value in determining the minimum coverage of the chemical is substantial when developing a decision support tool. When the goal was to maintain full coverage of the water surface, part of the approach is a higher frequency application of chemical at a lower dose. However, previous research in an unpublished field trial of variable application rates of WaterGuard highlighted the need for balance between dose and frequency (Seton 2023b). In this trial it was reported that when the MFR dose was reduced to be applied 3 times a week instead of once every 3 weeks, there was consistent underperformance compared to weekly application (Seton 2023b). This was likely due to only achieving partial coverage that was easily broken apart by climatic conditions (Seton 2023b). This objective utilised Brinks leading edge method, while tapering the dose down to determine the minimum coverage.

Instruments Required

Table 2 Instrumentation List for Spreading and Dispersion Experiment

Instruments and Equipment – Exp 1
Experiment Equipment
5 x AQUAPRO910 Round Pond
WaterGuard Gold * *dose information listed below*
Syringes 0.5ml-1ml
Arlec 2 x 3W 400lm Multipurpose Portable Work Light
1m Neonflex LED Light Strip
Data Collection
Over tank frame (2x adjustable shelving units, 2 framing timber beams, camera mount, lights, clamps, castor wheels)
Multi-meter with temperature probe
GoPro 13 with adhesive mount
2 x 1m Folding Ruler (the ends were weighted to prevent sag through the centre)
Experiment Turnover
Cleaning Supplies (non-corrosive chemical cleaner and cloths)
Sponge
Broom
Pressure Washer
2 x Hoses and Fittings
Submersible Pump
Safety and Risk Management
Anti-slip mats
Wet Floor Sign
Rubber cable and hose covers for Walkways
High Visibility Tape
Marking paint indicating safe walkways
Data Processing
Adobe Premiere Pro 2024
Excel
MATLAB R2023a

Table 3 WaterGuard Dose Information (Aquatain 2024)

WaterGuard Information	
This product is a liquid anti-evaporation film and water surface polish comprised of polydimethylsiloxane (PDMS)	
Manufacturer Recommended Dose (Normal and Harsh Conditions)	Converted for Experiment Scale AQUAPRO 910 Pond, Surface Area = 0.50265 m^2
1.5L per 1000m^2 once every 3 weeks.	0.75ml
3.0L per 1000m^2 once every 3 weeks.	1.5ml

Data Collection Apparatus: Design and Setup

The data collection apparatus for the experiment required careful consideration to ensure it was both safe and effective. The key requirements from the apparatus were as follows: First, the apparatus needed to be able to be moved safely by one person. Once in the appropriate location, the apparatus needed to lock into position preventing accidental movement during data collection. Finally, it needed to have both the lights, and the camera mounted in a consistent position approximately 50cms above the water surface. In the early stages of the experiment, the data collection apparatus went through multiple design iterations. This was integral to improving the speed that 5 repetitions could be completed in, minimising the temperature fluctuations further explored in section 5.1.4.

To setup the apparatus the first stage was to assemble two adjustable garage shelving units with the shelves placed at the same heights on both units. Once assembled, angle bracket castors were bolted onto the corners of the units (Figure 2.2.1). The casters on the outer edge of the unit had breaks to lock the position of the wheel and prevent rolling.

Figure 2.2.1 Assembly of data collection apparatus, demonstrating locking castors on the outer edge.

Figure 2.2.2 Annotated apparatus setup. 1. Fixed timber beam 2. Top beam 3. Mounting beam 4. GoPro 5. LED Light Strip 6. Floor spacing markers.

Once the shelves were assembled, they were spaced at an appropriate width to pass over the trough without touching it. The troughs used in this experiment had an outer diameter of 900mm, so the shelves were placed approximately 1800mm apart, measuring from inner edge to inner edge. Two pieces of 2400mm long framing pine were then used to brace the shelves so that they could move as a single unit. One piece was drilled through and bolted to the outer edge of both units. This piece served as the fixed point (Figure 2.2.2, 1.) that could be used to push or pull the unit. The second bracing piece was clamped firmly to the top of the unit (Figure 2.2.2, 2.), on the opposite side to the fixed point. A third piece of framing timber would be used to both brace the unit and mount lights and a camera. Prior to clamping the mounting timber (Figure 2.2.2, 3.) into position, the camera was tested to determine the height required to capture the entire trough. Once the appropriate height was selected, the shelves were adjusted accordingly, and the timber was clamped into position on the opposite side from the fixed timber. When assembling the apparatus, it was essential to consider the height of the trough walls and ensure that all beams can pass over the troughs without disturbing them. Finally, high visibility reflective tape should be attached to any area of the apparatus which pose a risk for tripping or injury.

With the apparatus assembled, the lights and camera were mounted. The midpoint of the mounting beam was determined, and the GoPro mount was attached so that the camera had an unobstructed view of the trough (, 1.). Underneath the beam, the LED light strip was run to provide a continuous reflected light on the water surface, near the centre of the trough (, 2.). Finally, the Arlec work lights were positioned to reflect on the water surface near the outer edges of the trough (, 3.).

Figure 2.2.3

Figure 2.2.3

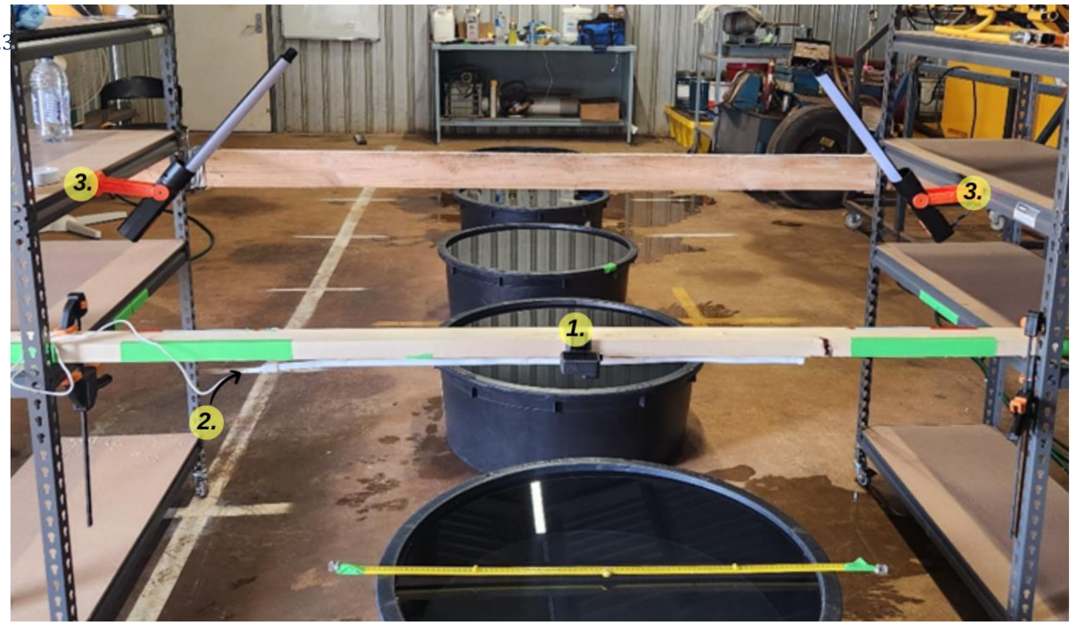

Figure 2.2.3 Annotated sensor and light placement, 1. GoPro13 2. LED Light strip 3. Arlec portable work light

Experiment Design and Method

The spreading and dispersion experiment was conducted within the P1 Laboratory located at the University of Southern Queensland (Toowoomba campus). The use of this facility required appropriate laboratory induction and an approved risk management plan.

Table 4 Doses of WaterGuard applied in spreading experiments.

Dose % of MFR	Dose (ml/m^2)	Dose Applied (ml)
100	1.50	0.75
50	0.75	0.38
40	0.60	0.30
30	0.45	0.23
20	0.30	0.15

The experiment design involved measuring the relationship between the leading-edge position and the application site over time at various doses. At each dose specified in Table 4, five replications of the experiment were conducted. The manufacturer recommended (MFR) dose served as the baseline to compare the results of the gradually decreasing doses to. When determining the minimum dose, the film was observed following application looking for the point where the film did not reach the edge of the trough or displayed any abnormal behaviour.

Each of the water troughs had a folding ruler placed across the diameter to assist in central application and measurement extraction from captured video (Brink et al. 2017). The water troughs were marked and filled to the same depth for each experiment. Once filled the water was left to settle for 15 minutes. At this point the water temperature and air temperature were recorded using a multi-meter with a temperature probe, and the water settled for a further 5 minutes. The reps aimed to be completed within an hour to minimise fluctuations in water temperature (Brink et al. 2017).

To complete a replicate of the experiment the multimolecular film forming chemical was thoroughly shaken to increase homogeneity between the active ingredient and bulking agent. The centre of the folding ruler was lined up with the central point of the trough and checked on the camera. The nominated dose was collected in the syringe, the lights were turned on and the recording device was started. The chemical was applied in the centre of the trough as close to the water surface as possible, avoiding making ripples. The recording device was stopped 30 seconds after the chemical appeared to have finished spreading. For at least one repetition at each dose, the recording was continued for up to 5 minutes to observe the film behaviour. If further observation was required after 5 minutes, a stopwatch was set, and a detailed observation log was kept recording any significant changes in the film behaviour or appearance. Following the completion of a set of five reps, the turnover process was initiated.

Turnover and Contamination

The experiment turnover involved thorough cleaning of the water troughs to remove residual multimolecular film for the next repetition. The viscosity and amphiphilic nature of the film made it challenging to remove from the plastic troughs, thus a standard turnover procedure was developed and followed.

Turnover Procedure:

1. Set up appropriate high visibility caution signs indicating the wet floor and slipping hazards.
2. Use submersible pump and 'dirty' water hose to drain ponds to appropriate location.
3. Once empty, relocate the troughs to a designated washing bay.
4. Apply dish detergent directly to the troughs and scrub the base and walls using an indoor broom.
5. Tip the trough on its side and use the pressure washer to rinse out the soapy water.
6. Apply detergent to a clean sponge and scrub the walls and base of the trough for at least 90 seconds.
7. Tip the trough on its side and use the pressure washer to wash out the soapy water.
8. Pressure-wash the trough on its side for at least 5 minutes, thoroughly cleaning the trough walls and base.
9. Dry the trough using a clean microfiber cloth
10. Touch the walls of trough, feeling for any slippery, slimy or greasy texture that may indicate there is still residual film. If there is no apparent film, proceed to the next step. Otherwise, repeat the process from step 6.
11. Use the pressure washer to rinse the trough of any residual fibres from the cloth.
12. Drain the water and allow the trough to dry ready for its next use.

In the event of unsuccessful turnover, upon refilling the trough a broken film or soap bubbles were observed. In that event, the water was discarded, and the turnover process was repeated. Contamination procedures were also developed and followed to decrease the possibility of failure in turnover.

Contamination Procedure:

1. Ensure separate hoses and hose fittings are used for filling and emptying troughs.
2. Use clean cloths only once during drying of troughs.
3. Pressure wash broom to minimise residual chemical buildup.
4. Use a clean sponge for each turnover to minimise residual chemical buildup.

Data Analysis (method)

The method of data extraction and analysis drew from Brink et al.'s approach of frame-by-frame analysis in Adobe Flash which has since been replaced with Adobe Premier. Videos were loaded into Premier, and the position of the application site, the leading edge and the timecode were recorded. The timecode was recorded at every 3cm interval from the application site, producing 14 data points. This approach enabled data to be processed quickly, while providing data in sufficient resolution. Using MATLAB, the average leading-edge positions were plotted with shaded regions representing the standard deviation, alongside a line indicating the position of the edge of the trough. Each set of data for the different doses were compared to determine any relationships between dose applied and spreading rate. It was also important identify the point at which the edge of the trough began to impact spreading rate, a phenomenon outlined in Brink et al.'s research.

2.2.2. Film Detection

Objectives and Justification

The objective of this experiment was to develop a method of detecting the presence of the multimolecular film on the water surface using remote sensing techniques. Film detection has the potential to play a huge role in smart multimolecular film applications. It does however, present a plethora of challenges as it has not been achieved before to the authors knowledge. For this reason, the first stage of this experiment involved consulting researchers with significant experience in using multispectral, hyperspectral, and other sensing techniques in agriculture. The most desirable result involved detecting the film with drone mounted multispectral sensor as it has the largest in-field application potential.

As research that could be used as direct justification for this experiment is limited, a preliminary experiment was conducted. The experiment was an informal trial to determine whether the multimolecular film had any likelihood of being detectable using spectral imagery with the available sensors at USQ. To achieve this, the film was applied to a container of water and Dr Bikram Banerjee, an expert in remote sensing, operated and interpreted the wavelengths captured by an ASD HandHeld2 VNIR Spectroradiometer. While the conditions for this experiment were not optimal (overcast with varying sunlight) there was a significant change in wavelengths between the clean water sample and the multimolecular film. The key takeaways from the experiment were as follows:

1. The sensor had greater success when applied on an angle to the water rather than from above it. For this reason, using a tripod and halogen light to simulate different sun angles (field goniometer) may assist in detection.

2. There may be some significance in the blue band of light however this will require further testing under formal, controlled conditions.
3. The likelihood of practical application may be low however, it is still worth investigating further.
4. It may be prudent to investigate whether the chemical is UV reactive or can be bound with a dye.

Figure 2.2.4 Preliminary experiment using ASD HandHeld2 VNIR Spectroradiometer on multimolecular film, located outside of P6 UniSQ Toowoomba Campus. (Photographs: Sarah Seton)

Instruments Required

This experiment utilised the same equipment as previously listed in section 3.2.1, with the addition of the following items:

Table 5 Additional Instrumentation Required for Detection Experiment

Instruments and Equipment – Exp 2
Experiment Equipment
Halogen Light
Black Light
Food grade pigment
2 x Tripods
Sensors (*Utilising what is available within UniSQ)*
MicaSense MX Complete Dual Cam *(unavailable due to repairs)*
DJI Multispectral Drone
Cubert Hyperspectral Video Camera
ASD HandHeld2 VNIR Spectroradiometer
Data Processing
Agisoft Metashape *or* Pix4D (spectral image processing software)

Methods

The approach to this experiment involved first determining which sensor was most likely to yield a result. As multispectral imagery is the more desirable result, the focus was directed at utilising spectral imaging prior to alternative options such as UV or pigment. Additional experiment setup was required to create a low-cost goniometer using tripods and a halogen light. The purpose of the goniometer was to control the light position and angle relative to the sensor. This additional controlled variable may make the calibration of sensors and detection of the film more achievable. The decision tree (Figure 2.2.5) illustrates the process that was adopted for developing a detection system.

Stage 1: Wavelength Analysis

The first stage of this experiment involved repeating the preliminary experiment under formal, controlled conditions. Two troughs were filled and placed underneath the data collection frame. In one trough a dose of film at 1.5ml/m^2 was applied, the other trough was left as a clean-water control. The handheld spectroradiometer was then attached to the frame, calibrated and used to capture wavelengths off both the clean water and multimolecular film. This data indicated whether the film induces a detectable difference in wavelengths, which was critical in both

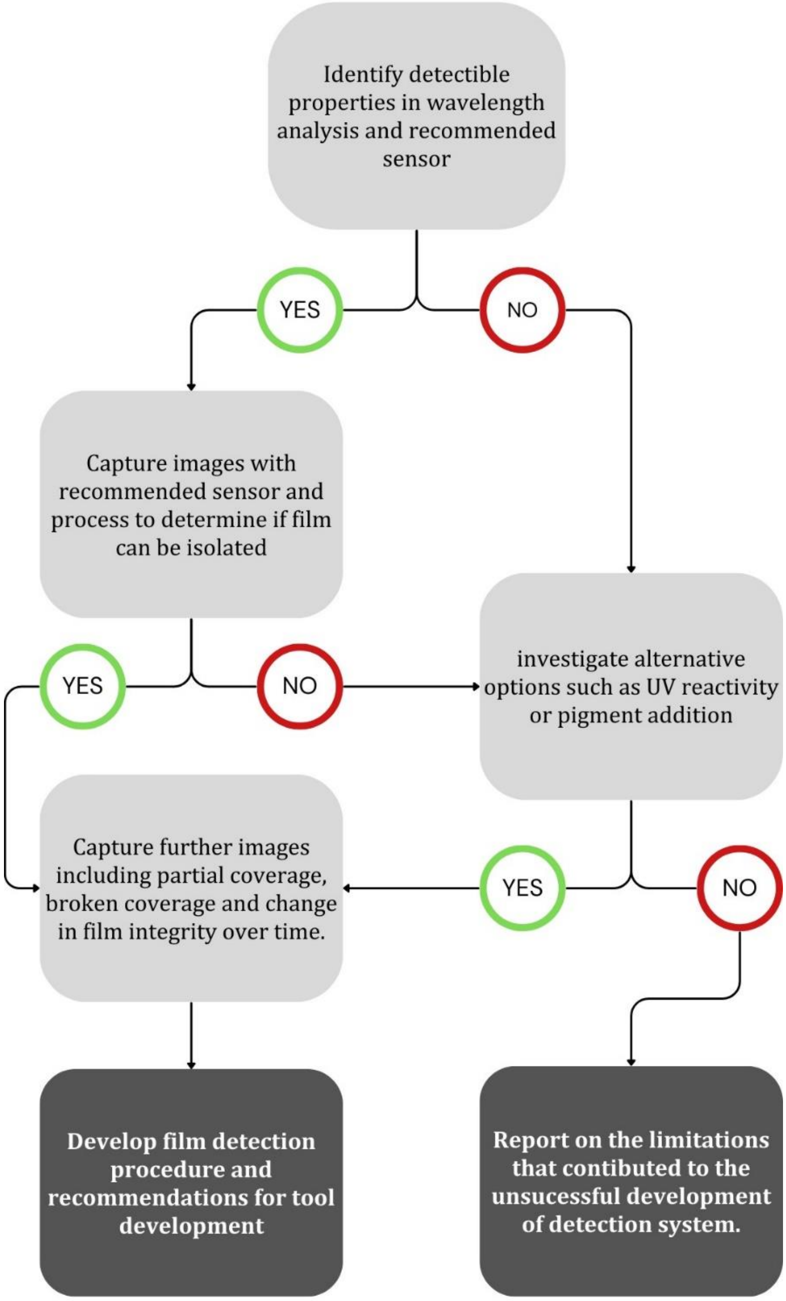

Figure 2.2.5 Detection experiment decision tree.

choosing a sensor for further image capture and post-processing.

Stage 2: Image Capture

Using the sensor identified as the most likely to be capable of isolating the relevant wavelength initial images were collected. These images included both the clean water and multimolecular film for contrast and were taken at multiple 'sun' angles. Post processing was used to isolate the wavelength of interest and determine if the film was detectible. In the event that this was successfully achieved, further image collection took place capturing partial coverage, broken coverage and the degradation of the film over time. Comparatively, if the film wavelength was unable to be isolated in image processing the experiment advanced to the next stage: testing UV response and pigmentation.

Stage 3: Investigate Alternative Options

If the film was unable to be detected in the previous stages, alternative options were considered. First, the chemical was tested for UV fluorescence. If any detectable properties were determined, the image capturing process described in stage 2 proceeded. If there was no UV reaction, a further consultation occurred with remote sensing specialists and polymer chemists to explore the option of binding a pigment into the multimolecular film that would be detectable using a multispectral sensor.

Stage 4: Outcomes

A report on the outcome of the experiment was generated. This report covered the process used to reach a conclusion, the potential for application and any significant limiting factors. Finally, a suggestion was made for either further tool development or future research.

Image Processing

Image processing was completed with the use of both sensor specific software and Agisoft Metashape to manipulate the appearance of the captured images.

CHAPTER 4: RESULTS

The aim of this study was to investigate the spreading properties of WaterGuard at different doses, including finding spreading rates and the minimum dose that can be applied per square meter of water surface. The secondary objective involved investigating the potential to detect the multimolecular film using different remote sensing techniques. In this chapter, the results are presented in three main sections: spreading rate, minimum dose and multimolecular film detection. Each section explores the key findings and observations, and an evaluation of error in the results.

3.1. Spreading Rate

3.1.1. Spreading Curves and Standard Deviation

The experiment investigated the spreading properties of five application rates of WaterGuard, listed in Table 4. At each application rate, five repetitions of data were collected tracking the position of the leading edge of the film during spreading. Spreading curves were rendered by processing and plotting the data for each application rate. Each trial was checked by plotting the five repetitions and visually identifying outliers. The repetition results were averaged exclusive of outliers, and the standard deviation at each data point was determined.

The spreading curves, Figures 4.1.1 to 4.1.5, demonstrated a clear change in spreading rate that occurred as the leading edge of the film approached the edge of the trough. The initial rising limb of the figures provides the most important data to this project; however, the timing and position of the gradient change represents a point of interest. Following the gradient change, there was a sharp increase in standard deviation across all doses, most significantly impacting the final data points. This uncertainty in the average data is represented by the dashed segments of the leading-edge lines. At the application rate of 0.30ml/m², shown in Figure 4.1.5 one repetition of data was excluded as an outlier from the spreading curves and all following analysis.

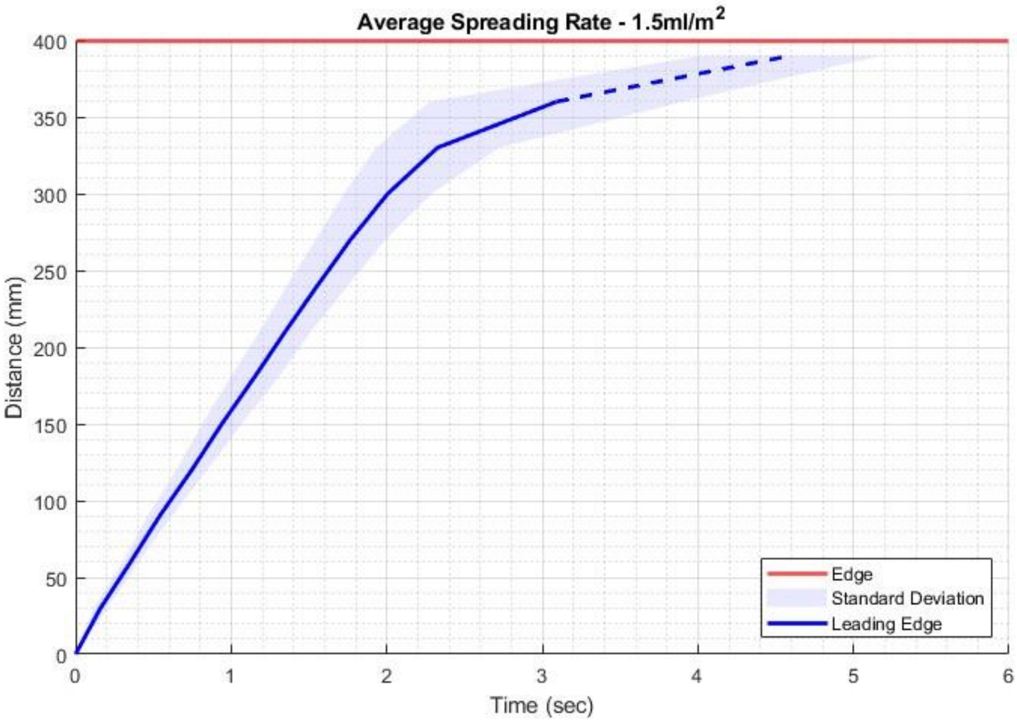

Figure 3.1.1 Spreading curve for the application of 1.5ml/m² (MFR) of WaterGuard.

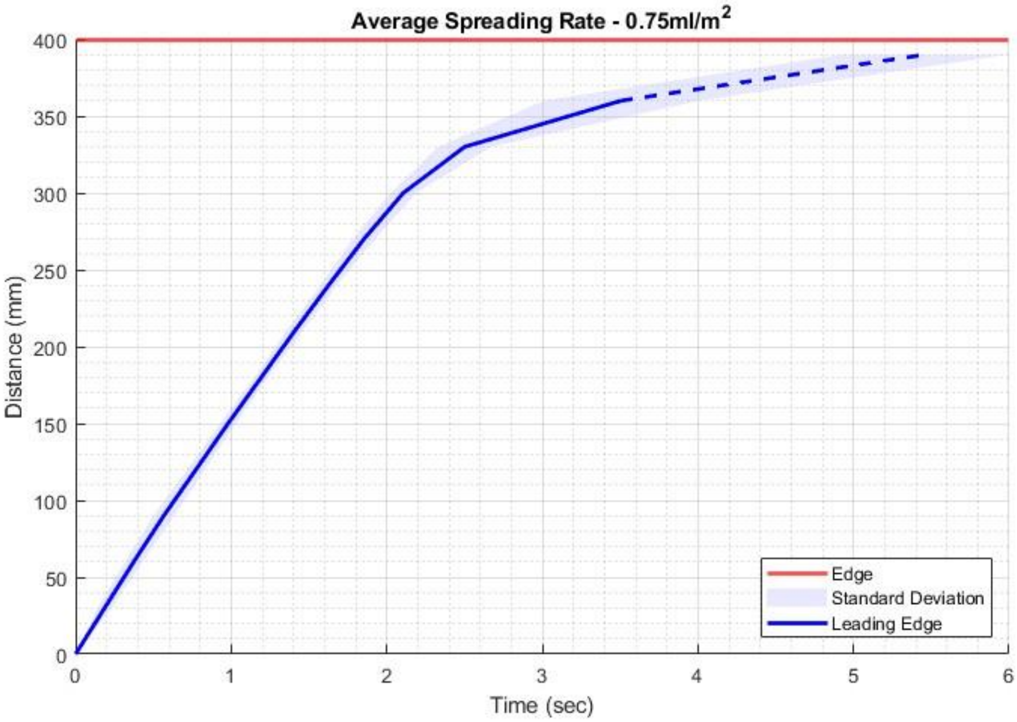

Figure 3.1.2 Spreading curve for the application of 0.75ml/m² (50% of MFR) of WaterGuard.

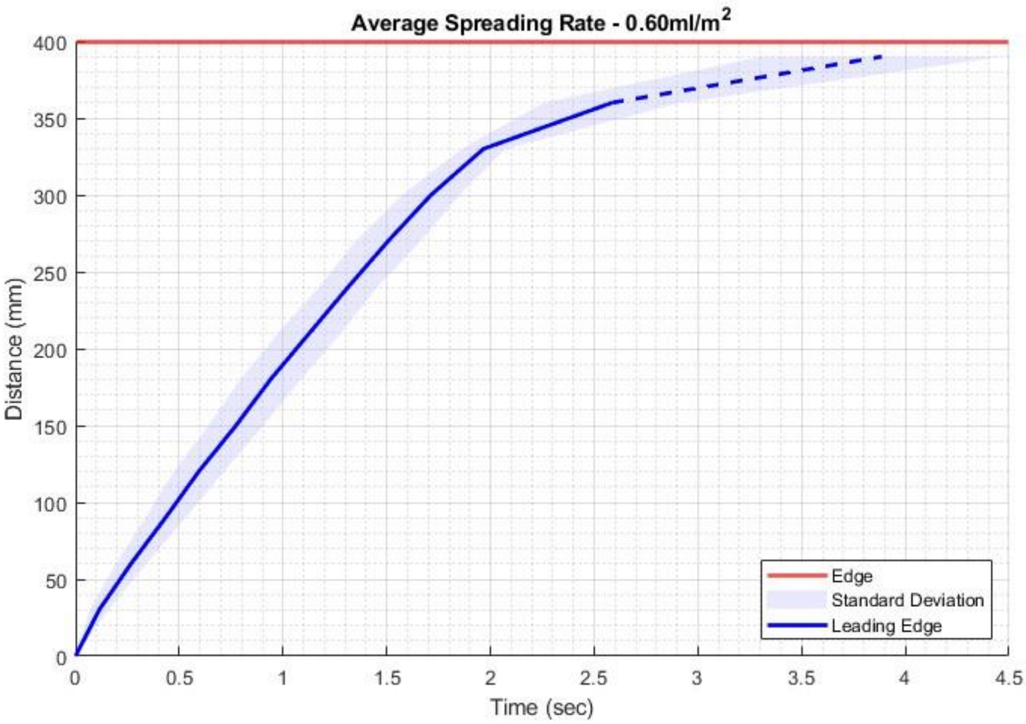

Figure 3.1.3 Spreading curve for the application of 0.60ml/m² (40% of MFR) of WaterGuard.

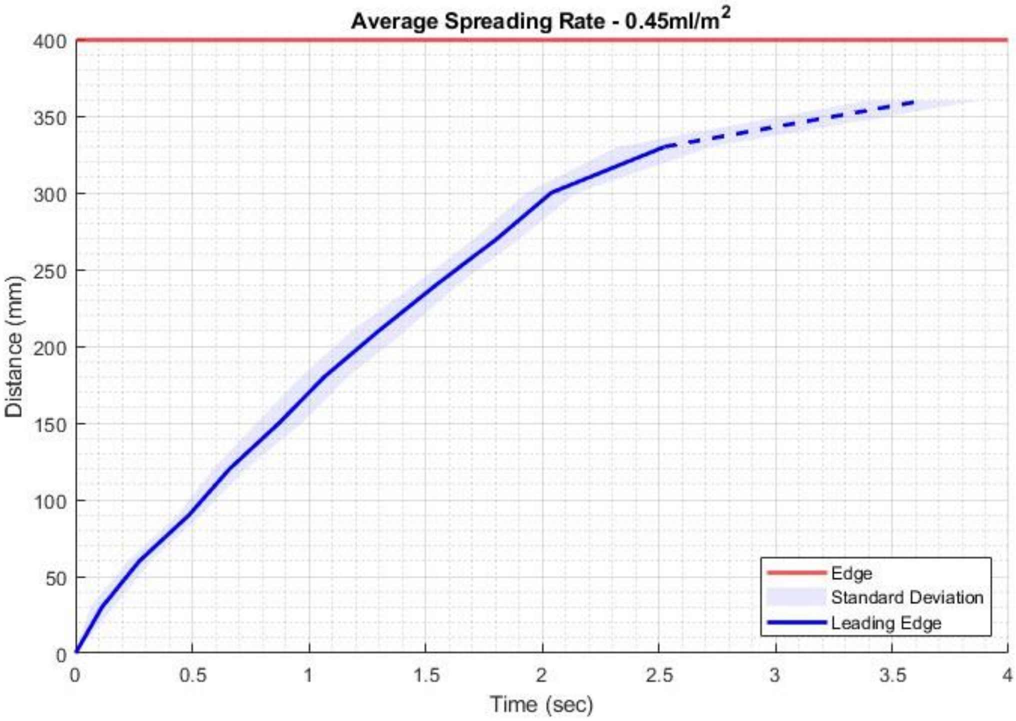

Figure 3.1.4 Spreading curve for the application of 0.45ml/m² (30% of MFR) of WaterGuard.

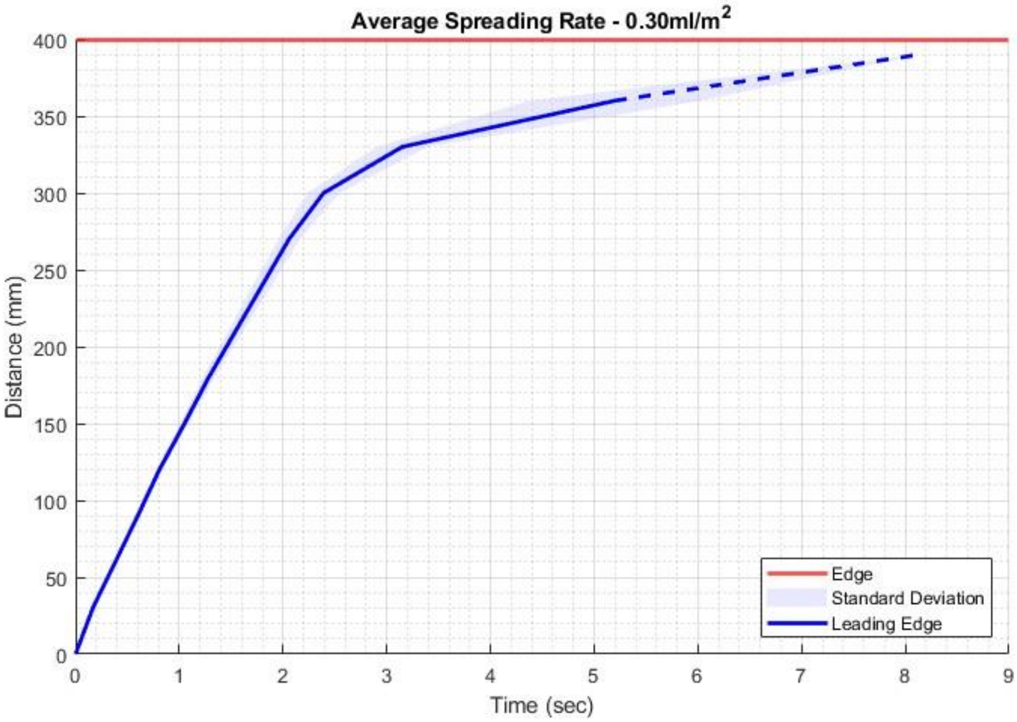

Figure 3.1.5 Spreading curve for the application of 0.30ml/m² (20% of MFR) of WaterGuard.

3.1.2. Spreading Rate

The spreading rate of each applied dose was determined by finding the gradient of the initial rising limb of the spreading curve, prior to the impact of the edge of the trough. This was achieved by fitting a linear forecast trendline to the data prior to significant gradient change, demonstrated in Figure 3.1.6. The gradient of the trendline and the root mean square (R-squared) values were then taken from the linear equation and recorded in Table 6 for analysis.

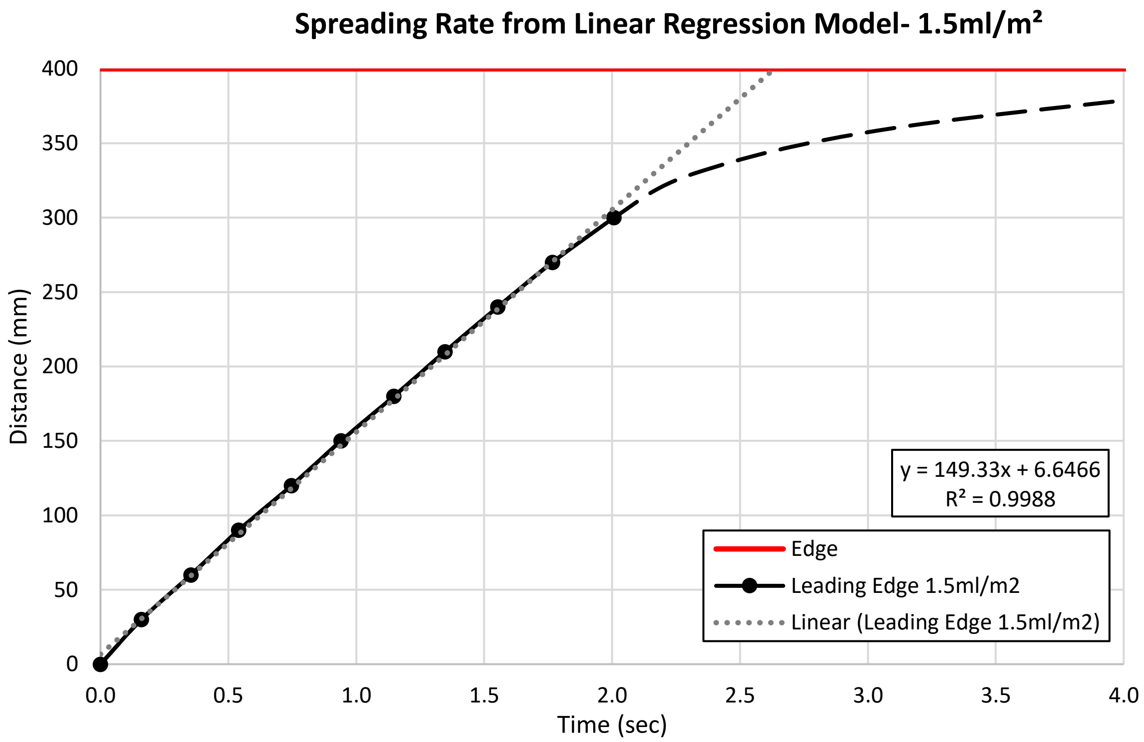

Figure 3.1.6 Linear regression model with equation for determination of spreading rate.

Table 6 Spreading Rates and Root Mean Square.

Dose Applied (ml/m^2)	Rank	Spreading Rate (mm/s)	R^2
1.50	2	149.33	0.9988
0.75	4	142.88	0.9984
0.60	1	173.00	0.9967
0.45	3	143.51	0.9927
0.30	5	132.55	0.9948

The linear regression models all had an R-squared value over 0.99, indicating an accurate fit to the data. The spreading rate analysis indicated that an application rate of $0.60ml/m^2$ spreads significantly faster than all other application rates. At $0.60ml/m^2$ the film spreads 15.85% faster than the MFR dose of 1.5ml/m^2 which was the next fastest result. At application rates of 0.75ml/m^2 and 0.45ml/m^2, the spreading rates were very similar, though the R-Squared value was slightly lower for 0.45ml/m^2, likely due to the slight fluctuations in the regularity of the scatter plot. Finally, the spreading rate for 0.30ml/m^2 was the slowest falling 12.66% behind the MFR and 30.52% behind 0.60ml/m^2.

To provide better visual representation of these findings, the average spreading curves have been plotted together in Figure 4.1.7. These curves clearly demonstrate the different spreading rates, while also highlighting the variability in the location of the point of change in spreading rate across the different doses.

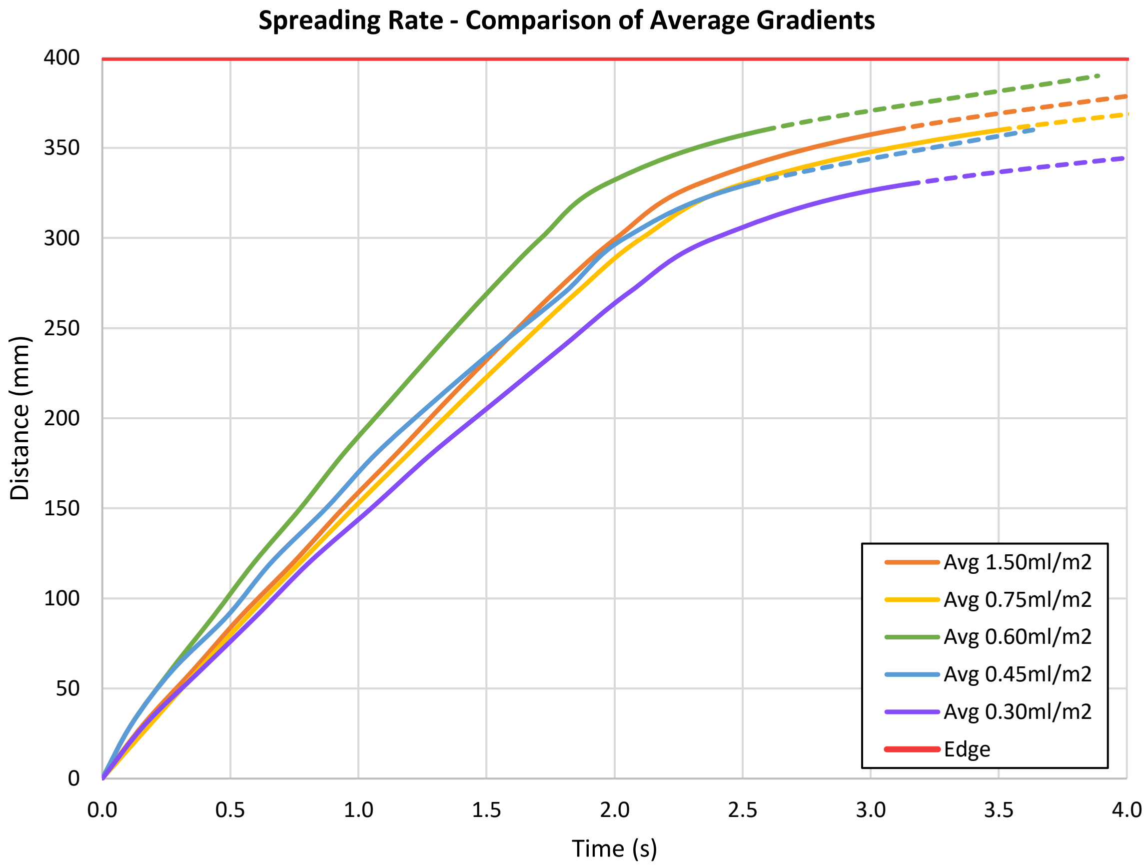

Figure 3.1.7 Combined plot of average gradients demonstrating differences in spreading rate.

3.1.3. Key Findings & Observations

This study found that there is a relationship between the spreading rate of WaterGuard and the dose applied. Specifically, at an application rate of 0.60ml/m^2 the spreading rate is greatly increased.

Observations throughout the experiments revealed two dose-related abnormalities in film behaviour. First, in applications of 0.75ml/m^2 and above when applied to the water surface the film would have an initial spreading event, followed by a secondary spreading event from the chemical that pooled briefly on application. Comparatively, in applications of 0. 45ml/m^2 or less, the film appeared to spread to its own detriment, tearing small expanding holes in the surface as it spread. Neither of these observations were immediately apparent at an application rate of 0.60ml/m^2.

3.1.4. Error Quantification

The experiment contained multiple sources of error including environmental, methodological and observational. First, the laboratory was not climate controlled, resulting in fluctuations in both the air and water temperature. The fluctuations, recorded in Table 7, show a standard deviation of ±0.9°C in water temperature, and ±2°C in air temperature.

Table 7 Temperature Variation across repetitions

Date Collected	Dose Applied ml/m^2	Air Temp. ˚C	Water Temp. ˚C
11/11/24	1.50	28.1	25.9
11/11/24	0.75	29.5	28.2
06/11/24	0.60	34.0	26.1
12/11/24	0.45	31.8	26.0
14/11/24	0.30	30.3	26.4
	Avg. Temp ˚C	30.7	26.5
	ST.DEV ˚C	± 2.0	± 0.9

The decision to reduce the data resolution by taking timecode readings at fixed distances from the application site resulted in potential error of ±0.033 seconds (1 frame) when there was no frame capturing the leading edge precisely aligning with the nominated distance. In addition, data extraction could be challenging if there was a gap in the lighting, potentially leading to small errors in the timecode extracted. This error primarily impacted the final data points as the film approached the edge of the trough and was prone to becoming misshapen or spreading very slowly, which was reflected in the sharp increase in the standard deviation.

Some errors resulted from the scale and shape of the troughs used in the experiment. The round nature of the troughs encouraged currents to form while the troughs were filled. Additionally, ripples were generated upon applying the chemical to the water surface, decreasing the accuracy of the initial measurement. These ripples occasionally reflected off the trough walls and travelled back through the leading edge, having an unknown effect on the spreading rate. Finally, potential contamination of the water from the turnover process, previous repetitions, dust or insects could have impacted the spreading rate and film behaviour.

3.2. Minimum Dose

The minimum dose was defined as the lowest quantity of multimolecular film per square meter that was able to maintain complete cover of the water surface. To determine if complete cover was being maintained, the film was closely observed following application for up to 60 minutes. During the process of determining minimum dose, the film exhibited abnormal behaviour at low doses. It was hypothesised that the film would spread to create a full circle, as observed in Seton's 2023 work, with the film edge failing to reach the edge of the trough. In practice, the film appeared to spread to its own detriment, initially appearing grainy, before developing expanding holes in the film, pictured in Figure 3.2.1and Figure 3.2.2. This effect was challenging to capture on camera thus observation was primarily relied on to monitor the film.

A dose was considered to have failed to maintain complete cover if upon application or in the following 60 minutes of observation, multiple expanding holes formed in the film, or the pattern demonstrated in Figure 3.2.2 was observed. Similarly, attention was paid to how close to the edge the film spread over the 60 minutes. In cases of complete cover, the film would either very slowly reach the edge or reach within 10-20mm from the edge. In cases of incomplete cover, the film would only partially reach the edge in some areas, otherwise breaking apart and mixing.

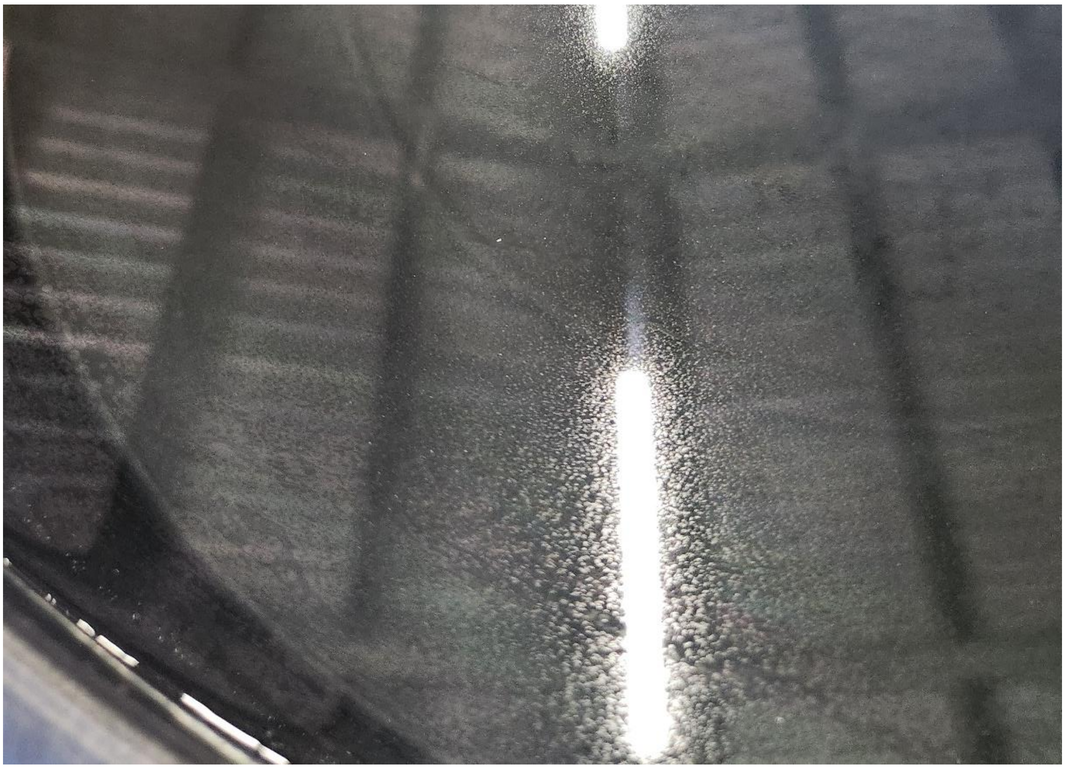

Figure 3.2.1 Grainy Multimolecular Film Section at low doses.

Figure 3.2.2 Anomaly observed in low dose multimolecular film applications.

Key Findings & Observations

It was apparent through observations that application rates of $0.45ml/m^2$ and lower were consistently insufficient to maintain cover. The final data point for all replications was 390mm from application site. In the five repetitions of $0.45ml/m^2$, the film did not reach the final data point. Similarly, only one of the five repetitions of $0.30ml/m^2$ successfully recorded a time for the final data point. In both $0.30ml/m^2$ and $0.45ml/m^2$, the film initially appeared grainy with several holes forming upon application. In the $0.30ml/m^2$ application, the abnormal film behaviour was evident after 6 minutes, where the film began to separate into small, rounded areas. In the following 10 minutes, the film further separated forming the pattern in Figure 3.2.2. The $0.45ml/m^2$ application formed the same pattern however, it took considerably longer for the abnormal pattern to form, reaching a similar visual stage after approximately 28 minutes. In Contrast, at a dose of $0.60ml/m^2$ the film appeared slightly grainy but maintained cover of the water surface over the 60-minute observation period.

3.2.1. Error Quantification

The primary source of error when determining the minimum dose was the reliance on almost exclusively observational data of something requiring considerable interpretation. This can introduce significant observer bias and render the data difficult to replicate. In addition, during the low trials when the film was most prone to breakage, slow mixing due to the residual water current was observed. Finally, due to the sharp increase in standard deviation following the change in spreading rate, any conclusions drawn from the data as the leading edge approached the trough edge may contain considerable error.

3.3. Multimolecular Film Detection

The first stage of the film detection experiment required a wavelength analysis to identify a spectral signature that would enable the film to be isolated when using multispectral or hyperspectral imagery. After testing under controlled conditions, it was determined that a spectral signature could not be identified utilising the sensors available to the author at the time of the experiment. Following the decision tree laid out in section 3.2.2 the multimolecular film was tested for UV fluorescence properties; however, no fluorescence was detected. The final option that was explored was the binding of a pigment into the multimolecular film prior to application, demonstrated in Figure 4.3.1. The multimolecular film was successfully coloured, and initial observations indicated that the pigment did not drop out of the film into the water, as seen in Figure 4.3.2. Due to significant time constraints, further experimentation with the pigmented film was not possible.

Figure 3.3.1 Multimolecular film mixed with green food colouring (Photo: Dr Bikram Banerjee 2024)

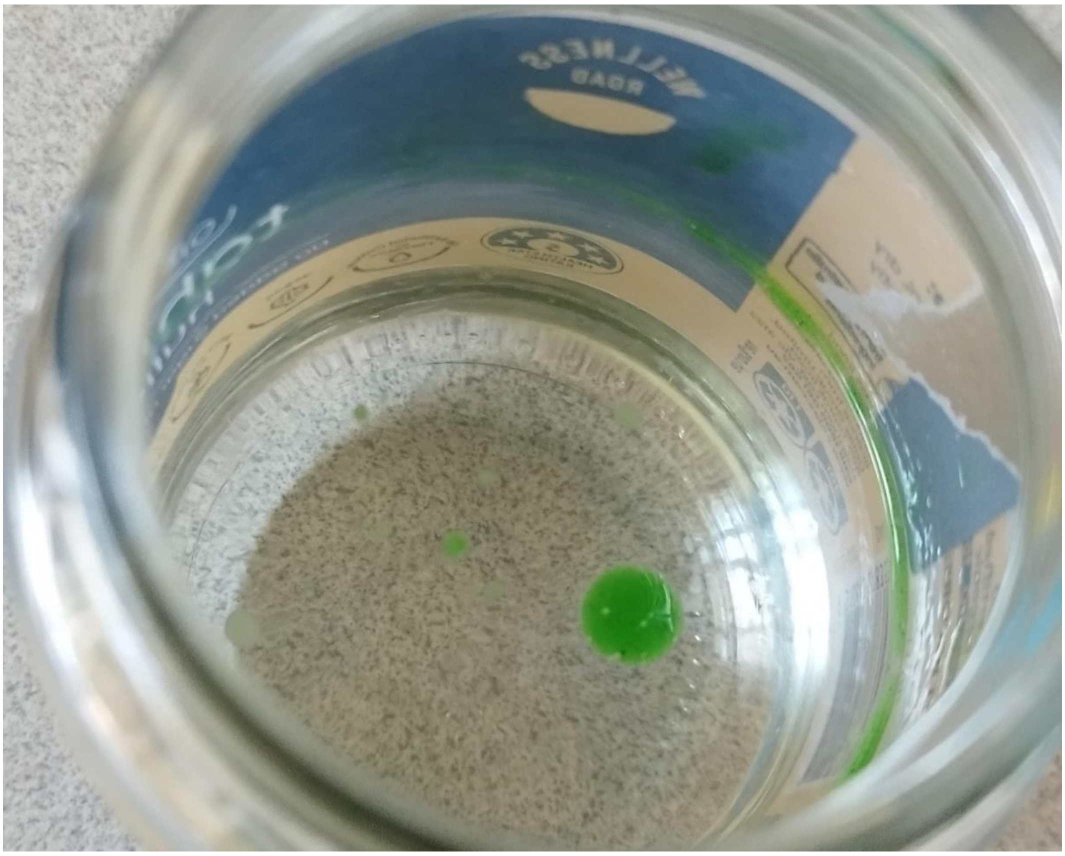

Figure 3.3.2 Dyed multimolecular film on water surface (Photo: Dr Bikram Banerjee 2024)

CHAPTER 5: DISCUSSIONS

4.1. Spreading Rate and Minimum Dose

4.1.1. Overview of Findings

The objectives of this experiment included exploring the spreading properties of Waterguard to find an optimal, and a minimum dose. This information would then be used to produce a recommendation for both the application rate, and the frequency of film reapplication. For a dose to be considered optimal, it was proposed that it would be the lowest quantity of chemical film that can be applied while completely covering the water surface. This dose, and the accompanying frequency of application would be likely to minimise the variability in ESE while maximising the return on investment for the consumer.

The results of this experiment indicate that an application rate of 0.60ml/m^2 spreads most rapidly, while maintaining full cover of the water surface. This result, in combination with the observed film behaviour suggests that 0.60ml/m^2 is the most optimal dose trailed in this experiment. The minimum dose to achieve full cover, likely falls between 0.45ml/m^2 and 0.60ml/m^2 however the slight grainy texture observed in the 0.60 ml/m^2 repetitions would suggest that the minimum is closer to 0.60ml/m^2.

4.1.2. Spreading Trend Analysis

The multimolecular film exhibited a two-phase spreading rate, rapidly slowing as the leading edge of the film approached the edge of the trough. Brink et al.'s 2017 paper discussed the edge effect and adopted the approach of disregarding data collected after a nominated time following which the spreading rate sharply reduced. This approach was adapted, as the point of significant gradient change occurred at inconsistent times and distances from the trough edge across the different application rates. Enhanced accuracy in recording the position of the leading edge near the trough boundary may have revealed the spreading rate pattern observed in Brink's research, reducing to zero over time. However, due to the low relevance of this data to the experiment objectives measurement of the leading-edge position ceased 10mm from the trough edge. Determining the position of the change in spreading rate was challenging. Notably at an application rate of 0.30ml/m^2 the gradient change falls short of the edge by over 100mm. While this appears to support the conclusion that the film did not maintain full cover at this dose, the trend is not consistent across other application rates, and it is thus recommended that further testing on a larger scale is required to validate any related results.

Additionally, the decrease in spreading rate made it challenging to determine the time at which the leading edge reached its pre-determined distance accurately, particularly for the final data points. This was reflected in the sharp increase in standard deviation in the final data points recorded, further supporting the decision to limit conclusions drawn from trends in spreading rate that occurred after the impact of the edge effect.

4.1.3. Dose Dependant Behaviour

The low dose anomaly recorded in section 4.2 was initially thought to be an error due to chemical contamination from the turnover process. After the first occurrence of the phenomena, six clean buckets were purchased, filled with water and <0.1ml doses were applied. In all 6 buckets, the same anomaly was observed as in the previous 5 trough replications. This suggested that the anomaly was not an error due to a failed turnover process, but a behaviour of the film at low doses.

The formulation of WaterGuard features an amphiphilic polymer, designed to increase the self-spreading ability of the multimolecular film. It could be hypothesised that at low doses, when the film is applied to clean water, the polymer's attractive force with the water surface is greater than the attractive force that holds the film together. This hypothesis could explain why the film appears to tear itself apart as it initially spreads. Following the initial spreading event, the film may be spread too thin, slowly conglomerating into the equilibrium film thickness forming the strange pattern observed in Figure 3.2.2. This behaviour could be likened to a rubber band, which stretched just beyond its elastic limit, will begin to exhibit signs of plastic deformation only partially returning to its original shape and size. The implication of this film behaviour is the importance of avoiding applying too little chemical for a given water surface area. While it is difficult to draw any conclusions without further investigation and field trials, it has been previously suggested that when the film is damaged it is more vulnerable to mixing and submergence rendering it less effective (Gallego-Elvira et al. 2013; Schmidt et al. 2020).

The film behaviour at doses of 0.75ml/m^2 or greater is also an interesting phenomenon. Upon application of the chemical, two spreading events were observed. Upon application of the chemical at the higher doses, a small amount of film forming chemical would briefly pool, not immediately dispersing. The first spreading event occurred the instant after the WaterGuard made contact with the water surface. The second event was delayed and appeared to spread from the residual pool of chemical. This behaviour could be linked to low dose behaviour of the film, trying to reach an equilibrium thickness. Alternatively, the second spreading could be pushing the first layer of the film towards the edge of the trough, until the spreading force of the second spreading event is equal to the resistance of the film concentrated around the outer portion of the water surface. The implications of this occurrence are less critical, as they are less likely to significantly impact the performance of the film, and more likely to impact the cost benefit to the consumer.

4.1.4. Error Evaluation

There were several potential sources of error for this experiment, each requiring careful consideration of their impact on the overall results. Steps were taken throughout the experiment to reduce the impact of errors on the results, or to quantify them for consideration in analysis. The errors and implications are as follows:

First, at low doses the active ingredient to bulking agent ratio in the multimolecular film may impact the results (Hancock et al. 2011; Schmidt et al. 2020). This error has been recorded in previous research as it is unavoidable when performing small scale trials of this nature. To minimise this error, before each application the WaterGuard was shaken thoroughly for one minute to promote homogeneity in the mixture. While no further strategies can be employed within this experiment, it is strongly recommended that any recommendations surrounding optimal dose are validated in large scale ESE trials.

Temperature fluctuations in both the air and water within the laboratory also had the potential to impact on the spreading rate of the chemical. While this issue was initially addressed by selecting a climate-controlled facility, such facilities became unavailable due to project delays. Two key strategies were employed to quantify and minimise the impact of temperature flux on the experiments. First, the air and water temperature were recorded at the surface of the water for each repetition of data. Additionally, the data collection apparatus was redesigned to enable all 5 repetitions of data to be collected within a 30–60 minute window. The importance of recording temperature fluctuations throughout the experiment was the impact that temperature has on fluid dynamics. For example, the initial 1.50ml/m^2 application rate trial was conducted at a water temperature of 20.1°C, more than 7 standard deviations outside of the mean. This trial and the results were completely removed from the data set and repeated, as the air and water temperatures were not within ± 3 standard deviations around the mean, significantly effecting the results.

The small size and shape of the troughs used for the experiment encouraged the formation of currents when filled with water. These currents could impact the surface properties of the water and therefore impact the spreading rate and film behaviour. To minimise the impact of currents, as the water filled the hose was moved to prevent a strong current in a single direction from forming. Additionally, the water was left to settle for 20 minutes prior to the experiment. While these measures did assist in reducing the motion of the water, the mixing observed over the 60 minutes following the experiment appeared to be elevated for a windless environment. While the mixing was mild and did not significantly affect the initial spreading rate of the multimolecular film, it would be recommended that any future attempts to recreate or validate the experiment observe longer periods to let the water settle, and if necessary, use a clean sheet of hard plastic inserted into the water to disturb the cyclical current.

Errors due to contamination of the experiment were possible, the primary sources being residual chemicals after the turnover process, dust and insects. As outlined in section 3.2.1, the turnover process went to extensive lengths to prevent this from occurring. In the case of chemical contamination of a replication, the residual film could be observed on the water surface. If this was observed, the replication was stopped, and the turnover process was undertaken a second time. With respect to dust and insects on the water surface, the troughs were filled freshly before each experiment and bright lights were kept turned off until the replication was being completed. Residual film could have significant impact on the results of the experiment, hence the approach of discarding the water and re-cleaning the troughs were necessary. In contrast, the presence of dust and insects was minimal and did not greatly affect the results.

The processing and interpretation of the spreading and minimum dose data could be impacted measurement errors and observer bias. The measurement errors discussed in section 4.1.4 resulted from the decision to decrease the resolution of the data from a frame-by-frame analysis to fixed intervals. These errors could have been minimised by keeping the high data resolution, however the additional processing time required did not make this a feasible option. To minimise the impact to the result, the data extraction process was consistent with rounding decisions when the required measurements were between frames. Similarly, when describing the texture of the film in the minimum dose experiments the observer kept detailed notes to reduce confirmation bias, describing the film in relation to similar textures, or the approximate quantity of holes over a specified number of mm in size within a 100mm^2 area. The errors due to observer bias were not initially considered in the contest of minimum dose, as the film behaviour was vastly different to what was hypothesised. The overall impact of the observational error on the experiment is challenging to quantify, however it would be recommended that for future replication of this experiment, a second camera is set up close to the water surface on an angle to record the film texture over the observational period.

The impact of the edge of the trough and small ripples from the chemical application on the spreading rate was difficult to quantify, an issue also evident in Brink et. al.'s 2017 paper. This error was not able to be minimised outside of ensuring the application of the multimolecular film was very gentle producing as few ripples as possible. However, the edge effect was taken into consideration during the data analysis phase of the experiment but like similar experiments of this nature, further trials at a larger scale would significantly strengthen the validity of the results.

Finally, in the event of obtaining unrepeatable or inconsistent results, the recordings and logbook were examined for contributing factors such as temperature changes, contamination or human errors. If there was clear evidence of mistakes such as residual film on the water surface significant temperature change, the 5 reps were collected again. In the case of an abnormal single repetition of data, the outlier was removed from the data set and all following calculations. This was necessary in the first replication of the 0.30ml/m^2 application rate, where review of the footage revealed that one of the lights was left off, making the position of the leading edge difficult to identify and therefore difficult to measure. The implications of removing an outlier from the results included a smaller sample of data to determine averages and standard deviations from. This may have caused artificially decreased variability.

4.1.5. Practical and Methodological Challenges

Throughout the duration of this project, there were a multitude of practical challenges including delays in funding release, changes in available research facilities and subsequent experiment redesigns. First, and most detrimental to the timeline of the project was the delay in the funding allocation. Funds were not released until late July, causing a significant delay in the acquisition of equipment, experiment setup and data collection. This resulted in the removal of experiments surrounding the films response to climatic variables and reduced the time available to more thoroughly investigate methods of film detection.

Furthermore, the delays in the timeline of the project impacted the availability of facilities. Initially, the project was designed to be conducted in a climate-controlled laboratory within P6, UniSQ. When that facility became unavailable, the project was redesigned for a shared, climate-controlled laboratory space in P9, UniSQ. Unfortunately, despite the extensive redesign, the space available in P9 was impractical and the project would pose a significant safety hazard for the other users of the laboratory. Finally, the project was moved to and carried out in P1, UniSQ. The P1 laboratory provided a large space to complete experiments safely. However, unlike the previous laboratories, P1 was an uninsulated shed meaning air and water temperatures could fluctuate by up to 10 °C in the space of 3-4 hours. These temperature changes significantly impacted the variability of results collected throughout the day, leading to the final redesign of the experiment data collection system that favoured rapid data collection described in section 3.2.1.

Part of the data collection system that needed to be re-considered was the camera used to record replications. Initially, a Samsung galaxy S22 was used to record the replications however, the phone camera had to be set to record in 4k to ensure that the measuring tape was legible. When recording in 4k, the phone was prone to overheating after a maximum of 4 minutes of recording, which was not conducive to performing 5 replications in fast succession. The phone was substituted for a GoPro 13 which was significantly better suited to the application.

4.1.6. Applied Dose Recommendations

Based on the outcomes of this study, the optimal application rate of WaterGuard is 0.60ml/m^2 or 6.0L/ha applied at a frequency of once every 8 days. This application rate not only had the highest spreading rate, effectively reaching the edges of the water surface but also maintained full cover of the water surface throughout the observation period. The frequency of application was directly derived from the MFR dose and frequency of 1.50ml/m^2 once every 3 weeks. The optimal rate is equal to 40% of the recommended rate, and 40% of 3 weeks is 8.4 days. For the purposes of real-world application and practicality, the 8.4 days is rounded down to every 8 days.

4.2. Multimolecular Film Detection

4.2.1. Overview of Findings

The objective of the multimolecular film detection experiment was to investigate potential methods of using remote sensing techniques to detect the presence and integrity of the multimolecular film on the water surface. The results of the experiment were inconclusive: A spectral signature for the film was not able to be identified using the ASD HandHeld2 VNIR Spectroradiometer. The film did not exhibit any signs of UV fluorescence and while the

WaterGuard was able to bind with a food grade pigment, time constraints prevented any further investigation.

4.2.2. Spectral Analysis

Spectral imaging represented the most desirable outcome for detection systems. As spectral sensors become more widely available and are used with drones in agriculture, a system that utilises existing equipment would be ideal. After the preliminary trial using the handheld spectroradiometer showed that when on an angle, there may be some detectable spectral signature. A field goniometer was proposed to take advantage of the potential for detection to be achieved on an angle to the water surface and the light. Due to significant time constraints, the proposal to capture hyperspectral data on a series of angles using the field goniometer was not able to be completed. Instead, the experiment only captured data from directly above the multimolecular film. During the experiment, the sensor showed inconsistent, minor readings on the ultraviolet edge of its spectral range. Dr Bikram Banerjee who helped conduct the experiment, suggested that detection was not possible using the currently available sensors, but recommended further investigation using hyperspectral sensors with a larger spectral range.

4.2.3. Practical and Methodological Challenges

The primary challenge associated with developing method of detecting the multimolecular film was the shortening of time constraints and the availability of sensors. In the proposal for this experiment, the MicaSense MX Complete Dual Cam multispectral sensor was available for use through UniSQ. Unfortunately, the MicaSense was sent away for repairs early in the year and was not available for this project. The remaining hyperspectral sensors had the same spectral range, however the software required for processing data produced by both the ASD HandHeld2 VNIR Spectroradiometer and the Cubert Hyperspectral Video Camera were inaccessible at the time of the experiment. Furthermore, the decision to include an option for binding a pigment to the multimolecular film did not thoroughly consider the implication on both the environment and potential effects that it may have on the spreading properties of the film. Overall, the project delays in combination with an ambitious scope of work resulted in significant cuts to the film detection experiments.

4.3. Implications and Limitations of Research

The limitations of this research, especially in the context of industry applications are significant. First and foremost, the extrapolation required to adapt the results from a one square meter scale to a scale of one hectare or greater is not feasible. The issue of laboratory scale compared to industrial scale is an ongoing problem for chemical EMT research (Schmidt et al. 2020). The requirement for controlled conditions immediately and significantly reduces the scale at which the experiment can be conducted. That being said, the dose recommendations and film behaviours could be validated in a larger evaporation field trial. Once validated, the primary industrial application of the spreading rates, film behaviours and dose recommendations are forming a foundation to build reapplication decision support tools and film behaviour models.

The implication of successfully creating a multimolecular film detection system has the potential to completely change the approach to developing smart application systems. Had this been successful the primary limitation would again be directly linked to development and testing exclusively occurring under controlled laboratory conditions, not accounting for the impact of factors such as cloud cover and variability in water quality and appearance often found on-site.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions and Recommendation for Future Research

This project aimed to investigate the spreading properties of WaterGuard, identifying any relationships between the dose applied and spreading rate and recommending an optimised dose. Additionally, the project trialled different methods of film detection using remote sensing techniques. The experiment revealed that at an application rate of 0.60ml/m^2 the multimolecular film spread rapidly and effectively maintained cover of the water surface. Dose dependant spreading properties were also discovered in the experiments, revealing an anomaly occurring at low doses and a secondary spreading event occurring at higher doses.

The findings of this research suggest that there are significant relationships between dose and the film behaviour, reinforcing the importance of understanding the applied dose when trying to maintain the integrity of the multimolecular film. Improvements in the effective use of multimolecular films in practical applications may be achievable by applying the recommended dose of 0.60ml/m^2 every 8 days. Despite the limited success in the investigation to develop a film detection system, this project has highlighted the need for further research in the area.

Future research in the field is critical to further the adoption of multimolecular films in Australian agriculture and at a large scale, improve the efficiency in which freshwater resources are used across the industry. Farmers and Irrigators in Australia are more likely invest in evaporation mitigation products that are backed by scientific research with comprehensive cost benefit analysis and smart application systems. The following sections highlight key topics and specific research questions that require further investigation.

5.1.1. Climatic Conditions and Evaporation Suppression Efficiency

Further research is required into the multimolecular film properties under different climatic conditions and at a larger scale, to more closely simulate what could be expected in practical applications. This research is vital to the development of smart application systems and decision support tools which are a key step in the adoption of multimolecular films (Schmidt et al. 2020). The following specific research topics need further investigation:

1. The spreading rate findings and recommendations made in this research project require validation on a larger scale including an in-field ESE trial.

2. The impacts of wind on the multimolecular film need to be investigated, identifying the threshold windspeed that induces film drift, the drift velocity of the film, the windspeed that causes submergence of the film and the impact of variable windspeeds on the spreading rate and shape of the film.

3. The spreading rate and film coverage needs to be investigated as a re-application rate on the various stages of film decomposition.

5.1.2. Ecology

Developing an understanding of the ecological impacts of using PDMS based multimolecular films such as WaterGuard is critical to their adoption on Australian farms. Irrigators in key agricultural regions of Australia are bound by a responsibility to protect local wildlife, soil health and the ecosystem. The key concerns requiring further research are as follows:

1. If the water that the film is applied to is being used to irrigated, will residual film build up, impacting the soil infiltration rates or the health of the crop. While this is unlikely to be a significant issue as the film sits at the surface of the water and irrigation pumping generally draws from a deeper point in the water, it should be investigated to ensure that massive and potentially long-term soil damage is prevented.

2. Areas such as the Murray Darling Basin are home to many endangered birds and amphibians which are attracted to the habitat that forms around open water storage, natural or manmade. How will the film impact the wildlife, not only in in terms of ingestion, but in the context of sticking to delicate skin and feathers? This issue is difficult to address but without some certainty, many farmers may be hesitant to adopt the technology.

3. How does the presence of a multimolecular film impact the water properties such as heat flux, gas exchange, dissolved oxygen (DO) content and microlayer health? Furthermore, how do any changes to the above impact the organisms living in and around the water? Extensive microlayer and microbial testing is required in combination with DO and temperature monitoring (Pittaway et al. 2023).

4. Finally, does the presence of the film have any impact on livestock that have access to open water sources for consumption? This question may be less critical under the assumption that the primary application of the film is in an irrigation context thus the farms are likely to be cropping farms.

The adoption of this technology must be considered through the farmer or irrigators perspective. Without knowing the impact that a multimolecular film may have on crop health, soil infiltration rates, or the local ecosystem they are risking their livelihood.

5.1.3. Detection

The development of a film detection method would greatly improve the ability to design the smart application systems, bringing multimolecular film based EMT's into the twenty-first century. At this stage, it is strongly recommended that further research is conducted surrounding the spectral signature of WaterGuard and other multimolecular films. Ideally, testing would be conducted using hyperspectral sensors with a larger spectral range, or the available sensors be properly investigated using a field goniometer and controlled light angles to identify a spectral signature that can be isolated.

5.1.4. Smart Systems and Economics

Ultimately, this project and the research recommendations come down to the development of smart application systems and decision support tools. Initially, decision support tools may be created to factor in weather conditions and forecasting to effectively maintain the integrity of the film. As long-term trials of the smart systems begin to provide consistent evaporation suppression efficiencies, cost benefit analysis may become achievable. This will significantly improve the marketability and adoption of multimolecular films in Australian agriculture.

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APPENDIX A: Risk Management Plan

4636	RISK DESCRIPTION	STATUS	TREND	CURRENT	RESIDUAL
	Spreading and dispersive properties of Polydimethylsiloxane (PDMS) - Experiments (P9 Toowoomba)	Live		High	Medium

RISK OWNER	RISK IDENTIFIED ON	LAST REVIEWED ON	NEXT SCHEDULED REVIEW
Sarah Seton	08/05/2024	20/05/2024	20/08/2024

RISK FACTOR(S)	EXISTING CONTROL(S)	CURRENT	PROPOSED CONTROL(S)	TREATMENT OWNER	DUE DATE	RESIDUAL
WaterGuard or Polydimethylsiloxane is the evaporation suppressant used in this experiment. WaterGuard is an inert non hazardous chemical requiring no PPE for handing (Watergaurd SDS 2019). The primary risks associated are spills or leaks during storage and experimentation.	Control: follow UniSQ procedure for handling and reporting incidents or hazards. (in this case a slipping hazard)	Medium	Store chemical in an appropriate storage container or laboratory chemical cupboard.		13/05/2024	Low
			When pouring or measuring chemical for application to water do so on a workbench or over a container to avoid creating slipping hazards.		15/05/2024	
The experiment methodology calls for dishwashing liquid or degreaser to be used to clean the residual chemical from the water troughs. In the event that this is unsuccessful liquid chlorine will be required. Liquid chlorine is classed as a hazardous substance (Signal word = Danger). It can cause significant injuries when in contact with skin or eye or is inhaled. It is also toxic to aquatic life and thus disposal should follow local guidelines.	Control: All hazardous chemicals must be stored in appropriate Dangerous Chemical Cabinets as outlined by university policy. ——— Control: Hazardous chemical spills must be reported in line with University Incident and Hazard reporting policy. The person using the chemical must also have had the induction required which includes the use of SDS and the chemical spill kit. ——— Control: PPE requirements are in line with those listen on the SDS. For Chlorine this includes, appropriate protective clothing, rubber gloves, safety glasses, and a respirator if required.	Medium	Find a non-corrosive / non-hazardous cleaner that can remove the chemical film effectively.		13/05/2024	Low
Because the experiments will involve a significant amount of filling and emptying 150-300L water troughs there is a very high likelihood of floors becoming wet and slippery creating a slip hazard. When gathering data the student will primarily be alone, however, the laboratory does have shared space so other lab workers/students entering the area is a possibility.	Control: University work health and safety procedures should be followed. Including clear signage of wet floors and required inductions for the lab space. ——— Control: Appropriate lab PPE, specifically appropriate footwear, should be worn at all times.	High	Addition of anti-slip mats through the lab space and workstation. Utilize methods of filling, emptying and cleaning water troughs with minimal spill. Provide ample supplies (mops / towels) to dry out wet areas of floor. Filling - Use of a hose. Emptying - Use of a small submersible pump and hose to direct water down a drain. Cleaning - Use of Outdoor washing bay (P6) to avoid getting soapy water on lab floors.		15/05/2024	Medium
The experiment will have several pieces of sensing equipment that may cause a tripping hazard in combination with the aforementioned possibility of wet floors. These create risk of slips and trips. In combination some sensing equipment will have to be elevated about the water troughs creating a falling risk.	Control: Follow UniSQ policy for reducing slip and fall risks in a workplace. This may include taping any chords to the floor, keeping a clear walkway and increasing visibility of hazards where needed.	Medium	Create a secure brace for all sensing equipment that must be elevated above water troughs to reduce falling risk.		15/05/2024	Low
			Develop and follow procedure for maintaining dry floors. Ensure appropriate signage is displayed when floors are wet.		15/05/2024	
This experiment will require electrical devices to be used around a trough of water. This can introduce risk of electrical shock and damage to equipment.	Control: Follow worksafe qld code of practice for managing electrical risks in the workplace.	Medium	ensure barriers prevent water and electrical connections from having contact in event of a spill. Use devices such as a weatherproof electrical box for things that require power chord. Ensure sensors and lights are securely mounted prior to operation around water.		15/05/2024	Low
This activity will require the handling of water troughs (5-10kgs empty), bending and twisting in both the experiment and the turnover (cleaning of troughs). It will also require maintaining a static position in the data analysis phase.	Control: Follow UniSQ ergonomic workspace assessment and take actions to ensure the area of static work is comfortable and healthy.	Medium	Utilize tools such as a trolly or a second person to move items that are either large or heavy.		13/05/2024	Low
			develop cleaning procedure that minimizes the need for staying in an awkward (bent or twisted) position while scrubbing.		15/05/2024	
There is always the potential for emergency situations when working within a lab setting.	Control: Be inducted in lab spaces to know where the emergency exits, fire extinguishers, first aid kits, gathering points etc are. review emergency plan for the P9.	Low	No Control:			Low

ATTACHMENTS
Waterguard-SDS-V4.1-Issued-July2019-21.pdf HYCLOR Liquid Chlorine 12.pdf

APPENDIX B: Data Management Plan

Products Sarah Seton (Student)

Home | My Record | My Research Outputs | Public Repository | My Projects | Tools | Tray | Tasks

View data management plan

Show changes

Research Data Management Plan (RDMP)

Plan title

Assessment of Multi-molecular films in Evaporation Suppression Under Varied Climatic Conditions

Description

Data will include videos from which the spreading rate data will be extracted, Multi-spectral and Hyper-spectral data (+ processed data) and some basic models surrounding film response to wind speed and decision support.

Language

English

Data Collection

How will the data be collected or created?

How are you planning to collect your data?

Data will be collected and extracted from experiments and observations. For example, in experiment 1 the data collected will consist of measured data like the dose and water temperature as well as video used to extract the spreading rate of the chemical on the water surface.

How will you name and structure your folders and files?

Naming:

file names will identify key features of the file such as file type, experiment and rep, experiment factor (i.e. dose), date and version.

for example – a video file for experiment one at manufacturer recommended dose

VID(file type)_E1(experiment number)R1(rep number)_MFR(dose)_24-05-13(date)

VID_E1R1_MFR_24-05-13.mp4

a document file that is subject to change such as the spreadsheet for data extraction finding spreading rate may be –

XLS (filetype)_E1R1-3(experiment and reps) _SR(spreading rate)_24-05-13(date)_v1-0(version)

XLS_E1R1-3_SR_24-05-13_v1-0.xlsx

Structure:

3 main files splitting the categories of content that will be produced, each file will have subfiles further separating the content by factors such as file type and experiment number.

Sample –

Data

> Experiment 1

>> Video

>> Photo

>> Measured

VERSIONS

13 May 2024 (Sarah Seton (Student))

13 May 2024 (Sarah Seton (Student))

> Experiment 2

> Experiment 3

Processing

> Experiment 1

>> Extraction

>> Models

>> Outputs

Documents

> Report

> Graphics

> Methodology

etc.

Outline how you will manage your file versioning

Versioning will be included in both file names and a table in the file. Each file that is subject to change will have a version history and document information section. Major versions will be saved as copies. Version will be at the end of file name in the format v1.0.

Outline how you will use metadata to describe your data

the metadata will help to identify and describe the data. This will include

- Title

- Creator

- Identifier

- Date

- Subject / key words

- Processing / method

- Version

- File inventory

- Rights (IP)

Add new dataset

Title

VID_E1

Description of the dataset

Collection of videos captured of application of PMDS chemical to water surface to measure the distance of spreading edge from center over time, this data can be extracted to determine the spreading rate.

Type of dataset

Video

What is the format of the data?

video recordings

How does your chosen format and software enable sharing and long-term access to the data?

TBC

Expected size of dataset

Don't know

Keywords to describe the dataset

Video

experiment 1

spreading rate

Does this dataset contain personal information?

No

Does this dataset contain sensitive data?

Unknown

Ethics and Legal Compliance

Are you aware of any ethical issues related to the data this RDMP describes?

No

Please complete an ethics application and link to it here

N//A

Does any of the following apply to your data?

The project is subject to a commercial or contractual agreement with external parties

If other, please specify

How will you manage any ethical issues?

Have you considered obtaining consent for data preservation and sharing?

No

Have you obtained consent?

Will the data be identifiable?

Not applicable (human data not used)

How will you protect the identity of participants if required?

N/A

Is this data of a sensitive nature?

No

How will sensitive data be handled to ensure it is stored and transferred securely?

Does this data relate to First Nations Peoples?

No

How will you manage copyright and Intellectual Property Rights (IP/IPR) issues?

Who owns the data?

Joint Ownership

Please specify parties

Cotton Research and Development Corporation

University of Southern Queensland

Will the data be protected by Australian Copyright?

Yes

Will the data be created or collected outside Australia where equivalent copyright applies?

No

If so, where?

How will the data be licensed for reuse?

At the discretion of UniSQ/CRDC

Are you using existing or third party datasets for this project?

No

Please provide details

Are there any restrictions on the reuse of third-party data?

No

If yes, please explain

Storage and Data Protection

How will the data be stored and backed up during the research?

How much storage do you require?

Less than 5TB

Will you need to include charges for additional services?

No

If yes, please provide details

Do you require storage for non-digital data?

No

If yes, please provide details

Specify where you will store 3 copies of your data.

For more details about UniSQ research data storage options, refer to UniSQ's Research Data Bank (ReDBank)

First copy

UniSQ OneDrive

Second copy

Institute/Centre/Faculty/School MS Teams

Third copy

HPC

How will you manage access and security?

How will you protect your data from loss and unauthorised access?

Data loss will be prevented through the use of maintaining 3 copies at all times in different locations / services. Access to this data will be restricted through both the service access and password protection.

Who needs to access your data?

Michael Scobie (supervisor)

Derek Long (researcher - machine vision expert)

Bikram Banerjee (researcher - hyperspectral expert)

Corey Plant (researcher - multispectral expert)

CRDC (funder)

If creating or collecting data in the field, how will you ensure its safe transfer into your main secured systems?

by utilising sanctioned UniSQ services such as MS teams.

Selection and Preservation

What is the required retention period for your data?

7 years after last action.

At the completion of the project, where will you keep your research data in order to meet the required retention period?

Data will be retained on both the HPC and a University approved storage device

Data Sharing

Is your data able to be shared?

No

Why not?

Contractual intellectual property agreement.

If the data can be listed in Research Data Australia to facilitate reuse and sharing, what level of access to the data will be possible?

Unknown at this stage

Will you share data via a repository, handle requests directly or use another mechanism?

shared on MS Teams and OneDrive

Are there ethical issues or other restrictions in sharing your data?

No

How will this be addressed in line with the relevant ethics requirements?

Responsibilities and Resources

Who will be responsible for data management?

Who is responsible for implementing the RDMP, and ensuring it is reviewed and revised?

Sarah Seton

How will data management responsibilities be split in collaborative research projects?

What resources will you require to deliver your plan?

Do you require training for using any of the hardware or software identified in your data management plan?

No

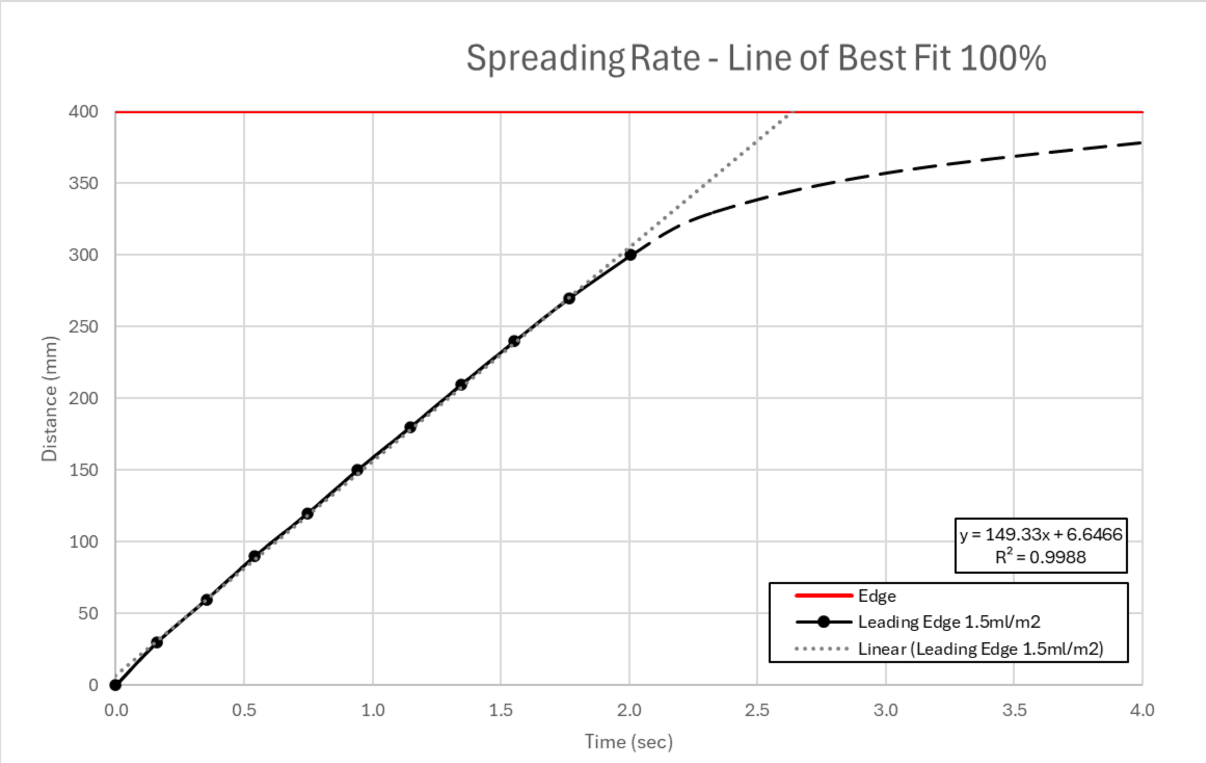
If yes, please provide details

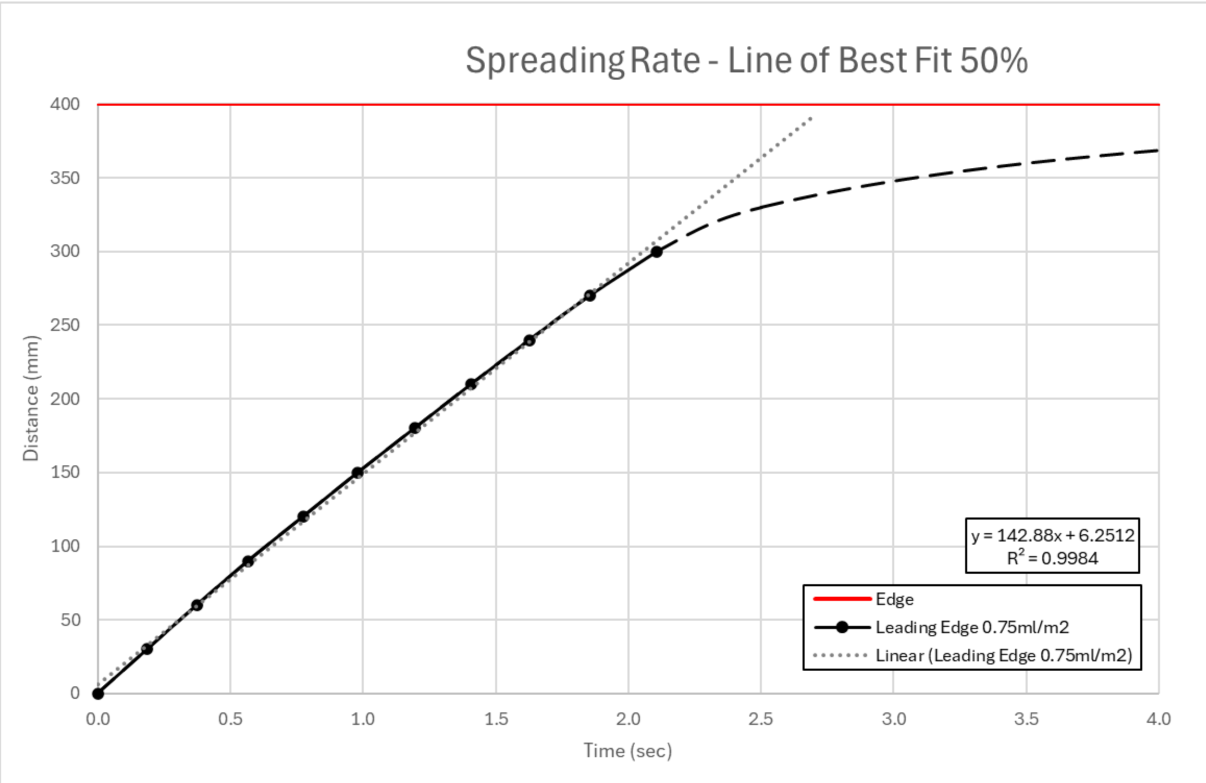
Do you require hardware or software which is additional or exceptional to existing institutional provision?

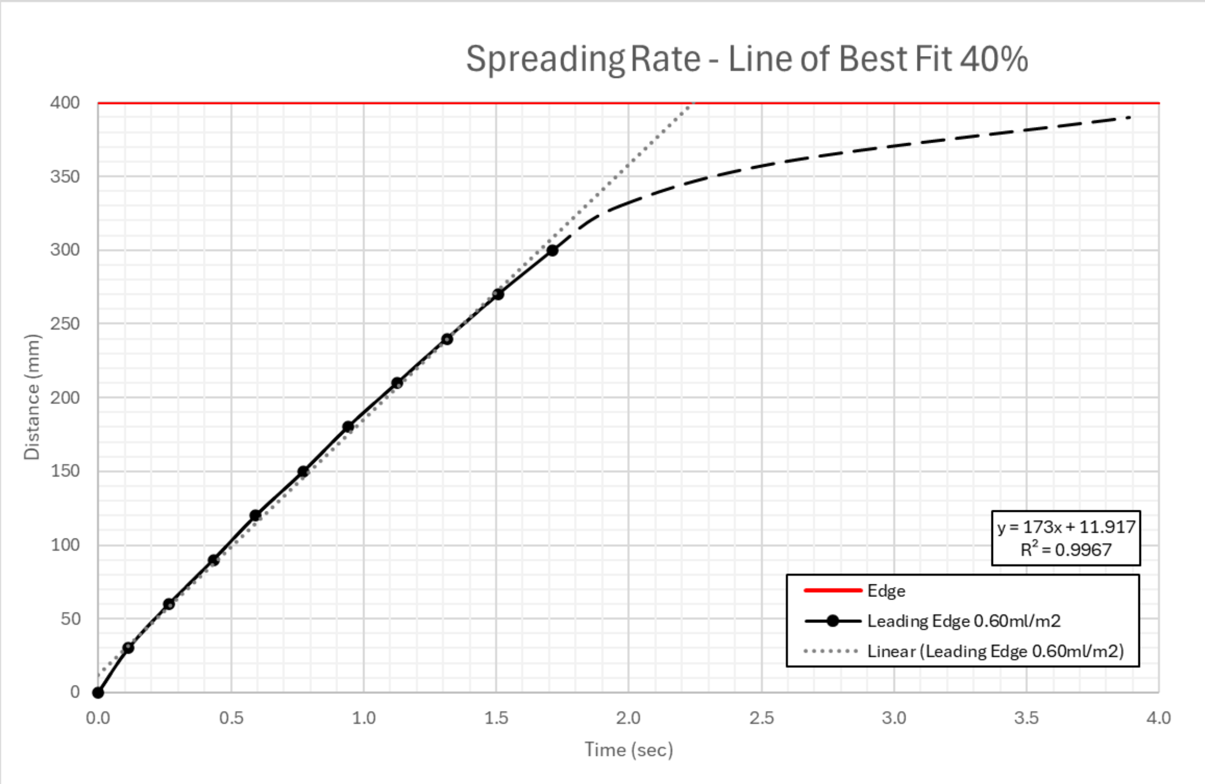
No

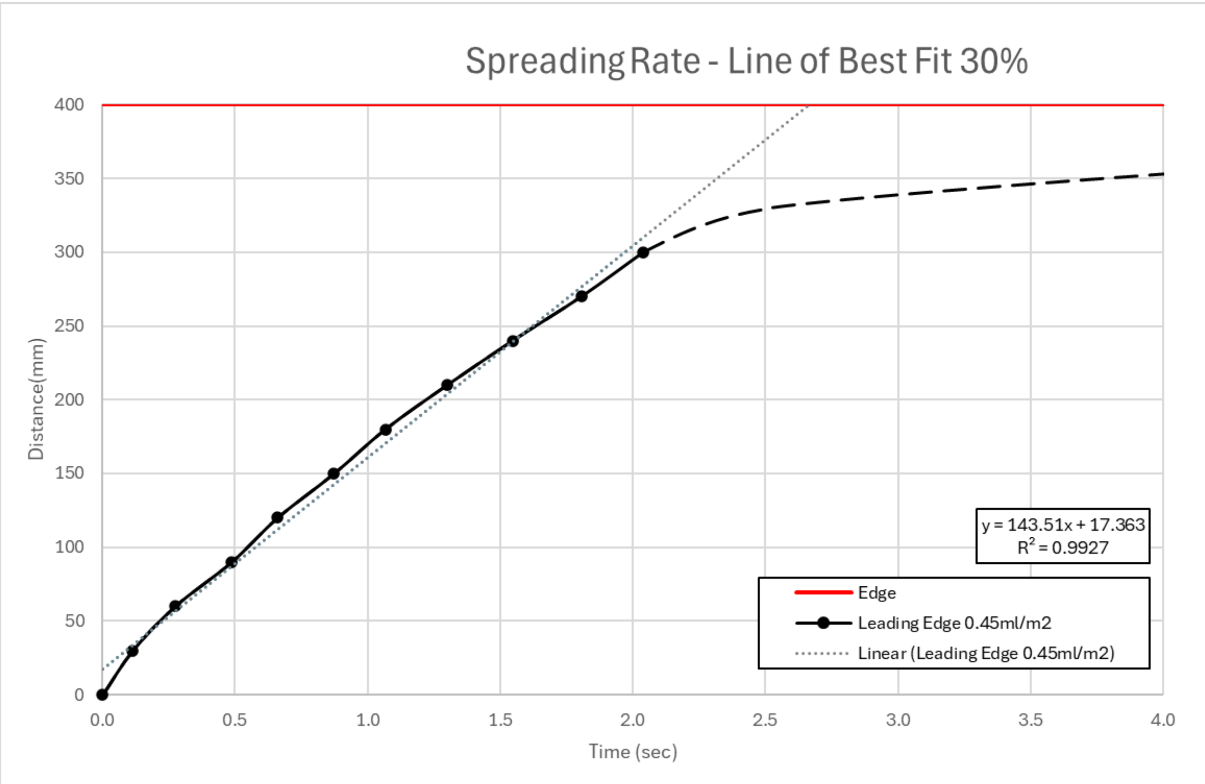
If yes, please specify

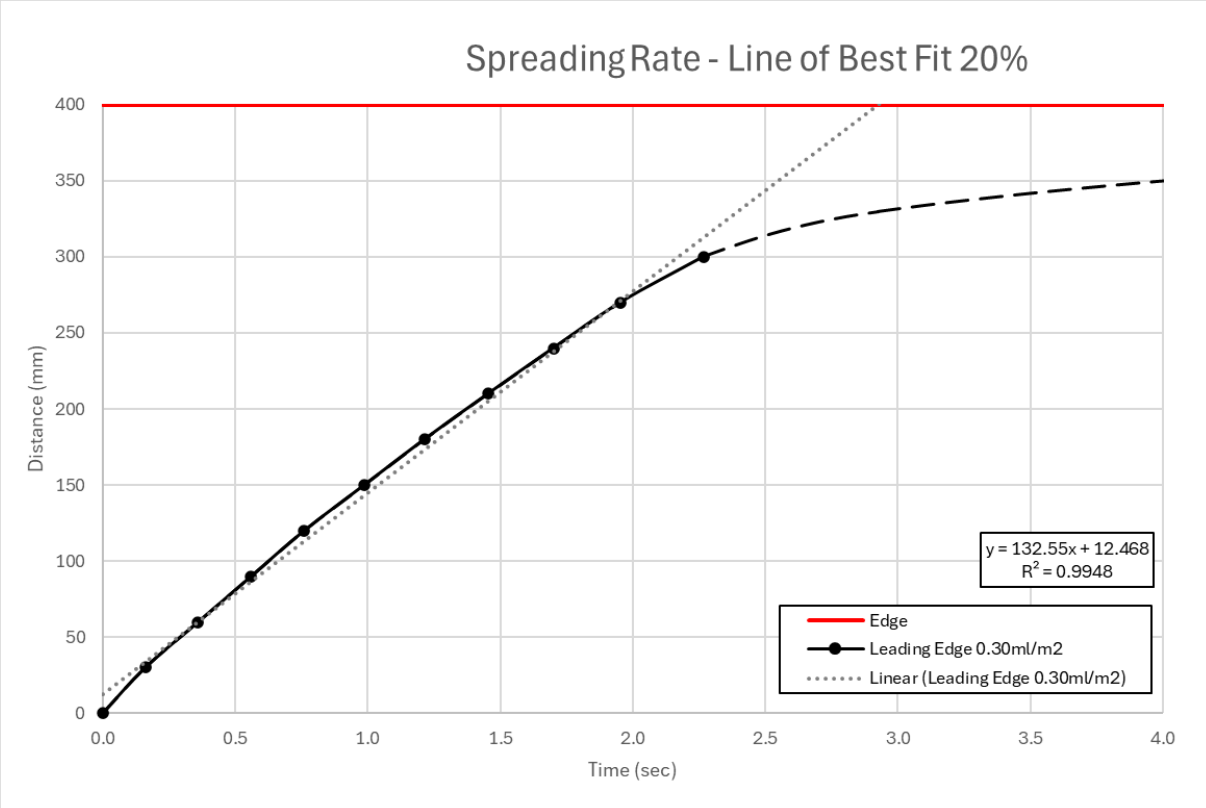
APPENDIX C: Lines of Best Fit






Spreading Rate - Line of Best Fit 40%
Distance (mm)
Time (sec)
y = 173x + 11.917
R² = 0.9967
Edge
Leading Edge 0.60ml/m2
Linear (Leading Edge 0.60ml/m2)
400
350
300
250
200
150
100
50
0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0


Spreading Rate - Line of Best Fit 30%
Distance(mm)
Time (sec)
y = 143.51x + 17.363
R² = 0.9927
Edge
Leading Edge 0.45ml/m2
Linear (Leading Edge 0.45ml/m2)
400
350
300
250
200
150
100
50
0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0



Spreading Rate - Line of Best Fit 20%
400
350
300
250
200
150
100
50
0
Distance (mm)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
Time (sec)
y = 132.55x + 12.468
R² = 0.9948
Edge
Leading Edge 0.30ml/m2
Linear (Leading Edge 0.30ml/m2)