Submission Cover Sheet

554

Fingerboards Mineral Sands Project Inquiry and Advisory Committee - EES

Request to be heard?: No - but please email me a copy of the Timetable and any Directions

Full Name: Dr Simon Bruce Perrin

Organisation: Bendigo and District Environment Council

Affected property:

Attachment 1: Kalbar_Submissio

Attachment 2:

Attachment 3:

Comments: see attached submission

Environment Assessment Unit
DELWP

Dr. Simon Perrin MBBS(Melb), FANZCA,
[redacted]
BENDIGO, 3550
28 October 2020

<u>Re: Kalbar Fingerboards Project, Environmental Effects Statement: September 2020</u>

Please regard this submission as an objection to the Kalbar Fingerboards Project as outlined in the Kalbar Fingerboards Project Environmental Effects Statement 2020 (EES).

My name is Dr. Simon Perrin, retired Medical Practitioner and Mining Spokesperson for the Bendigo & District Environment Council Incorporated (BDEC Inc.). This submission is a supplementary BDEC submission. I felt some obligation to support community values over the destructive mining processes that invariably harm communities as we have seen in Bendigo, Costerfield, Morwell and Stawell by preparing this submission.

Mr Ian McGee (retired engineer) will be submitting BDEC Inc.'s major submission as he has some local knowledge of the site AND the engineering challenges (risks) the proposed mining methods will incur, considering site location, soil types and water vulnerabilities being upstream of Ramsar registered wetlands.

The direct downstream location of two Ramsar recognised wetlands should have led to the immediate dismissal this proposal. We are left questioning the judgement of public servants and environmental regulators who allowed the Fingerboards project to have got to this stage. It would seem <u>intuitively obvious</u> this proposal cannot remain financially viable AND uphold the environmental standards claimed in this document.

My grounds for submitting this objection on behalf of BDEC are economic and environmental and a deep dismay in the EES process itself which is once again demonstrating an extraordinary bias in favour of the Proponent. I believe the process cannot be regarded as impartial or a balanced examination of a proposal.

A. Executive Summary

It is imperative that this Panel look beyond this application for a Mining licence and examine this Company's past performances and future behaviour. The Panel must seriously question whether this project will have any nett benefit. I sincerely hope a sense of responsibility to the Community guides you to look at these other relevant issues.

Failure to reject this proposal will result in a significant loss of confidence in the EES process (which I believe to date has failed to reject any mining application in Victoria). A recent Enquiry by the Victorian Auditor General's Office into Mine Rehabilitation available at
https://www.audit.vic.gov.au/report/rehabilitating-mines?section=
It raises the spectre of no net benefit of mining and highlights the poor Regulatory function of Earth Resources.

Examples of the end of the failure of regulatory processes can be seen in **Appendix A** from our local area Bendigo. What Bendigo was promised and what was delivered (aerial photos) was widely different. Appendix A also includes the Minister's admission from 20 years ago that communities need technical assistance to evaluate Consultants reports that may well be flawed. That recognition fell on deaf ears The mining industry is well aware of this imbalance and has continues to hone their approach knowing that lack of time and assistance renders EES applications a "lay down messier".

This situation has been facilitated by a progressive loss of technical and scientific knowledge within the Regulating Authorities. At some Environmental Review Committees the only tertiary scientific based degrees lie with the Community members. The Community is required to spend valuable time explaining the scientific principles to the Regulators so actual discussion can proceed.

The repeated disempowerment of communities through the EES process carries severe psychological and financial effects on individual landowners. This combined with lack of governmental (all levels) support for fundamental social and environmental values further contributes to the creation of a demoralised, untrusting community.

I would suggest that a loss of public confidence may be more important, to the community as a whole, than one mining company's confidence to manipulate the share market. I am sure during your Public Hearings you will repeatedly see and hear this public distress. Please give it weight.

There is an exponential effect on health and morale inside rural communities (not yet definable economically) that will exceed ANY potential economic weight of the "Fingerboards Project". The biggest risk being the surface stripping of the site which then never proceeds to actual production. This is effectively what happened in Bendigo. The stock market was successfully mined by a few individuals but the gold produced was never going to cover rehabilitation. The legacy of this is evident in Appendix A.

B. THE EES PROCESS and Natural Justice

i) I would first like to express my displeasure at the EES process that allows dismissal of genuine community input into the document tthen when a rather large document (10,000 pages) is displayed, only 40 working days are allowed for assessment and comment by individuals affected by the proposed development. These individuals, who must also hold down employment/ run businesses and/or run families, can only make written and verbal comments in what would otherwise be their leisure time.

ii) No resources are offered to "fact check" company statements or to scrutinise technical appendices with independent consultants. Those affected individuals must attempt to gain basic specialised knowledge, again in their own leisure time, in order to comment intelligently on the proposal. I note it took the company more than 24 months to create this document with multiple paid staff and full secretarial backup. Yet those with serious concerns regarding hazards this mine will entail receive only 40 days to comment with no support.

iii) As Panel Members you have agreed to be party to this process and accept financial reward for doing so. Virtually all submitters supporting the proponents will receive financial reward directly or indirectly AND have permanent residence <u>outside</u> the area of primary impact. This process flies in the face of natural justice but, without huge financial resources, this injustice cannot challenged by the affected adjacent landholders. For these reasons history may not judge your involvement kindly.

C. WHAT IS THIS KALBAR PROPOSAL OFFERING?

This proposal in essence involves the destruction of 1600 hectares, at least some of which is high conservation value land, on the promise of 200 direct jobs (20 of which already exist) and 200 indirect jobs (flow-on effect) over 20 years.

I would argue that Lindenow and East Gippsland will lose a resource with a more sustainable future than ANY extractive industry could possibly deliver. The project threatens low impact, sustainable, ESTABLISHED, industries such as Horticulture, Agriculture, Tourism (camping, fishing, boating, seaside holidaying). To do anything to threaten these industries is incomprehensible. They will be threatened for an exaggerated anticipated employment of 200 employed of mostly skilled <u>already employed</u> workers. This employment is unlikely to benefit the Gippsland economy as most workers will travel to work from outside the area as is routine in mining industrial practice. The Panel may have heard the term FIFO - f"fly in fly out" workers. In this case the FIFO workers will become DIDO workers (Drive In, Drive Out) from Melbourne, should this project reach the construction stage.

D. POSSIBLE OUTCOMES OF THE KALBAR PROPOSAL FOR LINDENOW

The Panel is being asked to allow the destruction of mature vegetation and community upheaval. it is an extraordinary risk to the riverine environment, the local horticultural industry and the pristine environment of the two Ramsar wetlands of the Gippsland lakes. The lakes environment is already under threat from reduced flows (falling precipitation and snow melts) secondary to global warming and previous pollution from mine activity in the catchment.

The tourism industry and the fishing industry risk of decimation by this proposal if any of technical incompetence, regulatory failure, contamination events, catastrophic dam wall failures in ANCOLD compliant dams. , radionuclide contamination/ seepage, and finally metallic ion seepage occur.

Local residents (so called "Receptors") also face similar risks as do the Horticultural and Agricultural industries.

The combined nett downside economic impact will likely outweigh any potential benefit promulgated by the Proponents and Earth Resource's Executives. BDEC Inc. has been informed Earth Resource Executives receive performance bonuses for **successfu**l mining applications. If confirmed, can the East Gippsland Community have any confidence the Primary Regulator will be impartial overseers of a mine with an extra-ordinary number of embedded hazards, including prejudicial adverse effects on the environment, human health, agriculture, horticulture and waterways?

Scenario 1. The mineral resource is confirmed but technical difficulty incurring additional costs prevents proceeding to full production - the mine is abandoned. What benefit to the East Gippsland community has been achieved? A vegetation resource is lost consisting of many pre-european habitat trees. 1,600 ha is a staggering 4,000 acres, 16 square kilometres, with consequent erosion threats, seepage threats, toxic dust treats, radiation threats and water "wars" for decades into the future.

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Scenario 2. The mineral resource is confirmed and the mine is abandoned because the cost of production, processing and transport far exceeds the market value of the product. Out come? - same as scenario 1. Oresome and GHD reports confirms the tenuous viability of this proposal unless "dry" mining is invoked to reduce cost (of water) at the expense of human health and potential catastrophic regional contamination. Kalbar repeatedly states it will be dampening dust with water stored onsite from winter water harvesting and processing recovery. There appears an incongruity between the GHD advice and Kalbar's undertakings in this EES.

How much water will be required just for dust suppression alone?

PTO

E. POSSIBLE OUTCOMES OF THE KALBAR PROPOSAL FOR LINDENOW cont.

An absolute minimum estimate of this can be gleaned from local Pan Evaporation measurements. Daily pan evaporation averages 3.81 mm /day on an annualised basis. This equates to 1390 mm per annum. Equivalent to 1.3 gigaLitres per 100 hectares per annum.

Assuming the total area of mine activity at any one time is 60 hectares, one 30ha "void" of rehabilitation/storage and one 30 ha void actively mined (2 sites of 300 metres X 1 km = 600,000m2 or 60 hectares). To cover **evaporation alone over 60 ha** will require something of the order of 1.3 gigaL X 60/100 = **0.76 GigaLitres /annum** or 2.1 megaL/day to cover that evaporation.

That does not include water to maintain dampness, compensate for seepage through porous sands, road dust suppression or more extensive disturbed mine area. These and other water requirements will place a huge burden on the Mitchell Basin, Ramsar wetlands and the other licensed users particularly in drought years when winter river flows barely exceed summer flow rates.

Scenario 3. The resource is confirmed but is in the hands of a company, which to date, has not actually mined mineral sands. Kalbar still asks the East Gippsland community to accept on blind faith that it has the technological and financial ability to "pull-off" this project. Rio Tinto could not see this as a financially viable prospect some 10 years ago, yet an unknown company with no proven performance stakes such a claim.This claim must be strongly questioned.

The implications of anonymous multinational investors in a local environmentally hazardous mine of dubious profitability should raise alarm bells for everyone with East Gippsland's best interests at heart.

F. PREFACE TO THE REMAINDER OF THIS SUBMISSION

The remainder of this submission will be in two parts. One will deal with problems related to systemic issues embedded in the very nature of the EES process.

The second will briefly expand on a few Project specific problems that became evident whilst examining systemic failures of process. These problems cannot likely be prevented or mitigated, if this project is to maintain financial viability. The Proponent has a vested interest in having as many of environmental, health and rehabilitation risks estimated as "low" to minimise expensive mitigation directives. These risk estimates become evident as one navigates through Document 24,Attachment-F, Risk Report. Discrepancies appear evident in the Risk Matrix approach. Specific project issues will be discussed as the debatable risk ratings are pointed out. PTO

Not surprisingly these risks fell into 5 easily anticipatable groups namely;-

i) water allocation and supply impacts on other users and the environment
ii) water contamination impacts on other users and Internationally recognised Ramsar Wetlands
iii) Dust contamination impacts on nearby residents, local horticultural industries. This dust will be an amenity and health issue.
iv) The safety issue using dispersive sands for tailings facilities risking catastrophic failure upstream of human users and Ramsar Wetlands.
v) Pre-commencement deposit of an adequate Rehabilitation Bond

G. SYSTEMIC ISSUES WITH EES PROCESS

1. **Natural Justice - see Section B above**

2. **Potential Conflicts of Interest with regard to consultants acting for the proponent. There are at least 65 prepared documents in this EES totalling 10,000 odd pages with 18 chapters, 22 Appendices, 15 Attachments, 10 Miscellaneous documents.**

3. **Multiple consultant drafts are routinely vetted by the proponents BEFORE release. One in three Environmental Consultants self report to have compromised environmental findings or down played the significance - see Appendix B. This publication reveals the pressure environmental consults are under to "water down" impacts. Without viewing first drafts submitted to Proponent there is no mechanism to know the veracity of any favourable report we are offered. We can be confident the Proponent is not checking drafts merely for spelling errors, many have slipped through! There is NO EES information promulgated by consultants completely independent of the mining industry, if not the Proponent. Unfortunately our Regulatory Agencies no longer have the in house knowledge or staffing to reliably assess such large technical documents.**

4. **Risk Matrices are used in 35 (!) Risk Assessments scattered through the EES document. Risk Matrices use a Liekert Scale with 4 or 5 levels of the seriousness of event consequence juxtaposed against the 4 or 5 liekert levels of likelihood. Neither scale of Likelihood or Consequence has a mathematical definition. Each is subjectively defined by loose verbal criteria. See Appendix E. The end result is another Liekert scale supposedly defining risk. Matrix Risk Assessment is fundamentally flawed being statistically invalid to the point that incongruous risks inserted into a matrix may be mathematically worse than a random guess! Jerome et al Appendix D.**

H. PROJECT SPECIFIC PROBLEMS EVIDENT WHEN EXAMINING RISK MATRICES

The process Matrix Risk Assessment process is wide open to abuse if the matrix formatter has an agenda to satisfy. Such as might occur in the revision of "drafts" submitted for appraisal to a contracting company or Proponent. . There are 33 (!) separate matrix tables in this EES assessing in excess of 200 items.

AppendixA003 p. 104, A008 p30
Appendix A007 p89, A014 p 4
Appendix A016 p70, A017 p 178, 184, 185
Appx A018 p98, 103-105, 112-113, 123, 130, 136-139, 145,156, 162, 166-196
EES Appx C p14
EES Document 20 Attachment B p5-3, 6-4, 6-5, p 205-212, p481- 488
EES Document 22 Attachment D p431-433
EES Document 24 Attachment F p7-18
Chapter 9 p323, 330, 338-342,
Chapter 10 p 61-62, 108, 117-119, 130, 141-142, 145-146, 155-156
Works Approval p54-56

Some risk assessments in this EES are simply bizarre. Examples follow in the following pages with commentary attached. Note this is a VERY limited critique because of the incredibly short time frame to cross reference 10,000(!) pages of selectively reported and interpreted studies. The following are examples of debatable risk conclusion. A low risk rating would seem imperative for project viability. The Proponent has a vested interest in ensuring final low risk status. Even a moderate risk requires additional mitigation with the associated expense.

EXAMPLE 1.

Document 24 /Attachment F page 1, Row 1 ,

Agriculture and horticulture,

Value -Fertile Soils,

Hazard - Contaminants transported by air (dust) and water, Mechanism - Physical disturbance, discharges and emissions,

Impact - Lost horticultural crops or reduced productivity due to dust deposition,

Standard mitigation -

Areas will be cleared in a staged manner, and only as required, to reduce dust generation by minimising the area of exposed ground at any one time (AQ01).

Drop heights for topsoil and overburden will be minimised as far as practicable to reduce dust generation (AQ03).

• Speed limits will be implemented and enforced on unsealed project roads to minimise dust generation (AQ04).

Phase - C,O,CL,

Likelihood - possible,

Consequence - moderate,

Additional Mitigation required -

• Topsoil stripping will be planned and conducted taking into account forecast and actual weather conditions to minimise dust generation (AQ05).

• Dust generation from haul roads will be controlled by applying water or chemical suppressants, cessation of haulage during adverse weather conditions, and as required in response to real-time air quality monitoring (AQ16).

The risk matrix (analysis) concludes

Final Likelihood - Unlikely,

Final Consequence - Minor,

Final Risk - Low !!!!!

Comment:

Contaminated edible vegetables are not a moderate consequence. It has the potential to shut down an entire industry and have Australian produce banned in China, Japan, Europe, if such contamination is detected during import. If the probability of such risk is allocated as "Possible" OR consequence is allocated as "Moderate" in view of potential impacts on international markets this risk becomes MODERATE.

Mt Moornarna wind data (Appendix F.) reveals at least 65 days with wind gusts of at least 50km/hr. A speed well above that required to elevate PM10 dust.

Which regulator will monitor hour to hour cessation in unfavourable climatic conditions?Does anyone seriously believe the Proponent will routinely cease activities on one in six days when high wind events are likely?

How much additional water will be required for dust suppression above evaporation?

EXAMPLE 2.

Document 24 /Attachment F page 9, Item/Row 4 ,
Specialist Study *Surface Water,*
Value -Surface water
Hazard - Mine and associated infrastructure
Value - availability and flows
Mechanism - Abstraction of water
Phase - C,O,CL,
Impact - Groundwater drawdown from project extraction transmitting to overlying surficial (sic) alluvial aquifers, reducing base flow to the Mitchell and/or Perry rivers and impacting on licenced (sic) users and other beneficial uses
Standard Mitigation

- **Water will be recovered and reused where practicable (such as runoff from ore stockpiles and supernatant water from the temporary TSF and tailings areas within the mine voids SW23).**
- **Surface water will be managed through an adaptive management strategy that includes trigger levels for surface water quantity and quality that determine when remedial action is required (in consultation with affected stakeholders) (SW28).**
- **Groundwater will be extracted from the Latrobe Group Aquifer in line with the conditions, timings, and limits detailed in a licence issued by Southern Rural Water**

Likelihood - rare,
Consequence - major,
Risk - Low.
Additional mitigation - hence "none required" .

Comment:
This risk assessment must be seriously questioned.
If this Likelihood was estimated as "unlikely" the actual risk would be MODERATE requiring Additional Mitigation. Such as purchasing additional water from outside the catchment or paying a premium to current users to wind back their business and sell water rights. Kalbar's business margins appear so tenuous that at the additional expenditure would likely spell the end of the project.

More importantly by whom and how was the "RARE" likelihood determined? "Possible" would seem a more realistic label this event has even occurred elsewhere even in Victoria viz. Costerfield, and is likely over the 20 year life of the project e.g. in a prolonged drought event. Did this likelihood determination occur before or after consultation with the Proponent? Appendix B is may be relevant here. One third of environmental constants admit to downplaying advice. We are not offered the providence of the individual Risk Assessments or Draft Versions. Again this fails the principles of natural justice. The overwhelming odds favour the Proponent who can submit claims knowing Community Reviewers have neither the time (40 working days) nor the funds (and then only after tax) to thoroughly investigate claims of "low risk". Some of which are clearly debatable.

EXAMPLE 3.

Document 24 /Attachment F page 9, Item 5 ,

Specialist Study *Surface Water,*

Value -Surface water

Hazard - Water,

Value - Surface water availability and flows

Mechanism - Abstraction of water

Phase - C,O,CL,

Impact - Reduced flow rates in the Mitchell River from project extraction impacting water dependent ecosystems, recreation, aesthetic enjoyment and traditional / spiritual values

Standard Mitigation

- **Surface water will be extracted from the Mitchell River in line with the conditions, timings, and limits detailed in any licence issued by Southern Rural Water (SW01).**
- **Mine contact water from outside of the mine void, temporary TSF or process water dams that is retained in water management dams will be offset by releasing the same volume of water from the freshwater storage dam. Water will be released downstream of the project area (to the Perry River catchment) or directly to the Mitchell River via the pipeline from the freshwater storage dam (SW03).**
- **Water will be recovered and reused where practicable (such as runoff from ore stockpiles and supernatant water from the temporary TSF and tailings areas within the mine voids) (SW23).**
- **Surface water will be managed through an adaptive management strategy that includes trigger levels for surface water quantity and quality that determine when remedial action is required (in consultation with affected stakeholders) (SW28).**
- **An adaptive management strategy will be implemented, based on water quality and quantity monitoring results, to determine whether offset water that would typically be returned to the Mitchell River may be directed to ephemeral drainage gullies in a controlled manner (SW35)**

Likelihood - Rare, (*definition - has occurred once elsewhere)*

Consequence - Moderate,

Risk - Low.

Additional mitigation - "not required" .

Comment

As in Example 1 , if likelihood was awarded "possible" this risk would become MODERATE and further mitigation would be required at considerable expense. This form of impact is repeatedly witnessed in the Murray Darling Basin as a consequence of water extraction. It is not a "rare" occurrence. Additionally, the definition of Major "consequence" is one where the "viability of (sic)value is reduced to some extent but stays within catchment". Loss of tourist income to a world recognised Ramsar site would seem to fit the definition of Major.

EXAMPLE 3.cont.

Comment cont.

Unlike example 2 above, the actual impact on water dependent ecosystems and recreation in downstream Ramsar recognised wetlands will likely impact on the monetary value attached to the recreational enjoyment e.g. tourism, fishing.

Is not a foreseeable risk of impact on Ramsar recognised ecosystems itself a "major" consequence?.

Does a moderate consequence of such a circumstance really sound plausible? Most likely further mitigation would require purchasing additional water from outside the catchment or paying a premium to current users to wind back their business and sell water rights to enhance environmental flows. Kalbar's business margins appear so tenuous that at the additional expenditure would likely spell the end of the project. The availability and cost of water influenced Rio Tinto's reticence to proceed with this mine.

Again by whom and how was the "RARE" likelihood determined? Did this allocation occur before or after the Proponent viewed the draft of Document 24? Were consultants given some form of informal briefing before the contract awarding? Again, we are not offered the full providence of the individual Risk Assessments or the Draft Versions.

Likewise, this fails the principles of natural justice. The overwhelming odds favour the Proponent who can submit claims knowing Community Reviewers have neither the time (30 working days) nor the funds (and then only after tax) to thoroughly investigate claims of "low risk".

EXAMPLE 4 .

Document 24 /Attachment F page 9, Item 8 ,
Specialist Study *Surface Water,*
Aspect -Surface water
Hazard - Water
Value - availability and flows
Mechanism - Abstraction of water
Phase - C,O,CL,
Impact - Reduced flow rates in the Mitchell River from project extraction impacting other licenced users (primarily year round irrigators)
Standard Mitigation

- **Surface water will be extracted from the Mitchell River in line with the conditions, timings, and limits detailed in any licence issued by Southern Rural Water (SW01).**
- **Mine contact water from outside of the mine void, temporary TSF or process water dams that is retained in water management dams will be offset by releasing the same volume of water from the freshwater storage dam. Water will be released downstream of the project area (to the Perry River catchment) or directly to the Mitchell River via the pipeline from the freshwater storage dam (SW03).**
- **Water will be recovered and reused where practicable (such as runoff from ore stockpiles and supernatant water from the temporary TSF and tailings areas within the mine voids) (SW23).**
- **Surface water will be managed through an adaptive management strategy that includes trigger levels for surface water quantity and quality that determine when remedial action is required in consultation with affected stakeholders(SW28).**

Likelihood - Rare,
Consequence - major,
Risk - Low.
Additional mitigation - "none required" .

Comment
This risk assessment too, must be seriously questioned. If Likelihood was estimated as "possible" or even "unlikely" the actual risk would become MODERATE requiring Additional Mitigation. Major +Possible = high risk. This form of impact has been occurred at multiple mine sites in Australia including in Victoria e.g. Costerfield. Realistically this is "likely" to occur during the life of the mine e.g. in prolonged drought periods, requiring the purchase of additional water from outside the catchment or paying a premium to current users to wind back their business and sell water rights. Kalbar's business margins appear tenuous enough that at the additional expenditure would likely spell the end of the project. If you were an effected irrigator you may well regard the financial consequence on yourself as "extreme".

EXAMPLE 4 cont.

Comment cont.

By whom and how was the "Rare" likelihood determined? Did this allocation occur before or after the Proponent reviewed Document 24? We are not offered the providence of the individual Risk Assessments or the Draft Versions. Again this fails the principles of natural justice. The overwhelming odds favour the Proponent who can submit claims knowing Community Reviewers have neither the time (30 working days) nor the funds (and then only after tax) to thoroughly investigate claims of "low risk"

EXAMPLE 5

Document 24 /Attachment F page 12, Row/Item 23 ,

Specialist Study *Groundwater,*

Aspect - Groundwater

Hazard - Tailings Disposal

Value - Groundwater Quality

Mechanism - In-void tailings deposition

Phase - O

Impact - Tailings seepage from the mine void resulting in quality impacts on drinking water supplied by the Woodglen ASR

Standard Mitigation

- **The design, construction, monitoring and rehabilitation of the temporary TSF will comply with the Department of Economic Development, Jobs, Transport and Resources: Technical Guideline Design and Management of Tailings Storage Facilities (DEDJTR, 2017) (TE27).**
- **The temporary TSF will be constructed using engineered cells with lined walls. Water will be managed using a decant system, sumps and drains to capture and reuse seepage (SW22).**
- **The design, construction and operation of the freshwater storage dam will follow the Australian National Committee on Large Dams (ANCOLD) Guidelines on the Consequence Categories for Dams (SW12).**

Likelihood - Rare,

Consequence - Major,

Risk - Low.

Additional mitigation - "not required" .

Comment

If likelihood was awarded "unlikely" status this risk would become MODERATE requiring additional mitigation. Additional mitigation would require securing the base of the voids with imported clay. An expensive proposition. The GHD report concluded the dispersive quality to the sands would render sealing impossible within profit constraints. Likewise, who and how was the "RARE" likelihood determined? Did this allocation occur before or after the Proponent viewed Document 24? We are not offered the providence of the individual Risk Assessments or the Draft Version.

Again, this fails the principles of natural justice. The overwhelming odds favour the Proponent who can submit claims knowing Community Reviewers have neither the time (30 working days) nor the funds (and then only after tax) to thoroughly investigate claims of "low risk".

EXAMPLE 6
Document 24 /Attachment F page 12, Item 20 ,
Specialist Study ***Terrestrial and aquatic biodiversity,***
Aspect - Terrestrial and aquatic biodiversity,
Hazard - Tailings Disposal
Value - Downstream waterways (potential habitat - listed aquatic species Perry River)
Mechanism - Physical disturbance
Phase - C, O
Impact - Impacts to the Perry River catchment (potential habitat for listed aquatic species) from structural failure of the temporary TSF resulting in release of tailings material (potential impact only until temporary TSF is decommissioned in year 5)
Standard Mitigation - The design, construction, monitoring and rehabilitation of the temporary TSF will comply with the Department of Economic Development, Jobs, Transport and Resources: Technical Guideline Design and Management of Tailings Storage Facilities (DEDJTR, 2017) (TE27).
Likelihood - Rare
Consequence - Major,
Risk - low,
Additional mitigation - "None required" .

Comment **- If likelihood was awarded "unlikely" this risk would become MODERATE requiring additional mitigation. Additional mitigation would require alternative TSF construction. An expensive proposition. The anticipated structure using compacted tailings to construct dam wall is known to have elevated risk.**

The minerals council has warned of dam failure associated with this dam construction. Failure of this style of TSF construction has occurred more than once e.g. Samarco in Brazil, Cadia in Australia (2018), Mishor Rotem in Israel (2017), Henan Xiangjiang Wanji in China (2016), Samarco in Brazil (2015), Mount Polley in Canada (2014), Xichuan Minjiang in China (2011) and Kolontor in Hungary (2010). FAILURE IS NOT RARE! Every mining company knows this. If they are truly not aware that would suggest a lack of engineering "know how" to be involved in such mining methods.

Likewise, WHO AND HOW was the "RARE" likelihood determined? This likelihood allocation is breath taking. Did this allocation occur before or after the Proponent viewed Document 24? We are not offered the providence of the individual Risk Assessments or the Draft Version. Does low risk really sound implausible?

Again, this fails the principles of natural justice. The overwhelming odds favour the Proponent who can submit claims knowing Community Reviewers have neither the time (30 working days) nor the funds (and then only after tax) to thoroughly investigate claims of "low risk".

EXAMPLE 7 .

Document 24 /Attachment F page 20, Item/Row 21 ,

Specialist Study *Surface Water,*

Aspect -Surface water

Hazard - Water

Value - availability and flows

Mechanism - Physical Disturbance

Phase - C

Impact - Retention of runoff onsite for onsite management reducing rainfall runoff reporting to Mitchell River and Perry River leading to reduced surface water availability for licenced (sic) users

Standard Mitigation

- **The design, construction, monitoring and rehabilitation of the temporary TSF will comply with the Department of Economic Development, Jobs, Transport and Resources: Technical Guideline Design and Management of Tailings Storage Facilities (DEDJTR, 2017) (TE27).**
- **The temporary TSF will be constructed using engineered cells with lined walls. Water will be managed using a decant system, sumps and drains to capture and reuse seepage (SW22).**
- **The design, construction and operation of the freshwater storage dam will follow the Australian National Committee on Large Dams (ANCOLD) Guidelines on the Consequence Categories for Dams (SW12).**

Likelihood - rare,

Consequence - Major,

Risk - Low.

***Comment* - If likelihood was awarded "unlikely" this risk would become MODERATE Yet again, this risk assessment must be seriously questioned. A MODERATE risk would require Additional Mitigation. Most likely this would require purchasing additional water from outside the catchment or paying a premium to current users to wind back their business and sell water rights. Kalbar's business margin appears so tenuous that the additional expenditure may spell the end of the project.**

We are not offered the hydrological data to back up this declaration of a "rare event". As high lighted in Appendix C&D, the combination of opposite extremes (eg.rare and major, likely and minor) in risk estimates using matrix method may not be better than random guess - Jerome et al, Appendix D. We see these combinations on multiple occasions within Document 24 / Attachment F.

EXAMPLE 8

Document 24 /Attachment F page 5, Item/ Row 12 ,
Specialist Study *Radiation*,
Aspect -Health
Hazard - Radiation
Value - Healthy People
Mechanism - Radioactive
materials (radionuclides present in backfilled tailings and overburden)
Phase - C,0,CL
Impact - Radioactive materials (radionuclides) present in backfilled tailings and overburden)
Standard Mitigation

- **Exposure to gamma radiation will be minimised through (RD03):**
  - **Providing site security and signage to restrict unauthorised access.**
  - **Locating product stockpiles at sufficient distances from other operations.**
  - **Only loading trucks immediately prior to departure from the site.**
  - **Transporting HMC in accordance with the Code of Practice for Safe Transport of Radioactive Material.**
- **Fines tailings will be placed at depth in the backfilled mine void so that any restrictions to drainage are far enough below the soil to avoid impacts on vegetation growth and grazing animals**

Likelihood - Rare,
Consequence - Negligible,
Risk - Low.
Additional mitigation - "None required"

Comment
If Likelihood was awarded "possible" and the Consequence "moderate" this risk would become at least MODERATE. It is extra-ordinary that exposure to radionuclides and their carcinogenic nature is dismissed a minor consequence!

Conveniently, or perhaps cynically, Thorium itself is not mentioned in the radiation risk in these assessment matrices. despite 21% of upper sands being constituted by ≤ 20 micron (easily airborne and potentially respirable) particulates containing ~20mg/kg Thorium (See Appendix G). The Upper sands and Clayey Gravel containing these 20 micron particulates will be stockpiled on site on a water challenged Project site.
AND
44% of fine tailings e are constituted by <20 micron (easily airborne and potentially inhalable) particulates containing ~ 60mg/kgThorium! See Appendix G
These fines will be stockpiled on site on a water challenged Project site.

EXAMPLE 8 cont.

Thoron and Radon are mentioned under Rehabilitation. However those elements on their own they would be most unlikely to pose an individual hazard UNLESS they were coming from the Thorium one had ingested, or inhaled, from dust. Gamma radiation does get a mention - as low risk - does not seem to be product of the Thorium or Uranium pathways.

Alpha radiation is NOT discussed in this risk table despite being the primary radiation component of the Thorium decay pathway. Alpha exposure is likely as Thorium in ingested dust pica, water tanks, local produce vegetables, poultry, etc will be sequestered in human bone or lymphatic system. The Lindenow Flats renowned for its "clean green" even Organic horticulture on the East side of the mine may be particularly at risk.

The Problem of Dust and Thorium contained within this Project

Why is the East side of the project site at risk?

Of all wind events > 50km/hr , 97% (!) of had westerly component. (Mt Moornarna data oct'19 - Sept '20) see Appendix F. Receptors to the East of mine site most likely to be impacted by contaminated dust containing Thorium and other toxic elements such as Chromium and Lanthanum. As already mentioned ≤PM20 component of upper sands (to be stockpiled onsite) is ~21%. Fine Tailings are 44% ≤PM20 particulates with a Thorium content of 60mg/kg.

Dust Assessment, and hence nuclide contamination estimate, as presented in Document 38 Appendix A009, Air Quality and Greenhouse Gas Assessment and Document 48, Appendix A019 Human Health Risk Assessment appears woefully inadequate with regard to receptor impact of dust deposition and Thorium content within. Table 9.2 on page 74 in Document 48, Appendix A019 Human Health Risk Assessment contains the following table and footnotes regarding mitigation.

This submission would like draw the Panel's attention to the Footnote 2. attached to Table 9.2 (see next page) viz.

" Seven receptors included' additional measures" to achieve Tier one screening criteria.

Stated another way 7 "receptors" could not meet the PM10 standard during year 5. To comply "Additional mitigation measures, for example, by ceasing overburden transport in both pits, and product transport between 6:00 p.m. and 7:00 a.m. on selected days, would be sufficient to prevent these exceedences."

Does any Panel Member seriously believe, in 5 years from now, a 24/7 operation is going to shut down overnight on short notice because of a "bit of dust"?

EXAMPLE 8 cont.

The Problem of Dust and Thorium contained within cont.

Table 9.2

The modelling inputs, assumptions and tables of predicted concentrations of air pollutants associated with particulate matter and dust deposition, at all receptors in the selected modelling years, can be found in the air quality assessment report (Katestone, 2020).

Table 9.2 Tier 1 assessment of predicted particulates in air at ground level at sensitive receptors – operation phase [(1)]

Pollutant	Averaging period	Statistic	Units	Tier 1 screening criteria	Maximum concentration at any receptor in year 5
PM_{10}	24-hour	Maximum	µg/m³	60	59.7 [(2)]
$PM_{2.5}$	24-hour	Maximum	µg/m³	36	17
Respirable crystalline silica	Annual	Average	µg/m³	3	0.9
Dust deposition	Monthly	Maximum	mg/m²/day	120	79
	Annual	Average	g/m²/month	2	0.47
	Annual	Average	g/m²/month	4	1.4

Bold text indicates an exceedance of the adopted Tier 1 screening criteria.

[1] Including background levels.

[2] Seven receptors included additional dust mitigation measures.

Using standard mitigation measures, the following contaminants are predicted to comply with the adopted Tier 1 health screening criteria:

- 24-hour average and maximum concentrations of $PM_{2.5}$ at all regional receptors.
- Annual average concentrations of respirable crystalline silica at all regional receptors.
- Monthly maximum and annual average dust deposition rates at all regional receptors

Using standard mitigation measures, predicted 24-hour average concentrations of PM_{10} are predicted to exceed the Tier 1 screening criteria on, at most, three days of the year. On the days with elevated concentrations, the project contributes between 19 and 88% to the total 24-hour average PM_{10} concentration at the worst-affected receptor. Additional mitigation measures, for example, ceasing overburden transport in both pits, and product transport between 6:00 p.m. and 7:00 a.m. on selected days, would be sufficient to prevent these exceedances.

Using standard, and when necessary, additional mitigation measures as noted above, the predicted 24-hour average concentrations of PM_{10} is predicted to comply with the adopted Tier 1 health screening criteria at all regional receptors.

The commentary below the table goes on to advise;- "Using standard, and when necessary, additional mitigation measures as noted above, on the days with elevated concentrations, the project contributes between 19% and 88% to the total 24-hour average PM10 concentration at the worst-affected receptor. We are not advised of other receptor's exposure to PM10.

EXAMPLE 8 cont.

Stated another way this project may be responsible for up to 88% of ALL PM10 dust at nearby receptors. Appendix G in this submission reveals most PM10 dust likely to emanate from this site will contain somewhere between 20 and 60 mg/kg of Thorium.

The Problem of Dust and Thorium contained within cont.

Without more specific data I will assume in the following calculations that

i) **50% (possible range 19-88%) of PM10 dust arriving at nearby "receptors" is derived from the Project site and**

ii) ii) **that dust will contain 20mg/kg Thorium.**

Having established that 97% of high wind gusts have a Westerly component (see Appendix F at end of this submission). I would draw the Panel's attention to Plate 8 on page 104 within Document 38 Appendix A009 - Air Quality and Greenhouse Gas Assessment. The plates describe annual dust deposition rates by use of contours in Year 5 of the operation phase. At the Eastern end of the mine site on Plate 8 are Receptor sites 15,16 and 29 which lie adjacent the 1gm/m2/month contour. By implication these sites will receive 12grams annually of dust deposition. Assuming 50% is PM10 arising from mine site i.e. 6 gms of PM10/m2/pa will originate from the mine.

Should that dust concentration settle on a house roof of 200m2 from which rainfall is collected into a 10,000 L domestic supply tank then 200 X 6gms = 1.2 kgs mine PM10 dust will enter that water tank. That dust will contain 1.2kg X 20mgs or 24mg of Thorium entering that water tank per annum. 1mg ofThorium has a Bequeral equivalent of 4Bq. Hence that 10,000L tank will receive 96Bq per annum. That dust will contain 1.2kg X 4mgs or 5mg of Uranium entering that water tank per annum. 1mg of natural Uranium has a Bequeral equivalent of 180Bq in secular equilibrium. Hence that 10,000L tank will receive 900 Bq per annum from Uranium. A total of 996 Bq per annum under maximum dust suppression conditions. e.g. Plant shutting down 7pm to 7 am. After 5 years potentially 4,980 Bq will have entered tank at a potential concentration of 0.49 Bq /L. I believe the accepted standard is 0.5 Bq/L. This is annual "Bequeral creep"and would seem to be occurring in the presence of the ADDITIONAL MITIGATION outlined in footnote 2 of Table 9.2 above. It has not been elucidated just how this additional mitigation will actually be ensured. BDEC fears it will be to left to "hands off" supervision or "self-regulation" / self-monitoring of fugitive emissions of this known carcinogen. Mitigation will only be successful if;-

religiously instituted,
religiously monitored and,
its effectiveness is religiously reviewed by every regulator at every step and,
substantial penalties imposed if failure of that mitigation occurs.

EXAMPLE 8 cont.

In all frankness, firm regulation has not occurred at any mine site in Victoria for the past 30 years in spite of the extraordinary toxicity of substances emitted. BDEC sees no evidence that improved oversight is suddenly about to occur at this high risk site.

Primary Regulators do not sufficient staff, they are subject to and have demonstrated themselves to have, conflicted interests in such projects. Earth Resources Section of DJRT has in its brief the instruction to promote Mining and Extractive Industries. This is inconsistent with tight regulation.

The EPA has a revenue base of licensing pollution and its field officers have particular difficulty in prosecuting corporations who breach pollution rules. The Panel will hear stories of multiple environmental breeches that have occurred at other mining sites.

The Panel may wish to enquire:-
Exactly, how many contamination breaches involving extractive industries have been prosecuted?

The answer may not bode well for any assumption of how this site will be regulated, post approval.

Other specific Issues that require in depth examination of the Fingerboards project this submitter has not been able to cover in the allocated time.

The remainder of this submission is not able to expand upon the following issues due to lack of time available, lack of financial resources and lack of secretarial assistance.

1. **Water - catchment wide issues.**

2. **Local domestic water and agriculture supply threat.**

3. **Ramsar wetland Impacts.**

4. **Contamination of the Lindenhow Flat's Horticultural Industry**

5. **On- site Dam engineering - AMCROD compliant registration and construction.**

6. **Indicator criteria, as propagated by Victorian EPA and NEPM, are 10 years out of date. The United States EPA 1;1,000,000 morbidity screening levels should be adopted as Best Practice benchmarks for all new projects until updated criteria are promulgated. Best Practice is the stated standardard in many State Envirionmental Pollution Policies but then the listed criteria within fall well below "Best Practice".**

7. Post Approval Regulation - who is responsible for health and contamination issues ERR?, EPA?, DHS?, Council? All Four? None? Again regulatory responsibility for Carcinogenic pollution near Bendigo remains non-committal at best. See Appendix A.

8. Work Plan Variations make a mockery of the EES approval process. With the stroke of a pen recommendations from the EES and Minister can be simply be reversed with an in camera agreement between ERR and the company without the courtesy of Community notification of a substantial variation impacting on that same community. Illustrative examples in Bendigo involving carcinogen exposure can be seen here; Submission 71 @
https://www.aph.gov.au/Parliamentary_Business/Committees/Senate/Environment_and_Communications/MiningandResources/Submissions

9 . The above senate submission highlights how the EES process can be distorted by enthusiastic companies supported by Regulators with limited scientific knowledge or Regulators enthusiastic about mining promotion.

10. The Panel may wish to question each ERR officer presenting at this panel as to whether performance bonuses are awarded for successful mining approvals are embedded into their employment contract. Their answers may be guarded.
11. Pre-commencement deposit of an ADEQUATE Rehabilitation Bond

<u>Postscript;</u> Whilst every attempt has been made to minimise typographical errors some will have undoubtably slipped through. We request permission to correct those should they become apparent. Like many community submissions to this enquiry, BDEC is a self funded, not for profit, completely voluntary community organisation with all expenses paid from after-tax membership fees and time pressured by the window of EES publication and Closure date for comment and current limitations on community meetings by Covid 19 restrictions. BDEC Inc. has no access to pro-bono or tax deductible secretarial or stationary services .

We also request permission to respond, in writing, to new information or altered mining procedures that become apparent or announced during the Panel process. The shifting sands of Proponent strategy which invariably accompanies the EES process systematically and strategically disadvantages Communities, who, in good faith, engage in a process unaware the boundaries will shift during their engagement.

We believe this Fingerboards Project is not in the best interests of Glendale, East Gippsland or Victoria and should not be approved.

APPENDICES

APPENDIX A Consequences of mining in Bendigo

APPENDIX B Consequences of information suppression in ecological and conservation sciences.

APPENDIX C What's Wrong with Risk Matrices?

APPENDIX D Limitations of the Entomological Operational Risk Assessment. Using Probabilistic and Deterministic Analyses

APPENDIX E Qualitative criteria for consequence, likelihood and Risk Matrix proposed used in Fingerboards EES

APPENDIX F Mt Moornarna Wind Events

APPENDIX G PM10 Tabulated content of stockpiled earths and Thorium content

APPENDIX A

Consequences of mining in Bendigo

1. Deborah Panel Report frontispiece
2. Minister's commitment on community access to INDEPENDENT consultant assessments
3. Promises given at Deborah EES
4. Abandoned Kangaroo Flat mine site.
5. Picture of abandoned Woodvale site
6. Pages 4 & 5 of EPBC submission

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MINISTER'S ASSESSMENT AND
PANEL REPORT

PROPOSED DEBORAH REEF UNDERGROUND GOLD MINE AT KANGAROO FLAT

SENT TO: MINISTER FOR AGRICULTURE AND RESOURCES

BY: ACTING MINISTER FOR PLANNING AND LOCAL GOVERNMENT

JUNE 1998

It would appear that a recommendation of the Williams United Panel on the need for a strategy for tailings dam rehabilitation, and supported by a specific Ministerial endorsement, has not received any significant attention and may merit further scrutiny.

Minister's assessment

I have noted the Panel's comments on this matter and shall bring them to the attention of the Minister for Agriculture and Resources.

6. Peer Review of EES Studies

Panel comment

B6. The Minister is requested to give consideration as to whether merit exists in the preparation [of] guidelines for Consultative Committees as to when it may be appropriate to request a proponent to provide a peer review on issues on which community representatives are having difficulty in determining whether a consultant report is or is not flawed.

Generally such action should only be necessary if represented agencies and/or the Council are unable to provide assistance in interpretation and Consultative Committee endorsement is given to initiate such action.

Minister's assessment

Noted. Guidelines for peer review are currently being finalised by the Department of Infrastructure.

No water, which comes into the site area, will be allowed to discharge to natural waterways. The topography of the site will be modified such that all areas drain to a collection dam toward the northern end of the site. This internal collection dam will be connected to existing underground workings that will be used as a water storage facility.

Both potable water and water from underground will be required for dust suppression.

Potable water will be used for dust suppression on the outside of the bund wall, top soil and sub soil stockpiles and areas on which final rehabilitation earthworks are underway or completed.

The underground water, which has a significant salt content, will be used for dust suppression on roads and during mullock emplacement. This water will be obtained from the underground workings below the site.

Water for use in the underground development will also be obtained from the underground workings. Potable water will be obtained from Coliban Water.

If the quantity of water on the site becomes excessive then the water level in the underground workings below the site will rise. If this occurs water will be pumped from those workings to the Carshalton - Londonderry pipeline and will ultimately be disposed of at Woodvale.

2.8 Rehabilitation.

The proposed end use of the Carshalton site is the return to Box Ironbark forest while retaining the area for use as an Historic Reserve. A significant proportion of proposed rehabilitation works will be completed during and immediately following the decline development phase.

During the decline development phase the following program will be undertaken:

- screen planting with indigenous species near Ham Street;
- covering of the outside of the bund wall and completed mullock emplacements with subsoil, topsoil and mulch;
- direct seeding of mulched areas with selected indigenous species;
- ongoing seed collection.

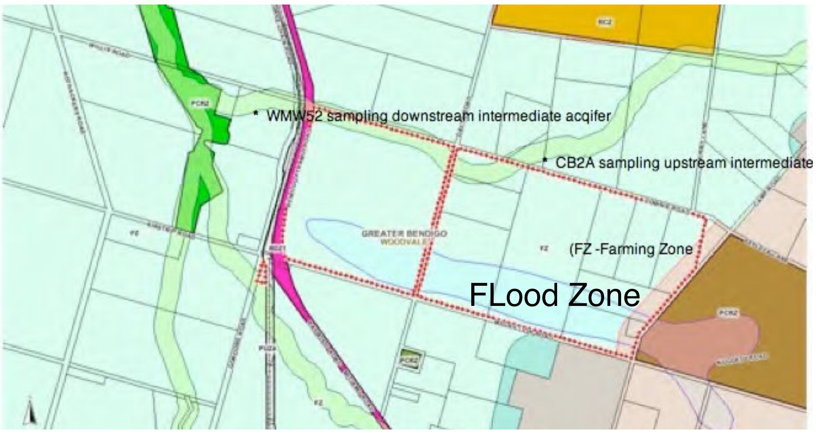
2.9 Exploration.

The decline will be positioned close to the lowest mined ribbon, above the expected position of an unmined ribbon. Holes of up to 300 metres in length will be drilled from the decline to determine the location of the ribbon. This information will enable design of the final section of the decline route.

8.

ii) BDEC would like to submit that the EPBC Act has been an abject failure

WOODVALE EVAPORATION PONDS



In the little community of Woodvale (pop. 300) there is a paddock with 100+ Tonnes of Arsenic and an estimated 200,000 Tonnes of salt lying on a one square kilometer patch of "farmland". These are the Woodvale Evaporation Ponds (W.E.P.) which hold 800 megalitres of water. The 100 Tonnes of the carcinogen Arsenic was concentrated on this site by deposition of vast quantities of Arsenic containing mine water from Bendigo. That water has been piped into this rural community over the past 30 years. Arsenic is America's No.1 toxic hazard and is a known Carcinogen. By way of comparison Asbestos is ranked No 94 on this priority listing. These "Ponds" are known to leak into the Aquifer. (snake-like underground water body on the North side of Ponds) and are traversed by a flood zone on the South (see above diagram). Both the Aquifer and the flood plain are connected to the Murray Darling Basin and the Ramsar Wetlands of Northern Victoria via Myers Flat Creek.

A Report commissioned by the Victorian Department of Environment, Land, Water & Planning (DELWP) titled "**Water Tank and soil sampling Woodvale**" was released in September 2015. That report revealed 42 of 53 **(78%)** domestic drinking water tanks, within 1 kilometer of these Ponds, contained some Arsenic. Of the 11 tanks containing no Arsenic, 10 had imported water. Woodvale is NOT a naturally high Arsenic area - the average subsoil Arsenic is 7mg/kg and is not readily soluble. Local natural Arsenic could not achieve Arsenic levels seen in some water tanks without mud exuding from taps.

The Report also revealed an increase of 8mg/kg of Arsenic in the top soil surrounding these Ponds, compared to the subsoil concentrations. When extrapolated to the 1 km radius of the report area it appears **8 Tonnes** of Arsenic has deposited over the surface soil, presumably by airborne spread. This is an unprecedented contamination event. No State Minister (Mining, Health or Environment) has yet responded to this site contamination report. Under the National Environment Protection Measurement (NEPM) Act these preliminary findings should trigger a Definitive Ecological Risk Assessment. Instead on the DELWP website we are offered "DHHS reviewed the final report and concluded that: "The testing found there were no rainwater tanks that had arsenic above the Australian Drinking Water Guidelines level. Soil tests at properties found no public health risk.". When challenged with the above information the four primary regulators (EPA, Bendigo Council, Earth Resources Regulation and DHHS) have simply repeated the website mantra) despite legislative obligations to abide by the "Precautionary Principle".

Six of the 53 rainwater tanks tested had Arsenic levels of 3 micrograms per Litre. Current literature would suggest lifetime exposure to 3 micrograms/Litre of Arsenic in drinking water is associated with a 16% increase in urological cancers (Saint-Jacques et al, Environmental Health 2014, 13:44) and a 30% increase in Lung Cancers (Santelli et al PLOS ONE I doi:10.1371/journal.pone.0138182, September 18, 2015).

The ONLY plausible explanation for the contamination seen at Woodvale is airborne spread arising from the Ponds themselves. According to EPA Victoria Guide SEPP 1194 to "Air Quality" the intervention limit for Arsenic is 0.003 µg/m3 whilst the intervention level for Asbestos is 60 times higher at 0.2 µg/m3. Imagine the community distress if the equivalent of (8Tonnes times 60) 480 Tonnes of Asbestos had been allowed to drift over a community near you. This appears to be the level of contamination that has occurred at Woodvale.

Please Turn Over for a Summary of the other health effects of Chronic Arsenic Exposure.

ii) BDEC would like to submit that the EPBC Act has been an abject failure

Other Health Effects of Arsenic

These health effects appear to occur regardless of route of exposure (inhaled, water, food), are dose dependent, with carcinogenic effects delayed for 10 years after exposure. Peaking at 25 years.
Yuan et al, Environ Health Perspect 114:1293–1296 (2006) (1mg/L As in drinking water)
If exposed as child your chance of dying from;
LUNG cancer risk before 50 years old is increased X 7.
BRONCHIECTASIS (lung disease) before 50 yo risk is increased X 12.4, in utero risk is X 46
EMPHYSEMA before 50 yo risk increased X 2
CORONARY ARTERY DISEASE before 50 yo risk is increased X 2.7 in men, X1.3 in women
KIDNEY cancer before 50 yo risk is increased X 3, if also exposed in utero X 7

Ferrecio et al, Health Population & Nutrition 24(2): 164–175 (2006)
If exposed as child your chance of dying from BLADDER cancer before 50 yo risk is increased X 8
If exposed as child your chance of dying from LIVER cancer before 50 yo is risk is increased X 1.5
If exposed as child your chance of dying from SKIN cancer before 50 yo is risk increased X 3

The 2015 "**Addendum to the toxicological Profile for Arsenic**' published by the USA **A**gency for Toxic Substances and Disease Registry Division of Toxicology and Human Health Sciences has added **Hypertension** in children and adults, **Myocardial Infarction**, **Stroke** as well as the **prenatal exposure** risks of **congenital abnormalities** (heart and neural tube defects) and **premature cancers** in offspring. Other effects of Arsenic exposure include **impaired immunity**, impaired neurological function and **impaired intellectual development** in children.

Pearce et al (Journal of Exposure Science and Environmental Epidemiology 2012) demonstrated an association between areas of high soil Arsenic in the Goldfields region of Victoria and the incidence of the following cancers; Melanoma X1.3, Colon X1.2, Prostate Ca X1.3 and possibly Leukeamia X 1.3. There are now clear pathological pathways to explain Arsenic's ability to induce and enhance cancers (Wenzhen Yuan, Xiangkai Li et al, Advances in Understanding How Heavy Metal Pollution Triggers Gastric Cancer BioMed Research International Vol. 2016, Article ID 7825432).

The risk of both Cancer and Death resulting from chronic Arsenic exposure is clearly dose dependent. One heaped teaspoon of the dry crust (or dust) from these WEP's, somehow ingested via food, contaminated water tanks or inhaled as dust at Woodvale over an entire year will probably exceed the safe threshold (0.3ug/kg/day) determined from the above studies. Unlike nuclear waste, Arsenic is forever, it does not breakdown.

The Woodvale Ponds site must be rendered harmless by the complete REMOVAL of the Arsenic to a safer location away from people and waterways connected to the Murray Darling Basin.

Written by Dr. Simon Perrin on behalf of the Bendigo & District Environment Council Inc.

APPENDIX B

Consequences of information suppression in ecological and conservation sciences.

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LETTER

Consequences of information suppression in ecological and conservation sciences

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Funding information
Ecological Society of Australia

Abstract

Suppressing expert knowledge can hide environmentally damaging practices and policies from public scrutiny. We surveyed ecologists and conservation scientists from universities, government, and industry across Australia to understand the prevalence and consequences of suppressing science communication. Government (34%) and industry (30%) respondents reported higher rates of undue interference by employers than did university respondents (5%). Internal communications (29%) and media (28%) were curtailed most, followed by journal articles (11%), and presentations (12%). When university and industry researchers avoided public commentary, this was mainly for fear of media misrepresentation, while government employees were most often constrained by senior management and workplace policy. One third of respondents reported personal suffering related to suppression, including job losses and deteriorating mental health. Substantial reforms are needed, including to codes of practice, and governance of environmental assessments and research, so that scientific advice can be reported openly, in a timely manner and free from interference.

KEYWORDS
academic freedom, advocacy, conservation policy, corruption, decision making, environmental impact assessment, freedom of information, public discourse, scientific censorship, scientific integrity

1 | INTRODUCTION

Governments and society have substantial power to limit biodiversity loss (Driscoll et al. 2018). Public discussion, advocacy (Garrard, Fidler, Wintle, Chee, & Bekessy, 2016), and information translation (Pielke, 2007) by scientists can influence how government and society use that power. This influence arises partly by providing expert advice to inform policy directly (Pielke, 2007), and by informing members of the public who may then change behavior or become advocates (Schaefer & Beier, 2013). Public advocacy, based on science, has a strong influence on government policy (Fagerholm, 2016) and can influence the extent of environmentally responsible behavior by corporations (Carberry, Bharati, Levy, & Chaudhury, 2019). Therefore, active science communication that truthfully informs decision makers and the public is integral to effective biodiversity conservation (Schaefer & Beier, 2013).

Unfortunately, suppression by governments of public-good science (Martin, 1999; Professional Institute of the Public Service of Canada [PIPSC], 2013; Union of Concerned Scientists [UCS], 2008), and exclusion of evidence from policy decisions by industry and governments (Dougherty, 2019; Enriquez-de-Salamanca, 2018; Sherwin, 2017) are common. By "suppression," we mean "an active process to prevent data from being created, made available, or given suitable recognition" (Martin, 1999). Suppression can be manifested through a range of mechanisms, such as prohibiting research communications, inappropriate modification of research outputs (Pincock, 2009; Yazahmeidi & Holman, 2007), and self-censorship, whereby scientists do not present their work in public for fear of retribution (Martin, 2019). Science suppression can result in important research not being undertaken at all ("undone science," Frickel et al., 2010), not used to inform policy (Lalor & Hickey, 2014), or not made publicly available (PIPSC, 2013), with consequences for democracy, the environment, biodiversity, and individual scientists.

Science suppression by governments has recently driven scientists into mass protests globally (Abbott, Callaway, & Casassus, 2017; Ross, Struminger, Winking, & Wedemeyer-Strombel, 2018). In the USA, recent suppression of science from both the health and environment sectors has reduced input of scientific expertise to policy development and weakened scientific capacity (Lin, 2019; Sherwin, 2017). Science and science communication by Canadian federal government scientists were seriously compromised by government funding cuts and "gag orders" from 2006 to 2015 (PIPSC, 2013; Westwood, Walsh, & Gibbs, 2017), and suppression of public-good research has been a long-term issue in Australia (Lowe, 2014; Pincock, 2009; Ritchie, Driscoll, & Maron, 2017; Wilson & Barnes, 1995).

Science suppression contributes to erosion of democratic institutions and governance (Crabtree et al., 2018; Scheufele & Krause, 2019). If the voting public do not know how their elected representatives are managing the environment, they cannot make informed choices at the ballot box (De Vries, Solaz, & Annual, 2017; Yazahmeidi & Holman, 2007). Further, information vacuums can occur when government scientists are gagged with respect to environmentally damaging policies. Information vacuums in the media can be filled by vested interests (Lalor & Hickey, 2013), leading to outcomes that compromise biodiversity (Driscoll et al., 2019). Biodiversity consequences related to science suppression have included development approvals in areas where new species have been discovered (Carroll et al., 2017), feral animal expansion and impacts on threatened native species (Driscoll et al., 2019), fisheries collapses (Hutchings, Walters, & Haedrich, 1997), and inadequate policies for climate change (Lowe, 2014; Spash, 2015) and fisheries (PIPSC, 2013). A third area of major consequence is the severe impacts on individual researchers, such as loss of employment (Yazahmeidi & Holman, 2007), ending of research careers (Martin, 1999), and undermining of personal and professional credibility (Swinburn & Moore, 2014). Having research communications blocked, modified, or otherwise denigrated causes workplace stress (Pincock, 2009) that can lead to severe health consequences, including depression, anxiety disorders, and even suicide (Bhui, Dinos, Stansfeld, & White, 2012; Lindblom, Linton, Fedeli, & Bryngelsson, 2006).

Suppression of scientific information has been examined in medical and environmental pollution research (Kuehn, 2004; Martin, 1999) and is systematically evaluated among Canadian and USA public servants (PIPSC, 2013; UCS, 2015) but has rarely been examined among university researchers (Wilson & Barnes, 1995). There has been no systematic, cross-sectoral evaluation of the nature or consequences of science suppression in ecology and conservation science, although it is known to occur (Lowe, 2014; Pincock, 2009; Ritchie et al., 2017; Wilson & Barnes, 1995).

Here we focus on the communication aspect of science suppression (corresponding to the limits to availability and recognition of science in Martin, 1999), particularly the constraints scientists face in communicating on topics about which they are knowledgeable. We present a nationwide survey of such suppression among Australian ecologists and conservation scientists working in three different sectors: universities, government, and industry. Australia has globally significant biodiversity, with high degrees of endemism, but also one of the world's worst contemporary conservation records (Woinarski et al., 2019). Yet, as in North America and Europe, there is pressure in Australia to protect political and industry interests by suppressing information about environmentally damaging policies or ventures (Carter, 2018). Science suppression in Australia is occurring in a broader context of political polarization of environmental regulation (Evans, 2016), increasing corruption (Brown et al., 2018), including "mediated corruption" related to environmental management (Grafton & Williams, 2020), and attempts by vested interests to discredit science (Spash, 2015). These are common themes around the world (Driscoll et al., 2018; Hardy, Tallapragada, Besley, & Yuan, 2019; Stocking & Holstein, 2009), so discoveries and lessons about science suppression in Australia have global relevance.

Through a survey of ecologists, conservation scientists, policy makers and practitioners in universities, government, and industry, our specific aims were to

1. Identify the role scientists perceive they have in public debate and the level of expertise they consider adequate to enter into debate;
2. Document the types of communication and topics that are suppressed and whether constraints are perceived as excessive or worsening;
3. Identify self-censorship and sources of influence that constrain public commentary;
4. Describe the reported consequences of constraints on communication; and
5. Identify areas for action to reduce science suppression and its consequences.

Our results indicate severe impacts on individuals and civic interests when ecology and conservation science is suppressed. They serve as a warning that existing governance and protocols for suppressing science, particularly within government and industry, are not in the best interests of society. We suggest some key considerations in formulating solutions to reduce the extent and impact of science suppression. More broadly, we seek to foster momentum towards removing barriers to the open sharing of public-good research.

2 | METHODS

2.1 | Data collection

We designed an online survey to gather information about the extent of constraints on communication and public commentary by Australian scientists in the broad area of ecology and conservation (see Appendix S1 for details of survey questions). Survey questions addressed five broad issues: (1) the role of scientists in public debate and level of expertise perceived as needed; (2) the types of communication and topics that are suppressed and whether constraints are perceived as excessive, or worsening; (3) the causes of constraints; (4) the consequences of constraints; and, (5) demographic information about the respondents (Appendix S1). The survey consisted primarily of closed-response, multiple-choice questions; participants were given the opportunity to provide short, open responses to clarify or enhance their responses to some questions. Participants were also given the option of submitting a longer-form open response to describe their own experiences with public engagement.

The survey was targeted at Australian ecologists, conservation scientists, conservation policy makers, and environmental consultants, including academics, government employees, and scientists working for industry such as consultants and nongovernment organizations. Advertisements encouraging voluntary participation in the survey were distributed by the Ecological Society of Australia (ESA) via its website, online newsletters (October, November, December 2018; February 2019), tweets (7,000 followers), and Facebook posts (10,000 followers) while the survey was open. Additional promotion occurred at the ESA annual meeting (November 2018) to over 600 ecologists. Participants were required to be over the age of 18 and able to read and respond to the survey in English. The survey was hosted on the online platform *Qualtrics* (qualtrics.com) and ran from October 25, 2018 to February 11, 2019.

Respondents to our survey were self-selecting and thus could represent a higher proportion of people who have experienced constraints on communication than would occur in a random sample. Not being based on a probability sample, the results cannot be used to infer the proportion of the ecological community who have experienced constraints on communication of information (Bethlehem, 2010). Nevertheless, our methods enable us to infer whether or not many ecologists have experienced constraints on science communication and to report the implications for environmental management, biodiversity conservation, and the well-being of individual scientists.

2.2 | Analysis

Incomplete responses and responses from countries other than Australia were removed prior to analysis. We classified workplaces into one of three categories: university, government, and industry. This three-category factor was used as the single predictor variable in subsequent analyses. Six respondents were excluded from analyses because they did not disclose their workplace (4) or they worked across all sectors (2). We did not further divide workplace categories to avoid having categories with small sample sizes. Questions with only two responses were converted to binomial responses (Yes = 1, No = 0) and analyzed using a binomial generalized linear model with logit link function (McCullagh & Nelder, 1989). For questions with multiple responses, we converted each possible response to a single binomial variable, then used multinomial logistic regression with the *mvabund* R package (Wang, Naumann, Wright, & Warton, 2012). This involved fitting all of the possible responses at once as response variables in the model, while fitting workplace as the predictor variable. For these analyses, we simplified some of the responses to exclude "other" and "NA" responses, both of which were rare and had limited meaning. We considered differences among workplaces statistically significant and warranting discussion if the p value was <0.05; otherwise, we report percentage responses for the entire sample. When $p < .05$, we also report p values for individual response variables to allow responses with the most clear differences among workplaces to be identified, but emphasize that effect sizes were also a key consideration in our interpretations of important findings (as recommended by Nakagawa & Cuthill, 2007). Details of questions asked, analyses performed, and responses excluded from analyses are provided in Appendix S1.

Open text responses to question 10 and 17 were analyzed according to a thematic approach (Boyatzis, 1998), in which responses were "coded" according to key themes and concepts that emerge (Blaikie & Priest, 2019). Responses were coded line by line using an open coding technique, in which individual responses could contain statements aligned with multiple themes (Appendix S4).

3 | RESULTS

A total of 220 people completed the survey, including 88 (40%) from universities, 79 (36%) from government, 47 (21%) from industry, and 6 (3%) who could not be classified. All university respondents had research roles. Most government respondents were also in research (73%), while 27% were in policy, middle management, or executive roles. Industry included environmental consultants (55%), non-government organizations (32%), or other industries (6%). For convenience, we refer to our sampled cohort as ecologists, but recognize that the respondents represent a more diverse group. Half (51%) of respondents identified as male, 43% identified as female, 5% chose not to indicate a gender, and 1% did not identify as male or female. Our sample spanned all career stages (28% early, 48% mid, 24% late career).

3.1 | The role of scientists in public debate and level of expertise needed

The vast majority (98%) of respondents, regardless of workplace, believed that scientists should be involved in public policy discourse in some way (Q1, see Appendix S1 for details of each question and test statistics in Appendix S2a, S2b, S3). In decreasing order of public engagement, 33% of respondents believed it is a duty to participate in public debate or policy advocacy, while 38% thought scientists should be freely able to do so. Twenty-seven percent believed scientists have a duty to provide the factual information that informs public debate (Q1). Only 2% thought scientists could consider it optional to provide factual information and < 0.5% thought scientists should never be involved in public policy debates or other advocacy.

The minimum level of expertise needed to be sufficiently knowledgeable to engage in public commentary was most often reported as thorough study of literature with research on a broadly related topic (33%), closely followed by thorough study of the peer-reviewed literature and other primary sources (31%, Q2). Twenty-five percent selected less-stringent criteria, including reading several papers (16%), reliable secondary sources (8%), or media reports (<1%). Proportions did not differ among workplaces (Appendix S2a, S2b, S3).

3.2 | Types of communication and topics that are suppressed

Government (34%) and industry (30%) respondents reported higher rates of undue modification of their work by their employers than did university respondents (5%, $p < .0001$, Q3; see Appendix S2, S3 for all test statistics). Undue modification, defined as substantive changes to a text or story that downplays, masks, or misleads about environmental impacts (e.g., Pincock, 2009), was most commonly reported for internal (29%) and traditional (28%) media communications (Q4, see Table 1 for related quotes). However, conference presentations (12%) and journal articles (11%) were also considered to have been unduly modified by employers. Internal communications were reported to be unduly modified by significantly more government respondents (59%) than industry (36%) or university (0%) respondents ($p = .04$ Q4, Appendix S1, S2a).

Approximately half of government (52%) and 38% of industry respondents indicated they had experienced prohibition from public communication about their research,

TABLE 1 Selected quotes from respondents that illustrate some of the processes and outcomes of science suppression. Text in parentheses has been edited for clarity or to ensure anonymity

Process illustrated	Quote
	Types of communication suppressed
Interference in internal communications	"Due to 'risk management' in the public sector … Ministers are not receiving full information and advice and/or this is being 'massaged' by advisors."
Consistent messaging critical for government	*"If a person is known to work for the organisation, regardless of whether the opinion is private or professional, there is a risk that one's opinion may (be) confused with that of the organisation's."*
Unable to act in a personal capacity	*"an email was circulated to our whole department (environmental) warning us not to attend protests or comment publicly on the development"*
	Sources of influence constraining public commentary
Industry self-censorship	*"I have seen develop a secretive self-censorship approach by many companies for fear of losing work or losing employment."*
Influence of senior managers	*"(government) staff are rewarded or penalized on the basis of complying with opinions of senior staff regardless of evidence."*
Heavy-handed codes and practices	*"The number of reviews and approvals and the level of the delegate required to give these approvals is excessive."*
University vested interests	*"I proposed an article in The Conversation about the impacts of mining … The uni I worked at didn't like the idea as they received funding from (the mining company)."*
	Personal consequences of constraints on public commentary
Declining motivation in the workplace	*"I became disenchanted with the organisation I work for and as a result I've been less inclined and motivated to dedicate myself to my job."*
Job insecurity	*"I declared the (action) unsafe to proceed. I was over ruled and properties and assets were impacted. I was told to be silent or never have a job again."*
Bullying	*"I was directly intimidated by phone and Twitter by (a senior public servant)"*
Mental health affected	*"I would say it severely compromised the mental health of myself and another member of the office and was a large contributor to both of us leaving."*
	Environmental consequences of constraints on public commentary
Industry views kept out of public discourse	*"This creates major conflicts of interest, reinforced by governments allowing (industry) to treat data collected as commercial in confidence. This means experts most able to comment on the details of big mining and construction projects are hopelessly conflicted and legally gagged from discussing these projects in public."*
Biodiversity impacts of industry silence	*"a project … clearly had unacceptable impacts on a critically endangered species.… the approvals process ignore(d) these impacts … Not being able to speak out meant that no one in the process was willing or able to advocate for conservation or make the public aware of the problem."*
Government views constrained and public remain uninformed	*"we are often forbidden (from) talking about the true impacts of, say, a threatening process … especially if the government is doing little to mitigate the threat … In this way the public often remains 'in the dark' about the true state and trends of many species."*
Fake news filling evidence void	*"I could see that social and media debate was exploiting the lack of information to perpetuate incorrect … interpretations … to further their own agendas"*

compared with 9% of university respondents ($p < .0001$, Q5). Communications via traditional (40%) and social (25%) media were the most commonly reported kinds of communication that were prohibited across all workplaces (Q6). However, there were also instances of internal communications (15%), conference presentations (11%), and journal papers (5%) and being prohibited (Q6 Appendix S1).

A little over half (56%) of survey respondents felt that constraints on public commentary had become more severe in recent years (Q7). Most government respondents (61%) believed constraints on public communication are excessive, as did 34% of industry and 16% of university respondents (Q8). Further, a lower proportion of government respondents (47%) thought constraints imposed by written policies were reasonable (compared with 73% industry, 68% university; Q9).

Sixty-two respondents from government provided text responses about whether policies constraining communication were reasonable. Thirty-one (50%) reported that constraints were reasonable, and 42% of these respondents indicated that consistent messaging from the agency

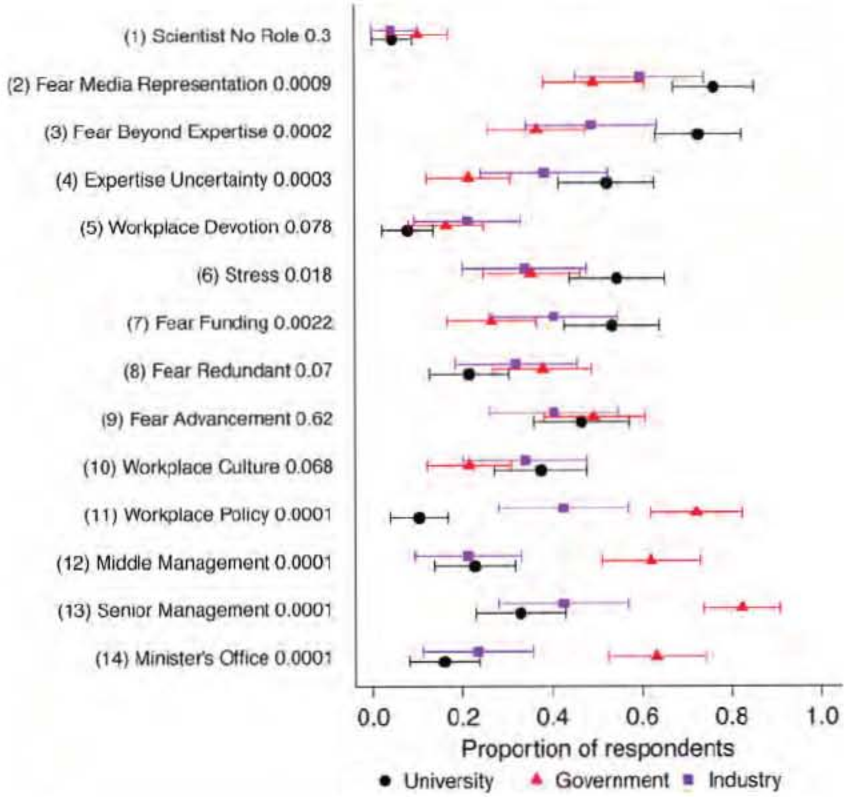

FIGURE 1 Motivations for refraining from contributing expert knowledge to public debate for respondents from universities, government or industry (Q14). Responses indicate the proportion of survey respondents who agreed or strongly agreed that a particular category motivated silence. Error bars indicate 95% confidence limits. Overall p from multivariate analysis <.0001. Univariate p values indicated for each category, testing for difference among workplaces. Detailed responses (from top to bottom) were (1) scientists have no role in making public commentary beyond information provision; (2) concern about how I may be represented by the media; (3) fear about being drawn to comment beyond the boundaries of my expertise; (4) uncertainty about the boundaries of my expertise; (5) I see my primary obligation as being to my organization, rather than to the public; (6) I find it stressful to discuss contentious issues; (7) fear of risk to funding opportunities; (8) fear of being made redundant; (9) fear of reduced opportunities for advancement; (10) workplace colleagues/peer pressure/work culture; (11) workplace policy; (12) middle management; (13) senior management; (14) minister's office (also see Appendix S1). $N = 220$ for each response

was paramount (Q10, Table 1). On the other hand, an equal number of government respondents thought current written policies were not reasonable, with 52% of those aggrieved by being unable to speak publicly, even in a personal capacity (Table 1). Twenty-three percent of these respondents thought that current policies were not reasonable because they prevent important information reaching the public (Table 1).

Public commentary was constrained across a wide range of topics and varied among workplaces (Q11). Industry and government respondents most commonly reported commentary regarding threatened species was constrained (industry 56%, government 46%, university 28%). Industry respondents reported constraints more commonly than other sectors regarding impacts of mining, urban development (both results industry 38%, government 19%, university 15%), and native vegetation clearing (industry 47%, government 31%, university 22%). Government respondents more often reported being constrained in commenting on logging (27%) and climate change (24%) compared with university (8%, 5%, respectively) and industry (16%, 3%, respectively). The most common constraint on university respondents (35%) were in relation to feral animals.

3.3 | Sources of influence constraining public commentary

Seventy-five percent of respondents reported having refrained from making a contribution to public information or debate when given the opportunity (Q12), most commonly in traditional media (36%), or social media (35%). However, a small number of respondents self-censored conference presentations (9%) and peer-reviewed papers (7%) (Q13).

Respondents usually reported multiple reasons for refraining from public commentary (Q14; Figure 1, Table 1). University respondents, more than other workplaces, avoided public commentary out of fear of how they would be represented by the media (76%), fear of being drawn beyond their expertise (73%), stress (55%), fear that funding might be affected (53%), and uncertainty about their area of expertise (52%). Important factors constraining commentary from government respondents, more than from university and industry respondents, included senior management (82%), workplace policy (72%), minister's office (63%), and middle management (62%). Fear of barriers to advancement (49%) and concern about media misrepresentation (49%) also discouraged public communication

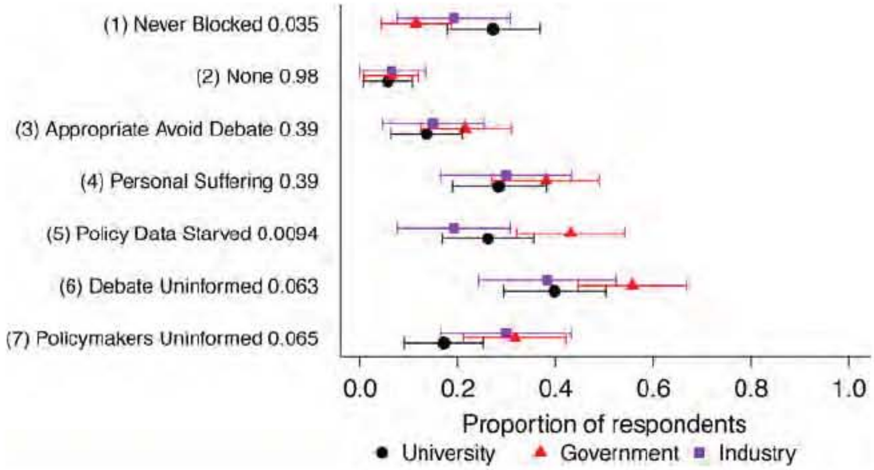

FIGURE 2 Civic and personal consequences of research suppression for respondents from universities, government, or industry (Q15). Error bars indicate 95% confidence limits. Overall *p* from multivariate analysis .02. Univariate *p* values are indicated after each category name, testing for difference among workplaces. Detailed responses (from top to bottom) were (1) I've never been blocked or refrained from public commentary on an issue about which I am knowledgeable; (2) no consequences; (3) I avoided influencing public debate, which I think was appropriate; (4) personal suffering (e.g., I feel stressed or morally compromised); (5) policy not informed by relevant data; (6) there was insufficient public discourse and debate (e.g., public remained uniformed, public debate dominated by vested interest groups so public misled); (7) policy makers did not have access to relevant information for developing new or updated policies (also see Appendix S1). $N = 220$ for each response

by government respondents, though at rates similar to or lower than other workplaces. Industry respondents were silenced most often by concern about how they would be represented in the media (60%), fear of being drawn beyond their expertise (49%), and constraints from senior management (43%) and workplace policy (43%).

3.4 | Consequences of constraints on public commentary

Respondents commonly (45% of all respondents) reported inadequate public discourse, and 25% reported policy makers were inadequately informed (Q15). Government respondents reported that policy was not being informed by relevant evidence more often than university or industry respondents (43% government; Figure 2, Table 1).

Personal suffering associated with constraints on commentary did not vary significantly among workplaces and was reported by approximately one third of respondents (Q15). Job satisfaction was compromised by constraints on commentary for 56% of government, 36% of industry, and 22% of university respondents (Q16). Forty-two percent of respondents indicated they had been harassed or criticized for their communications (Q18), and of those, 83% believed the harassers were motivated by political or economic interests (Q19). In 27% of cases, the respondent was publicly defended by their organization (Q20).

Seventy-seven respondents reported specific impacts on job satisfaction of constraints on communication, with 37% reporting moral compromise, feeling inauthentic, or frustrated over being unable to freely communicate (Q17, Table 1, Appendix S4). Sixteen respondents (21%) indicated they had experienced job insecurity, loss, impacts to their career, or had left the field. Seventeen percent were unable to do their job properly or felt disempowered, 10% reported a decline in motivation to contribute to their workplace's objectives, and 5% felt unvalued. Eighteen percent of respondents to this question reported mental health impacts, and 7% had been harassed or threatened (Appendix S4). In the face of workplace suppression, 34% of respondents had covertly provided information to colleagues who had fewer constraints, a percentage that did not differ significantly among workplaces (Q21).

4 | DISCUSSION

Our study provides insights into the extent to which practicing ecologists in universities, industry, and government are free to share scientific information and engage in public commentary about conservation-related issues. Engagement in public debate was overwhelmingly supported by our respondents, with over half suggesting it is a duty rather than a freedom. This reflects views previously expressed by senior public servants and former government ministers in the USA (Lalor & Hickey, 2013). So it is concerning that we revealed substantial restrictions on ecologists' willingness or ability to engage, resulting in important civic, personal, and environmental consequences (Figure 3).

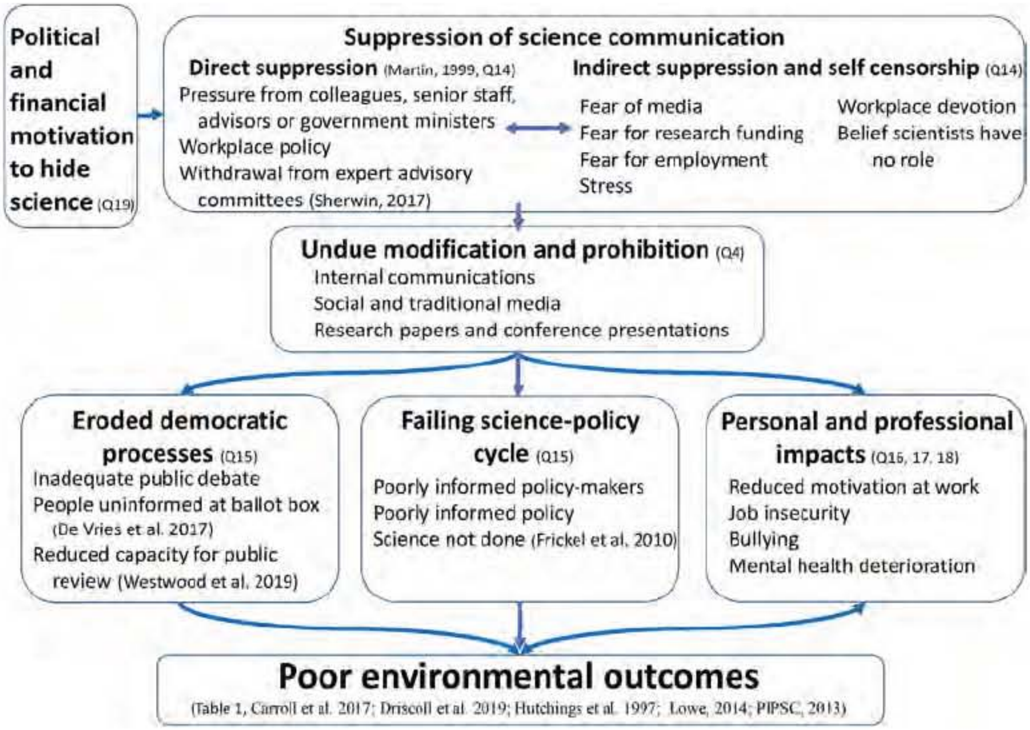

FIGURE 3 Key processes and outcomes in suppression of science communication, derived from the literature and survey results (indicated by question number, see Appendix S1). The potential for political or financial gains frequently drives suppression of scientific communication. Science communication can be suppressed by direct or indirect motivators, and these motivators are likely to influence each other. Suppression takes the form of undue modification or complete prohibition of communications, and this leads to three broad outcomes: eroded democratic processes, the failure of science to inform policy, and personal and professional impacts. Poorly informed policy, eroded democratic processes and an unmotivated workforce all result in continuing decline of biodiversity, and biodiversity loss feeds back to further degrade personal well-being

4.1 | Science commonly suppressed

Australia has not experienced the extreme research suppression as seen in Iran, Malaysia, Indonesia, Egypt, and Serbia, which include arrests and university closures (Altbach, 2001; Catanzaro, 2019). Yet, in our study, the suppression of science through constraints on commentary and communication was commonly reported within government, industry, and, less often, at universities. The science suppression reported included complete prohibition on communication, as well as alteration of communications to paint government or industry actions or decisions in a misleading, more environmentally friendly, light. The rate of alteration of communication with the media (28%) was similar to the rate reported by Canadian government scientists during the Harper government (24%; PIPSC, 2013), while the reporting rate by government respondents of complete prohibition of communication (52%) was lower than reported in Canada (90%; PIPSC 2013). Even internal communications were reported to be suppressed and modified, meaning that government ministers, senior managers, and corporate leaders might not receive frank information about the risks to biodiversity posed by their policies, decisions, and, ultimately, actions.

Topics that were suppressed are some of the most demanding and complex environmental issues. Australia has the worst record of mammal extinctions globally (Woinarski, Burbidge, & Harrison, 2015) with feral animals, changed fire regimes, and land clearing the key threats (Kearney et al., 2019; Woinarski et al., 2015). Australia is regarded as one of the world's 11 deforestation fronts (WWF, 2015) and is likely to suffer widespread biodiversity loss from climate change and habitat loss over coming decades (Hughes et al., 2017; Segan, Murray, & Watson, 2016). Yet our respondents reported that information about these critical topics has been distorted and suppressed.

Policies suppressing communication were most commonly considered unreasonable by government respondents because they limit how they can behave as private individuals. This kind of suppression was recently tested in court. Australia's High Court held that the Australian Government was within its rights to dismiss a public servant for making anonymous, out-of-hours social media posts that were vitriolic and scathing of government policy, because that action was contrary to codes of conduct

(Pender, 2019a, 2019b). Less vitriolic, more objective criticism may not cross this ill-defined boundary for acceptable public commentary (Pender, 2019b). The ruling therefore does not specifically prohibit science-based advice from being shared by public servants on social media. Contrasting with the ambiguity in Australia, recent advances in Canada define explicit protections for expressing private opinions (Government of Canada, 2018).

4.2 | What constrains public commentary?

Fear of dismissal or impeded advancement is likely generated by direct suppression of research (Martin, 1999), with respondents indicating this pressure comes primarily from senior management, but also government ministers' offices and middle management, particularly for government respondents. This is consistent with research from the medical field, where senior managers were reported to be temporary political placements, with a primary objective of ensuring the minister's political longevity (Yazahmeidi & Holman, 2007). Political motivations of senior bureaucrats were also reported as a barrier to integrating science into environmental policy in Canada (Lalor & Hickey, 2014). In Chile, political advisors in ministers' offices have obscured communication between department staff and ministers (Fuenzalida & Riccucci, 2019). Staff from politicians' offices can also mediate communication from the public service to parliament, and rather than representing their members' electoral constituents, such staff often bring biases, particularly those who take advice from conservative and industry groups (Hertel-Fernandez, Mildenberger, & Stokes, 2019).

Indirect suppression (Martin, 1999), including self-censorship by university and industry respondents, was related to fear of interacting with the media and uncertainty about their areas of expertise. The latter result is surprising because most respondents did not hold extreme or demanding views about the level of expertise needed to be sufficiently knowledgeable to engage in public commentary. By clarifying misconceptions around science communication (Garrard et al., 2016), providing media training that addresses risks of misrepresentation (Besley & Tanner, 2011), and implementing policies that actively support science communication (UCS, 2015), it may be possible to reduce pressure to self-censor.

4.3 | What happens when science is suppressed?

In addition to its implications for weakening democracy (Crabtree et al., 2018; Yazahmeidi & Holman, 2007), and less effective conservation policy (Carroll et al., 2017; Driscoll et al., 2019; Lowe, 2014; PIPSC, 2013; Spash, 2015), our survey revealed substantial personal consequences of communication constraints. Respondents most often reported frustration and moral compromise over science suppression, while one fifth reported that science suppression affected their employment and a similar proportion indicated mental health consequences. Despite bullying being against codes of conduct in most workplaces (Hurley, Hutchinson, Bradbury, & Browne, 2016), bullying is nevertheless experienced by ecologists who speak out, both from within their organizations and from other organizations (Table 1; Appendix S4). These severe personal consequences, alongside the civic and conservation consequences, demand a strong and urgent response from universities, government, and industry.

5 | HOW TO MOVE FORWARD

Devising reforms that ensure open and timely access to science requires substantial work and collaboration by professional scientific societies, industry unions, nongovernmental organizations, industry, government agencies, and political parties. Here we identify some of the key elements that these actors could consider in addressing science suppression across universities, government, and industry.

Australian universities already benefit from policies that support academic freedom (Martin-Sardesai, Irvine, Tooley, & Guthrie, 2017), but our findings suggest more work is needed. Areas for consideration include prioritizing academic freedom over income streams (Table 1), amending research contracts that include clauses constraining academic freedom (Ries & Kypri, 2018) and mounting public and, if necessary, legal defense of academics when they are unfairly attacked over their research or communication (Kuehn, 2004).

Workplace policies were a major cause of information suppression in government and industry. Assessment of government agencies' media policies by the U.S. Union of Concerned Scientists (UCS, 2015) highlights features of effective codes including an "explicit personal views exception" and "rhetoric promoting openness." Similarly, the Canadian code for scientific integrity in the public service supports federal government scientists to speak freely in public about their research without political interference (Government of Canada 2018; PIPSC, 2018). It also clarifies when public servants can speak in a private capacity, while making research available in a timely manner. Fostering a culture that values open sharing of science is an important reform (Carroll et al., 2017; Yazahmeidi & Holman, 2007), and this type of pro-communication code is likely to support change in that direction. Nevertheless, the

Canadian model allows suppression when there are "clear and compelling reasons for doing so" (Government of Canada, 2018). These reasons may sometimes benefit biodiversity (Tulloch, Auerbach, & Avery-Gomm, 2018) but may also be politically motivated which is a long-recognized limitation of undertaking science within government agencies (Hutchings et al., 1997).

The key limitation to free communication of science for government agencies is that they must maintain the government's trust. Releasing controversial information could be seen as political, or as a failure to serve their policy agenda, potentially reducing trust, and, ultimately, effectiveness of the public service. We suggest the importance of trust between agencies and ministerial offices is why many government respondents argued that communication constraints were needed to ensure consistent messaging. Messaging that is consistent with a minister's office likely helps maintain trust between the agency and the minister, but our results imply this can require science suppression to avoid drawing public attention to environmentally damaging policies. This creates tension, with increasing political influence on agencies from ministerial offices and political appointments within agencies (Fuenzalida & Riccucci, 2019; Lalor & Hickey, 2014) straining agency codes of conduct that require high standards of accountability and service to the public (Shergold, 1997).

An analogous tension exists for environmental consultants between their own professional standards and the needs of their employers (Dougherty, 2019), often resulting in poor environmental outcomes (Enriquez-de-Salamanca, 2018) and information suppression (Table 1). With these inherent constraints on government and industry employees, we suggest new authorities, independent of government and industry, are needed to ensure that expert knowledge properly informs government decision-making and promotes public awareness. Similar conclusions have recently been drawn in Canada (Jacob et al., 2018; Westwood et al., 2019a).

A range of models are available for achieving independent scientific input into public and policy debate (Hutchings et al., 1997). The Australian Productivity Commission's charter provides one model for independent research that delivers publicly open advice to the government (Productivity Commission [PC], 2020), albeit with the limitation of not making reports simultaneously available to the public and policy-makers (see also: Hutchings et al., 1997). Such commissions can minimize political interference by reporting directly to a nonpartisan committee rather than a government minister (Brown et al., 2018; Environmental Defenders Office [EDO], 2013), by ensuring security of tenure for commissioners, and having guaranteed, sufficient funding (PC, 2020; Westwood et al., 2019b). An independent authority that was responsible for environmental research related to environmental assessment and policy decisions would not have the conflicts that are inherent within government and the environmental impact assessment process, eliminating some key drivers of science suppression.

An independent authority could also help implement other reforms to environmental impact assessment processes that would help reduce science suppression in industry. Reforms could include enforcing scientific rigor, independent peer review of reports, and open, timely publication, and archiving of data, reports, and decisions (Singh, Lerner, & Mach, 2018; Westwood et al., 2019a).

Professional societies should defend scientists when they come under attack, should foster a culture that supports open communication (Kuehn, 2004), and take a lead role in advocating for change (Martin, 1999; Swinburn & Moore, 2014). Further, our study shows that covert leaking of information already occurs. Professional societies can provide mechanisms to support information provision that is safe for the informant (e.g., https://www.transparency.org/; https://www.peer.org/) and can document cases of suppression to demonstrate the need for reform (Westwood et al., 2017).

Our survey implies that other areas need attention including the availability of mental health services in workplaces and explicit recognition that science suppression can involve bullying that contravenes policies about safe and equitable working environments. Further, media training is needed to reduce concerns about interacting with the media (Besley & Tanner, 2011). There are personal actions that individuals can take to improve resilience to any fallout from speaking up, including learning from others, building networks of support and, where legal reprisals are possible, protecting financial resources (Martin, 2019).

6 | CONCLUSION

Ecologists, particularly those working in biodiversity conservation, play a vital role in informing government policy and public debate, and this in turn affects environmental management (Boon, 2019; Pecl et al., 2017; Schaefer & Beier, 2013). The right and duty to express their expert knowledge is clearly supported by almost all of the ecologists we surveyed. However, suppression of science was commonly reported in our study and is widespread globally, with science compromised in many countries (Lin, 2019; PIPSC, 2013; UCS, 2008). Reforms, ranging from personal preparation to establishing new independent agencies, need to be further developed and implemented to help government, industry, and universities reduce constraints on open and honest scientific communication. Climate change and biodiversity loss are among the biggest challenges facing humanity (Ceballos, Ehrlich, & Dirzo, 2017; IPBES, 2019), and successfully addressing these challenges will depend, in part, on free access to scientific knowledge that supports good policy and robust democratic processes.

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AUTHORS' CONTRIBUTIONS

All authors contributed to designing the survey questions, interpretation, and writing. GG and AK implemented the survey. DD led the project, completed analysis, prepared figures and led writing.

ETHICS STATEMENT

Human Research Ethics approval for this project was granted by RMIT University's College Human Ethics Advisory Network DSC CHEAN B 21607-07/18.

DATA ACCESSIBILITY STATEMENT

Categorical response data are available through the Deakin University DRO data repository https://dro.deakin.edu.au/.

CONFLICT OF INTEREST

We may receive less research funding for being outspoken on this issue. We receive grants that have contracts restricting academic freedom, and some of us self-censor to avoid risks to grants from government, resulting in personal moral conflict and less informed public.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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APPENDIX C

What's Wrong with Risk Matrices?

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What's Wrong with Risk Matrices?

Louis Anthony (Tony) Cox, Jr.*

Risk matrices—tables mapping "frequency" and "severity" ratings to corresponding risk priority levels—are popular in applications as diverse as terrorism risk analysis, highway construction project management, office building risk analysis, climate change risk management, and enterprise risk management (ERM). National and international standards (e.g., Military Standard 882C and AS/NZS 4360:1999) have stimulated adoption of risk matrices by many organizations and risk consultants. However, little research rigorously validates their performance in actually improving risk management decisions. This article examines some mathematical properties of risk matrices and shows that they have the following limitations. (a) *Poor Resolution*. Typical risk matrices can correctly and unambiguously compare only a small fraction (e.g., less than 10%) of randomly selected pairs of hazards. They can assign identical ratings to quantitatively very different risks ("range compression"). (b) *Errors*. Risk matrices can mistakenly assign higher qualitative ratings to quantitatively smaller risks. For risks with negatively correlated frequencies and severities, they can be "worse than useless," leading to worse-than-random decisions. (c) *Suboptimal Resource Allocation*. Effective allocation of resources to risk-reducing countermeasures cannot be based on the categories provided by risk matrices. (d) *Ambiguous Inputs and Outputs*. Categorizations of severity cannot be made objectively for uncertain consequences. Inputs to risk matrices (e.g., frequency and severity categorizations) and resulting outputs (i.e., risk ratings) require subjective interpretation, and different users may obtain opposite ratings of the same quantitative risks. These limitations suggest that risk matrices should be used with caution, and only with careful explanations of embedded judgments.

KEY WORDS: AS/NZS 4360; decision analysis; enterprise risk management; Military Standard 882C; qualitative risk assessment; risk matrix; semiquantitative risk assessment; worse-than-useless information

1. INTRODUCTION

A *risk matrix* is a table that has several categories of "probability," "likelihood," or "frequency" for its rows (or columns) and several categories of "severity," "impact," or "consequences" for its columns (or rows, respectively). It associates a recommended level of risk, urgency, priority, or management action with each row-column pair, that is, with each cell. Table I shows an example of a standard 5 × 5 risk matrix developed by the Federal Highway Administration for assessing risks and setting priorities in addressing issues as diverse as unexpected geotechnical problems at bridge piers and unwillingness of landowners to sell land near critical road junctions.

The green, yellow, and red cells indicate low, medium, and high or urgent risk levels based on ratings of probability (vertical axis) and impact (horizontal axis) ranging from "VL" (very low) to "VH" (very high).

Table II shows a similar example of a 5 × 5 risk matrix from a 2007 Federal Aviation Administration (FAA) Advisory Circular (AC) introducing the concept of a safety management system for airport operators. The accompanying explanation states: "Hazards are ranked according to the severity and the likeli-

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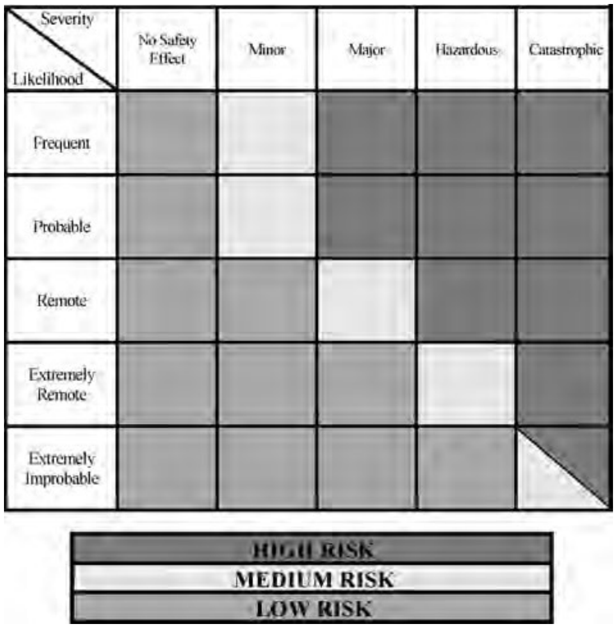
Table I. Standard 5 × 5 Risk Matrix for Federal Highway Administration

Probability\ Impact	VL	L	M	H	VH
VH	Green	Yellow	Red	Red	Red
H	Green	Yellow	Red	Red	Red
M	Green	Green	Yellow	Red	Red
L	Green	Green	Yellow	Red	Red
VL	Green	Green	Green	Yellow	Red

Source: Federal Highway Administration, 2006 http://international.fhwa.dot.gov/riskassess/images/figure_12.htm.

Table II. Example of a Predictive Risk Matrix for the Federal Aviation Administration



Source: Federal Aviation Administration, 2007 www.faa.gov/airports_airtraffic/airports/resources/advisory_circulars/media/150-5200-37/150_5200_37.doc.

hood of their risk, which is illustrated by where they fall on the risk matrix. Hazards with high risk receive higher priority for treatment and mitigation." Many similar examples can be found for regulatory agencies, regulated industries, and public- and private-sector organizations. Training courses and software tools, such as MITRE's *Risk Matrix* tool for program risk management (MITRE, 1999–2007) help to automate risk matrix creation, application, and documentation.

The use of such risk matrices to set priorities and guide resource allocations has also been recommended in national and international standards. It has spread through many areas of applied risk management consulting and practice, including enterprise risk management (ERM) and corporate governance (partly under the influence of the Sarbanes Oxley Act and international standards such as AUS/NZ 4360:1999); highway construction project risk management (Table I); airport safety (Table II); homeland security; and risk assessment of potential threats to office buildings, ranging from hurricanes to terrorist attacks (Renfroe & Smith, 2007).

Risk matrices have been widely praised and adopted as simple, effective approaches to risk management. They provide a clear framework for systematic review of individual risks and portfolios of risks; convenient documentation for the rationale of risk rankings and priority setting; relatively simple-appearing inputs and outputs, often with attractively colored grids; opportunities for many stakeholders to participate in customizing category definitions and action levels; and opportunities for consultants to train different parts of organizations on "risk culture" concepts at different levels of detail, from simply positioning different hazards within a predefined matrix to helping thought leaders try to define risk categories and express "risk appetite" preferences in the color coding of the cells. As many risk matrix practitioners and advocates have pointed out, constructing, using, and socializing risk matrices within an organization requires no special expertise in quantitative risk assessment methods or data analysis.

Yet, despite these advantages and their wide acceptance and use, there has been very little rigorous empirical or theoretical study of how well risk matrices succeed in actually leading to improved risk management decisions. Very little prior technical literature specifically addresses logical and mathematical limitations of risk matrices (but see Cox *et al.*, 2005). Risk matrices are different enough from other topics (such as multivariate classification, clustering, and learning with correct classes provided as training data) to require separate investigation of their properties, in part because "risk" is not a measured attribute, but is derived from frequency and severity inputs through *a priori* specified formulas such as *Risk* = *Frequency* × *Severity*. This article explores fundamental mathematical and logical limitations of risk matrices as sources of information for risk management decision making and priority setting.

2. A NORMATIVE DECISION-ANALYTIC FRAMEWORK

Many decisionmakers and consultants believe that, while risk matrices may be only rough

Table III. A 2 × 2 Risk Matrix

Consequence Probability	Low	High
High	Medium	High
Low	Low	Medium

approximate tools for risk analysis, they are very useful for distinguishing qualitatively between the most urgent and least urgent risks in many settings and are certainly much better than nothing, for example, than purely random decision making. This section examines these beliefs from the standpoint of optimal statistical decision making in a simple framework for which it is possible to obtain exact results.

The simplest possible risk matrix is a 2 × 2 table that results from dichotomizing each of the two axes, referred to here as "probability" and "consequence." (Many other axes such as "frequency" and "severity" or "likelihood" and "magnitude" are also used, but changing the names does not affect the logic.) Table III shows such a matrix. Now, consider using it to categorize quantitative risks. For simplicity, suppose that the two attributes, *Probability* and *Consequence* have quantitative values between 0 and 1, inclusive (where 0 = minimal or zero adverse consequence and 1 = maximum adverse consequence). Define the quantitative risk for any (*Probability*, *Consequence*) pair to be their product, *Risk* = *Probability* × *Consequence*, as advocated in many risk matrix methodology documents. The risk matrix designer can choose where to draw the boundaries between *low* and *high* values on each axis. Let the boundary between *low* and *high* consequence corresponds to a numerical value x between 0 and 1; and let the boundary between *low* and *high* probability correspond to a value y between 0 and 1.

To assess the performance of the risk matrix in supporting effective risk management decisions, consider the following specific decision problem. The decisionmaker must choose which of two risks, A and B, to eliminate. (She can only afford to eliminate one of them.) The quantitative values of *Probability* and *Consequence* are *a priori* independently and uniformly distributed between 0 and 1 for each of A and B. The only information that the decisionmaker has is knowledge of which cell of the risk matrix each risk falls in. (Thus, the risk matrix provides statistical information about the true but unknown quantitative risk; it is a lossy information channel.) *How well can the information provided by the risk matrix be used to identify the quantitatively greater risk?* Equivalently, how well can the categorizations of quantitative risks provided by the matrix be used to identify the decision that maximizes expected utility (minimizes expected loss)?

The answer depends on how the risk matrix is designed and on the joint probability distribution of *Probability* and *Consequence* values. In general, the two risks can be ranked with no error if one risk falls in the *high* (red) cell in the upper right of Table I and the other falls in the *low* (green) cell in the lower left (since every risk in the *high* cell is quantitatively as well as qualitatively greater than any risk in the *low* cell). The probability of this event is $2 \times (1 - x)(1 - y)xy$. This symmetric function is maximized by choosing $x = y = 0.5$. (Otherwise, if the two risks have the same qualitative rating, then there is no way to choose among them based on the risk matrix, and we can assume that there is a 50-50 chance of making the right choice, that is, 50% error probability. If one of the two ratings is medium and the other is not, then the error probability from choosing the risk with the higher rating is positive, since some points in the cell with the higher qualitative rating have smaller quantitative risk values than some points in the cell with the lower qualitative rating; see Lemma 1 in the next section.)

The probability that two risks can be unambiguously ranked (i.e., with zero error probability) using the risk matrix with $x = y = 0.5$ is $(1/2) \times (1/4) = 0.125$ (i.e., it is the probability that one of them falls in one cell of the "*high*/*low*" diagonal and the other falls in the other cell of that diagonal). The probability that the two risks cannot be compared using the matrix with better than random accuracy (50% error probability) is the probability that both risks receive the same qualitative rating; this is $0.375 = (1/4) \times [(1/2) + (1/4) + (1/2) + (1/4)]$ (considering the four cells clockwise, starting with the upper left). The probability that the two risks can be compared using the matrix with error probability greater than zero but less than 50% is $1 - 0.125 - 0.375 = 0.5$.

Next, suppose that the risk matrix is constructed with $x = y = 0.5$, but that it is applied in decision settings where the joint probability distribution of *Probability* and *Consequence* is uncertain. Now, how well the matrix can identify which of two risks is greater depends completely on the joint probability distribution of (*Probability*, *Consequence*) pairs. For example, if *Probability* and *Consequence* values are uniformly distributed along the diagonal from (0, 0) to (1, 1), then there is a 50% probability that the two risks can be classified with zero error probability (if one of them is in the *high* cell and the other is in the *low* cell); otherwise, the error probability is 50% (if both are in the same cell). Thus, under these very favorable conditions of perfect positive correlation, the error probability is $0.5 \times 0.5 = 0.25$. Conversely, if *Probability* and *Consequence* values are perfectly negatively correlated and are concentrated along the diagonal from (0, 1) to (1, 0), then all risks will be assigned a risk rating of "Medium" (although their numerical values range from 0 at the ends of the upper-left to lower-right diagonal to 0.25 in the middle), and the risk matrix will provide no useful information for discriminating between greater and lesser risks. Under these less favorable conditions, the decisionmaker using the risk matrix can do no better than random decision making, and the error probability increases to 50%.

Finally, if *Probability* and *Consequence* values are negatively correlated and concentrated along the line $Probability = 0.75 - Consequence$ (for *Consequence* values between 0 and 0.75), then all points on this line in the medium cells (i.e., for *Consequence* values between 0 and 0.25 or between 0.5 and 0.75) have *smaller* quantitative risks than any points in the *low* cell (i.e., for *Consequence* values between 0.25 and 0.5). For example, the pair (0.1, 0.65) would be classified as a medium risk (although its quantitative risk value is $0.1 \times 0.65 = 0.065$), while the pair (0.37, 0.38) would be classified as a *low* risk, even though its quantitative risk value is more than twice as great, $0.37 \times 0.38 = 0.14$. (More generally, such counterexamples can be constructed by noting that each iso-risk contour $Probability \times Consequence = constant$ is convex, so that a straight line passing through the two points where such a contour intersects the edges of a cell of the matrix will lie above the contour within the cell but below it outside the cell.)

For this unfavorable joint distribution of (*Probability*, *Consequence*) pairs, the information provided by the risk matrix is *worse than useless* (Cox & Popken, 2007) in the sense that, whenever it discriminates between two risks (by labeling one *medium* and the other *low*), it reverses the correct (quantitative) risk ranking by assigning the higher qualitative risk category to the quantitatively smaller risk. Thus, a decisionmaker who uses the risk matrix to make decisions would have a lower expected utility in this case than one who ignores the risk matrix information and makes decisions randomly, for example, by tossing a fair coin. (Similar examples can be constructed for the *high* risk cell in the upper right corner of Table III. For example, the (*Probability*, *Consequence*) pair (0.6, 0.6) is rated as *high* and the pair (0.48, 1) is rated as *medium*, even though the latter has a higher quantitative risk (0.48) than the former (0.36).)

The question of how risk matrices ideally should be constructed to improve risk management decisions has no simple answer, both because risk matrices are typically used as only one component in informing eventual risk management decisions and also because their performance depends on the joint distribution of the two attributes, *Probability* and *Consequence*, as illustrated in the above examples. Since risk matrices are commonly used when quantitative data are limited or unavailable, this joint distribution is typically unknown or very uncertain. This knowledge gap implies that the actual performance of a risk matrix and whether it is helpful, no better than random, or worse than useless may be unknown. It also prevents easy application of traditional decision-analytic, statistical, artificial intelligence, and engineering methods for similar problems (e.g., for optimal classification and for discretization of multivariate relations) that require the joint distribution of the attributes as an input.

However, the simplest case of a 2×2 risk matrix does suggest two important related conclusions. First, it is not necessarily true that risk matrices provide qualitatively useful information for setting risk priorities and for identifying risks that are high enough to worry about and risks that are low enough to be neglected or postponed. (As just discussed, the information they provide can be worse than useless when probability and consequence are negatively correlated.) Second, use of a risk matrix to categorize risks is not always better than—or even as good as—purely random decision making. Thus, the common assumption that risk matrices, although imprecise, do some good in helping to focus attention on the most serious problems and in screening out less serious problems is not necessarily justified. Although risk matrices can indeed be very useful if probability and consequence values are positively correlated, they can be worse than useless when probability and consequence values are negatively correlated. Unfortunately, negative correlation may be common in practice, for example, when the risks of concern include a mix of low-probability, high-consequence and higher-probability, low-consequence events.

Although this section has been restricted to 2×2 risk matrices, the nature of the counterexamples in which the optimal statistical decision is to ignore risk matrix information (e.g., examples with joint distributions of probability-consequence pairs concentrated on negatively sloped lines that intersect with convex iso-risk contours where they cross cell boundaries) implies that simply changing the position or number of grid lines cannot eliminate the problem. A similar construction can be carried out no matter how many cells a matrix has and no matter where the cell boundaries are located. Generalizing the decision problem to that of selecting a subset of risks to remediate, from among a larger set of many risks (rather than only deciding which of two risks is greater) also does not change the main conclusion. For some joint distributions of probability and consequence values, normative decision theory would require *not* using the qualitative risk rating information provided by a risk matrix, as it reverses the correct (quantitative) risk ratings that would be obtained using perfect information.

What can be salvaged? Several directions for advancing research on risk matrices appear promising. One is to consider applications in which there are sufficient data to draw some inferences about the statistical distribution of (*Probability*, *Consequence*) pairs. If data are sufficiently plentiful, then statistical and artificial intelligence tools such as classification trees (Chen *et al.*, 2006), rough sets (Dreiseitl *et al.*, 1999), and vector quantization (Lloyd *et al.*, 2007) can potentially be applied to help design risk matrices that give efficient or optimal (according to various criteria) discrete approximations to the quantitative distribution of risks. In such data-rich settings, it might be possible to use risk matrices when they are useful (e.g., if probability and consequence are strongly positively correlated) and to avoid them when they are not (e.g., if probability and consequence are strongly negatively correlated).

A different approach is to consider normative properties or axioms that risk matrix designers might ideally want their matrices to satisfy, and then to identify whether such matrices exist (and, if so, whether they are unique). This normative axiomatic approach, explored in the following section, can be used even when sufficient data are not available to estimate the joint distribution of probability and consequence values.

3. LOGICAL COMPATIBILITY OF RISK MATRICES WITH QUANTITATIVE RISKS

What does a risk matrix mean? One natural intuitive interpretation is that it provides a rough discrete (ordered categorical) approximation to a more detailed—but not readily available—underlying quantitative relation. At least in principle, the underlying relation is described by a risk formula such as one of the following:

$$\textit{Risk} = \textit{probability} \times \textit{consequence} \text{ (or } \textit{frequency} \times \textit{severity or likelihood} \times \textit{impact} \text{ or } \textit{threat} \times (\textit{vulnerability} \times \textit{consequence}) \text{, etc.)}$$

(We will use "frequency" or "probability" and "severity" or "consequence" as the default names of the two axes, and "risk" as the name for their product, but the analysis applies to any similar mathematical structure, regardless of the names.) For example, it might be supposed that the division of the probability axis into five ordered qualitative categories (e.g., from very rare to almost certain) corresponds roughly to a partitioning of a quantitative probability axis into the intervals [0, 0.2), [0.2, 0.4), [04, 0.6), [0.6, 0.8), and [0.8, 1] (where square brackets indicate that the corresponding end point is included in an interval and parentheses indicate that it is not). Similarly, the five ordered categories for the severity axis might naturally be interpreted as corresponding to numerical intervals, [0, 0.2), [0.2, 0.4), [04, 0.6), [0.6, 0.8), and [0.8, 1], on a quantitative value scale (e.g., a von Neumann-Morgenstern utility scale) normalized to run from 0 to 1, where 0 = no adverse impact, 1 = worst possible adverse outcome considered, and values between 0 and 1 represent adverse impacts or consequences with values intermediate between no adverse impact and worst possible adverse impact.

However, such an intuitive interpretation of the risk matrix as an approximation to an underlying quantitative model can only be sustained if the risk matrix satisfies certain constraints. To be most useful, a risk matrix should, at a minimum, discriminate reliably between very high and very low risks, so that it can be used as an effective screening tool to focus risk management attention and resources. This requirement can be expressed more formally as the following principle of *weak consistency* between the ordered categorization of risks provided by the matrix and the ranking of risks by an underlying quantitative formula, such as one of those above.

DEFINITION OF WEAK CONSISTENCY: *A risk matrix with more than one "color" (level of risk priority) for its cells satisfies* weak consistency *with a quantitative risk interpretation if points in its top risk category represent higher quantitative risks than points in its bottom category.*

Here, "quantitative risk" is defined as the product of a point's coordinates when the axes are interpreted quantitatively, for example, *frequency* × *severity*. If weak consistency holds, then all risks in the top qualitative category are quantitatively larger than all risks in the lowest qualitative category. In this case, the risk matrix can discriminate reliably between at least some risks, even though it does not require quantifying the probability and consequence attributes. It may then serve as a useful screening tool, which is one of the main practical uses of risk matrices. But if weak consistency does not hold, then risks that are screened out as being relatively small according to the matrix may in fact be larger than some of those that the matrix classifies as top priority, thus leading to a misallocation of risk management resources. It is therefore desirable to construct risk matrices that satisfy weak consistency, if possible.

Weak consistency is not an arbitrary axiom. It is implied by the hypothesis that *some* quantitative interpretation of the risk categories in a matrix exists, at least in principle (i.e., that there is some underlying quantitative risk scale such that the consecutive ordinal risk categories of the matrix correspond, at least approximately, to consecutive intervals on the quantitative scale), even if this scale is unknown, imprecise, or undefined in practice. If it does not hold, then a risk matrix does not mean what many users might expect it to mean, that is, that risks rated in the top category (red) are larger than those rated in the bottom category (green). Thus, transparency of interpretation provides another incentive for designing risk matrices to satisfy weak consistency.

3.1. Discussion of Weak Consistency

More generally, a risk matrix partitions alternatives (typically representing different threats, hazards, risk reduction or investment opportunities, risk management actions, etc.) into distinct categories corresponding to the different priority levels or "colors" of the matrix cells. Weak consistency implies that this partitioning assigns the highest qualitative level (e.g., red) to the alternatives that actually do have higher quantitative risk values than those assigned the lowest qualitative level (e.g., green). If weak consistency holds, the qualitative classification given by the matrix is, in this sense, at least roughly consistent with what a quantitative analysis would show. Red cells do represent unambiguously higher risks than green cells, where we use "red" to denote the highest urgency level (that of the upper right-most cell, if the matrix axes are oriented to represent increasing probability or frequency on one axis and increasing severity of consequences on the other) and we use "green" to denote the lowest urgency level (that of the lowest left-most cell in such a table). This provides a logical basis for screening risks into "larger" (red) and "smaller" (green) categories.

Table IV. A 5 × 5 Matrix Compatible with *Risk = Probability × Consequence*

Prob\Consequence	0–0.2	0.2–0.4	0.4–0.6	0.6–0.8	0.8–1
0.8–1	Green	Green	Yellow	Red	Red
0.6–0.8	Green	Green	Yellow	Yellow	Red
0.4–0.6	Green	Green	Green	Yellow	Yellow
0.2–0.4	Green	Green	Green	Green	Green
0–0.2	Green	Green	Green	Green	Green

Table IV shows an assignment of risk levels that satisfies weak consistency for a 5 × 5 matrix in which the rows and columns are interpreted as equal partitions of two numerical scales, each normalized to run from 0 to 1. Any point in a red cell has a quantitative value (calculated as the product of the horizontal and vertical coordinates) of at least 0.48, while no point in any green cell has a value greater than 0.40.

3.2. Logical Implications of Weak Consistency

Weak consistency is more restrictive than might be expected. For example, neither of the colorings in Tables I and II satisfies weak consistency. See Lemma 2.) Indeed, it implies some important constraints on possible colorings of risk matrices.

LEMMA 1. *If a risk matrix satisfies weak consistency, then no red cell can share an edge with a green cell.*

Proof: Suppose that, to the contrary, a red cell and a green cell do share an edge. The iso-risk contour (i.e., the locus of all frequency-severity combinations having the same value of the product *frequency* × *severity*) passing through the midpoint of the common edge is a curve with negative slope. (It is a segment of a rectangular hyperbola, running from northwest to southeast.) Thus, it divides both cells into regions above and below this contour curve. Points that lie above this contour in the green cell have higher quantitative risk values than points lying below it in the red cell, contradicting weak consistency. Therefore, in a risk matrix satisfying weak consistency, red and green cells cannot share an edge. QED

Comment: It is sufficient for this proof that iso-risk contours exist and have negative slopes. Thus, risk could be any smooth increasing function of frequency and severity (or whatever attributes the two axes of the matrix represent), not necessarily their product. However, the product of the coordinates is often used in practice in discussions of the concept of quantitative risk that accompany risk matrices, and we will use it as the default definition for quantitative risk in numerical examples.

LEMMA 2: *If a risk matrix satisfies weak consistency and has at least two colors ("green" in the lower left cell and "red" in the upper right cell, if axes are oriented to show increasing frequency and severity), then no red cell can occur in the left column or in the bottom row of the risk matrix.*

Proof: Contours for all sufficiently small risk values (namely, values of all risk contours below and to the left of the one passing through the upper right corner of the lower left-most cell) pass through all cells in the left-most column and in the bottom row of a risk matrix. If any of these cells is red, then all points below one of these contours in the red cell will have lower quantitative risk levels than points above it in the green lower left-most cell of the table. This would contradict weak consistency; thus, no such red cell can exist. QED

An implication of Lemmas 1 and 2 is that any risk matrix that satisfies weak consistency and that does not assign identical priorities to all cells must have at least three colors: for example, red for the upper right-most cell; green for the lower left-most cell; and at least one other color (i.e., priority rating), which we will call yellow, to separate red and green cells.

3.3. The Betweenness Axiom: Motivation and Implications

The hypothesis that a risk matrix provides an approximate qualitative representation of underlying quantitative risks also implies that arbitrarily small increases in frequency and severity should not create discontinuous jumps in risk categorization from lowest priority ("green") to top priority ("red") without going through any intermediate levels ("yellow"). (Notice that this condition is violated in Tables I–III, but holds in Table IV.) Indeed, if the successive risk categories in a risk matrix represent (at least approximately) successive intervals on some underlying quantitative risk scale, then continuously increasing quantitative risk from 0 to 1 should cause the corresponding qualitative rating to pass through increasingly severe categorical values. A weaker condition is that the qualitative risk should pass through at least one intermediate value between green and red as the quantitative risk increases continuously from 0 to 1. Otherwise, a risk matrix does not mean what users might intuitively expect: that intermediate risk categories describe risks between the highest (red) and lowest (green) ones. These considerations motivate the following axiom.

DEFINITION OF BETWEENNESS: *A risk matrix satisfies the axiom of* betweenness *if every positively sloped line segment that lies in a green cell at its lower (left) end and in a red cell at its upper (right) end passes through at least one intermediate cell (meaning one that is neither green nor red) between them.*

Comment: Tables I and II both have red cells in Row 2 and violate betweenness, that is, in each an arbitrarily small increase in frequency and severity can cause a risk to be reclassified as red instead of green, without going through yellow. A 2×2 table such as Table III lacks sufficient resolution to allow betweenness, since there are no cells between the green lower left cell and the red upper right cell. Thus, betweenness can only be required for 3×3 and larger risk matrices.

Only some risk matrices satisfy both weak consistency and betweenness. Among all 3×3 matrices having more than one color, only one coloring of the cells satisfies both axioms. Using our conventional coloring scheme (green for lowest risk, red for highest risk, yellow for intermediate risk), this is the matrix with red in the upper right cell, green throughout the left column and bottom row, and yellow in all other cells.

3.4. Consistent Coloring

The final normative axiom considered in this article is motivated by the idea that equal quantitative risks should ideally have the same qualitative risk rating (color). Although this condition is impossible to achieve exactly in a discrete risk matrix, for the reason shown in the proof of Lemma 1 (essentially, horizontal and vertical grid lines cannot reproduce negatively sloped iso-risk contours), one rough approximation might be to enforce it for at least the two most extreme risk categories, red and green, while accepting some inconsistencies for intermediate colors. Accordingly, we will consider a requirement that all cells that contain red contours (meaning iso-risk contours that pass through other red cells) should themselves be red, unless the low resolution of the risk matrix causes them to also contain green contours. (A cell that contains both red and green contours has insufficient resolution to separate top-priority and bottom-priority risks and will not be required *a priori* to have either color.) Conversely, cells that contain green contours but no red ones should themselves be green. This motivates the following axiom of *consistent coloring*.

Definition of consistent coloring. *(1) A cell is red if it contains points with quantitative risks at least as high as those in other red cells (and does not contain points with quantitative risk as small as those in any green cell). (2) A cell is colored green if it contains some points with risks at least as small as those in other green cells (and does not contain points with quantitative risks as high as those in any red cell). (3) A cell is colored an intermediate color (neither red nor green) only if either (a) it lies between a red cell and a green cell; or (b) it contains points with quantitative risks higher than those in some red cells and also points with quantitative risks lower than those in some green cells.*

Intuitively, one might think of an iso-risk contour as being colored green if it passes through one or more green cells but not through any red cells; as being colored red if it passes through one or more red cells but not through any green cells; and as being colored yellow (or some other intermediate color) if it passes through both red and green cells (or through neither red nor green cells). Then, the consistent coloring principle implies that any cell that contains green contours but no red contours must itself be green, while any cell that contains red contours but no green ones must itself be red. This is admittedly only one possibility for trying to capture the intuitive idea that all sufficiently high risks should have the same color ("red") and all sufficiently low risks should have the same color ("green"). Other normative axioms could perhaps be formulated, but this article will only use the three already defined.

3.5. Implications of the Three Axioms

Theorem 1: *In a risk matrix satisfying weak consistency, betweenness, and consistent coloring: (a) all cells in the left-most column and in the bottom row are green (lowest-priority); and (b) all the cells in the second column from the left and in the second row from the bottom are nonred.*

Proof: See the Appendix.

Corollary: *A 3 × 3 or a 4 × 4 risk matrix satisfying weak consistency, betweenness, and consistent coloring (and having more than one color) has a unique coloring, as follows. The left column and bottom row are green; the top right cell (for a 3 × 3 matrix) or the 4 top right cells (for a 4 × 4 matrix) are red; and all other cells are yellow.*

Proof: Theorem 1 implies that the left column and bottom row are green. Assuming that the upper right cell is red (since there is more than one color and this is the most severe cell), consistent coloring implies that the two cells in a 4 × 4 matrix that share edges with it must also be red and that the cell that both of these share edges with (diagonally below and to the left of the upper right cell) must also be red. Betweeness then implies that all other cells in a 3 × 3 or 4 × 4 matrix must be yellow. QED.

This result shows that it is possible to construct 3 × 3 and 4 × 4 matrices (although not 2 × 2 matrices) satisfying all three of the normative axioms proposed in this section. There is only one way to do so, however: any other colorings violate one or more of the axioms. For larger matrices, there is greater flexibility, as illustrated next.

3.5.1. Example: The Two Possible Colorings of a Standard 5 × 5 Risk Matrix

Table V shows two possible colorings of a 5 × 5 risk matrix that are consistent with the axioms of weak consistency, betweenness, and consistent coloring and also with a fully quantitative interpretation of the two axes, whose product gives a quantitative measure of risk (e.g., *risk* = *frequency* × *severity*; *expected utility* = *success probability* × *utility of success*; *reduction in perceived risk* = *perceived reduction in expected annual frequency of adverse events* × *perceived average severity per event*; and so forth). The axes are normalized to run from (0, 0) at the lower left corner of the matrix to (1, 1) at the upper right corner, and the grid lines partition the axes into equal quantitative intervals.

In these tables, a "green contour" (with numerical value of 0.18) extends from the upper left cell to the lower right cell of the matrix (both of which are green, by Theorem 1), passing through a total of 9 cells. (All cells containing this contour are green, as

Table V. Two Possible Colorings of a Standard 5 × 5 Risk Matrix

	0–0.2	0.2–0.4	0.4–0.6	0.6–0.8	0.8–1
0.8–1	0.18, 1	0.21, 0.86	Yellow	Red	Red
0.6–0.8	Green	0.24, 0.75	Yellow	Yellow	Red
0.4–0.6	Green	0.36, 0.5	0.42, 0.42	Yellow	Yellow
0.2–0.4	Green	Green	0.5, 0.36	0.75, 0.24	0.86, 0.21
0–0.2	Green	Green	Green	Green	1, 0.18

	0–0.2	0.2–0.4	0.4–0.6	0.6–0.8	0.8–1
0.8–1	0.18, 1	0.21, 0.86	Green	Yellow	Red
0.6–0.8	Green	0.24, 0.75	Green	Yellow	Yellow
0.4–0.6	Green	0.36, 0.5	0.42, 0.42	Green	Green
0.2–0.4	Green	Green	0.5, 0.36	0.75, 0.24	0.86, 0.21
0–0.2	Green	Green	Green	Green	1, 0.18

are all cells below and to the left of it, by consistent coloring.) The upper right-most cell is defined to be red (top risk priority). The cell to its left and the cell below it each contain points with higher quantitative risks than those of points in this top priority cell's lower left corner; therefore, they must also be red (by consistent coloring) unless adjacent green cells make them yellow. The other yellow cells are implied by betweenness.

4. RISK MATRICES WITH TOO MANY COLORS GIVE SPURIOUS RESOLUTION

The foregoing analysis implies that, for a 5 × 5 risk matrix to be consistent with a fully quantitative interpretation as in Table IV, it must have exactly three colors. This is violated in many practical applications. For example, Table VI shows a default risk matrix used in some commercial risk management software tools designed to help support risk analysis standards and recommendations. Such a four-color matrix is inconsistent with the assumption that the colors represent relative sizes of underlying quantitative risks as in Table IV. For example, if the horizontal and vertical axes of Table VI are interpreted quantitatively as in Table IV, then Table VI assigns a higher rating to (0.81, 0.21) than to (0.79, 0.39), even though the former has a product of 0.17 and the latter a product of 0.31.

4.1. Example: A 4 × 4 Matrix for Project Risk Analysis

The use of risk matrices for risk analysis of projects has been described as follows by the California Division of the Federal Highway Administration.

> Risk is computed as the probability of occurrence multiplied by the consequence of the outcome. Probability is between 0 [minimal] and 1 [certain]. Consequence is expressed in terms of dollars, features, or schedule. Multiplying probability of occurrence and consequence [impact analysis] together gives a risk assessment value between 0 [no risk] and 1 [definite and catastrophic]. . . .Below is an example of the matrix used for such an evaluation. The numbers are the order in which the risks are to be considered. Anything that is in the box labeled "1" is the highest priority.

	Likely 0.7–1.0	Probable 0.4 to 0.7	Improbable 0.0 to 0.4	Impossible 0
Catastrophic 0.9 to 1.0	1	3	6	
Critical 0.7 to 0.9	2	4	8	
Marginal 0.4 to 0.7	5	7	10	
Negligible 0 to 0.4	9	11	12	

Source: California Department of Transportation, 2007 www.fhwa.dot.gov/cadiv/segb/views/document/Sections/Section3/3_l9_4.htm.

Table VII presents this risk matrix with its horizontal and vertical axes exchanged and oriented to be increasing, consistent with the conventions in previous examples.

The matrix has 13 priority levels as possible outputs, far greater than the three levels needed for a

Table VI. Default 5 × 5 Risk Matrix Used in a Risk Management Software System

Likelihood\Consequence	Insignificant	Minor	Moderate	Major	Catastrophic
Almost certain	Blue	Orange	Red	Red	Red
Likely	Light green	Blue	Orange	Red	Red
Possible	Light green	Blue	Blue	Orange	Red
Unlikely	Green	Light green	Blue	Blue	Orange
Rare	Green	Green	Light green	Light green	Blue

Source: Adapted from www.incom.com.au/risk.asp?ID=471.

Table VII. Example Risk Matrix for Airport Projects

Probability\Consequence	Negligible 0 to 0.4	Marginal 0.4 to 0.7	Critical 0.7 to 0.9	Catastrophic 0.9 to 1.0
Likely 0.7–1.0	9	5	2	1
Probable 0.4–0.7	11	8	4	3
Improbable 0.0– 0.4	12	10	7	6
Impossible 0	0	0	0	0

quantitative risk interpretation consistent with our axioms. The excess levels make it inconsistent with a coherent quantitative interpretation. For example, it assigns a priority rating of 8 to a quantitative risk of 0.42 (from a probability = 0.65 of a loss of relative severity 0.65 on a scale from 0 = no loss to 1 = worst catastrophic loss considered), but it assigns a much higher priority rating of 3 to a lower quantitative risk of 0.37 (probability = 0.41, consequence = 0.91). (Recall that output levels in the cells are numbered so that 1 = top priority.) Similarly, a loss of 0.6 with probability 1 receives a lower priority level than a quantitative loss of 0.8 with probability 0.5 (5 vs. 4), even though the former has a quantitative risk greater than the latter (0.6 vs. 0.4). A priority level of 12 is assigned to a probability 0.33 of consequence 0.33, but a priority level of 6 is assigned to a numerically identical risk consisting of a probability 0.11 of consequence 0.99. Thus, as expected, the priority ratings implied by the 13 distinct priority levels in this matrix do not successfully represent the relative sizes of these quantitative risks. (That the qualitative ratings reverse the quantitative ratings in such examples cannot be justified by risk aversion, since the consequence axis is explicitly assumed to have been already transformed, scaled, or defined in such a way that the product of the two coordinate axes, probability and consequence, is the measure of quantitative risk that the qualitative matrix attempts to represent.)

The upper left-most cell of the risk matrix in Table VII illustrates *range compression*: discrete categorization lumps together very dissimilar risks, such as an adverse consequence of severity 0 occurring with probability 1 and an adverse consequence of severity 0.39 occurring with probability 1.

The two possible 5 × 5 risk matrices in Table V have very limited resolution. They assign a green rating to all risks less than 0.24, and a red rating to all risks greater than 0.64 (on a scale normalized to run from 0 to 1). Attempts to use more colors or risk rating levels to improve resolution, as in the preceding example, necessarily create more ranking-reversal errors, in which quantitatively smaller risks are assigned qualitatively higher rating levels than some quantitatively larger risks.

As a rough measure of the degree to which these limitations might affect practical work, suppose that the cases being classified by a risk matrix have their two components independently and uniformly distributed between 0 and 1. Then the probability that a randomly selected pair of points can be correctly and unambiguously rank-ordered by a matrix such as the one in Table IVa (i.e., the probability that one point falls in a red cell and the other in a green cell) would be only (3/25 red fraction) × (17/25 green fraction) = 8.2%. Thus, over 90% of the time, the matrix will not be able to rank-order the two points correctly with certainty.

5. RISK RATINGS DO NOT NECESSARILY SUPPORT GOOD RESOURCE ALLOCATION DECISIONS

How well can the information provided by a risk matrix guide risk management resource allocation decisions? This section examines some limitations that hold even if the risk matrix provides qualitative ratings that perfectly represent underlying quantitative risks.

5.1. Example: Priorities Based on Risk Matrices Violate Translation Invariance

Suppose that a risk manager can afford to eliminate all but one of the following three risks: (A) lose $95 with certainty; (B) lose $75 with certainty; (C) lose $95 with probability 50% (else lose nothing). Which one should she keep to minimize risk (here defined as expected loss)? According to the priority ranking in Table VII (and interpreting the normalized consequence axis running from 0 to 1 as corresponding dollar losses running from $0 to $100), the answer is (C). (This has the lowest rating, 3, compared to ratings of 1 for A and 2 for B. Recall that in Table VII, lower numbers in the cell indicate higher priority.)

Now, suppose that all potential losses are reduced by $15, so that the new alternatives are: (A') lose $80 with certainty; (B') lose $60 with certainty; (C') lose $80 with probability 50% (else lose nothing). According to Table VII, one should now choose to keep (B') (rating = 5, compared to ratings of 2 and 4 for the A' and B', respectively). Thus, simply reducing the potential loss by the same amount for all three risks changes the prescribed priority ordering among them. This violates the principle of translation invariance for coherent risk measures (Artzner *et al.*, 1999). Moreover, keeping (B') instead of (C') is inconsistent with minimizing risk (defined as expected loss in this example). Thus, the risk matrix in Table VII does not necessarily support effective risk management decision making.

Similarly in Table VI, if a risk manager can eliminate exactly two out of four risks, corresponding to the four lower left-most cells in the table, and if ties are broken at random, then the probability that the risk in the second column and the bottom row will be eliminated is one-third (since the risk in the higher-rated cell to its northeast will certainly be selected, followed by any one of the remaining three tied risks). Translating all consequences one cell to the right (by adding the same incremental consequence value to each of them) increases the probability to one-half (since this alternative will now tie with one other for second place). But a second translation by one step to the right reduces the selection probability to zero (since now the two blue cells in the second row dominate the two cells in the first row). Finally, one more rightward shift of the four alternatives increases the probability that this one will be selected to one-half again.

In Table IV, if only one of four risks in the four upper left cells (e.g., with respective (probability, consequence) values of (0.9, 0.1), (0.9, 0.3), (0.7, 0.1), and (0.7, 0.3)) can be selected to eliminate, and if ties are broken at random, then the probability that the numerically greatest of these risks, namely, (0.9, 0.3), would be selected for elimination is only one-fourth. Translating all four consequences rightward by the same amount, 0.4, would increase this selection probability to 1. Translating them further rightward by an additional 0.2 would reduce the selection probability to one-third (since the three red cells would then be tied). Thus, the probability of assigning top priority to the numerically greatest risk does not satisfy translation invariance. (This same pattern also occurs for successive rightward translations of the four lower left-most cells in Table I.)

5.2. Example: Priority Ranking Does Not Necessarily Support Good Decisions

Setting: A risk manager has identified the following three risk reduction opportunities:

- Act A reduces risk from 100 to 80. It costs $30.
- Act B reduces risk from 50 to 10. It costs $40.
- Act C reduces risk from 25 to 0. It costs $20.

(This example can also be constructed so that all three acts start from the same base level of risk, say 50, and A, B, and C reduce risk by 20, 40, and 25, respectively. Using different base levels allows for the possibility that the different options A, B, and C being compared protect different subpopulations.) The risk manager's goal is to purchase the largest possible total risk reduction for the available budget.

To assist risk-management decision making, suppose that a risk matrix is used to categorize opportunities A, B, and C. Resources will then be allocated first to the top-rated alternatives, working down the priority order provided by the risk matrix until no further opportunities can be funded.

Problem: How should a risk matrix categorize A, B, and C to support the goal of achieving the largest risk reduction from allocation of limited funds?

Solution: The answer depends on the budget. For a budget of $40, the largest feasible risk reduction is achieved by funding B, so the best priority order puts B first. If the budget is $50, then funding A and C achieves the greatest risk reduction, so B should be ranked last. At $60, the best investment is to fund B and C, so now A should be ranked last. In short, *no categorization or rank-ordering of A, B, and C optimizes resource allocation independent of the budget.* No possible priority order (or partial order, if some ratings are tied) is optimal for budgets of both $49 and $50. This illustrates a limitation on the type of output information—ordered categorical classification—provided to decisionmakers by risk matrices. Such information is in general not sufficient to support effective allocation of risk-reducing resources because solutions to such resource allocation optimization problems cannot in general be expressed as priority lists or categories that should be funded from the top down until no further items can be afforded (Bertsimas & Nino-Mora, 1996).

Thus, the input information going into a risk matrix (ordinal ratings of event frequencies and severities) is simply not sufficient to optimize risk management resource allocations, or even to avoid very poor allocations, as in the above example. Calculating optimal risk management resource allocations requires quantitative information beyond what a risk matrix provides, for example, about budget constraints and about interactions among countermeasures. In general, risk rankings calculated from frequency and severity do not suffice to guide effective risk management resource allocation decisions.

5.3. Categorization of Uncertain Consequences is Inherently Subjective

To use a risk matrix, it is necessary to be able to categorize the alternatives being compared into the cells of the matrix. However, decision analysis principles imply that there is no objective way to categorize severity ratings for events with uncertain consequences. Subjective risk attitudes play an essential (but seldom articulated) role in categorizing severity for such events. Thus, the information in a risk matrix represents a mixture of factual (probability and consequence) information about the risk and (usually unstated) psychological information about the risk attitude of the person or people performing the risk categorization. Since the risk attitudes of the builders are seldom documented, it can be impossible to determine how consequence severity classifications should be changed when someone else views or uses the matrix.

5.4. Example: Severity Ratings Depend on Subjective Risk Attitudes

For a decisionmaker with an exponential utility function, the certainty equivalent (CE) value of a prospect with normally distributed consequences is $CE(X) = E(X) - k \times Var(X)$, where k is a parameter reflecting subjective risk aversion ($k = 0.5 \times$ coefficient of risk aversion); E(X) is the mean of prospect X; Var(X) is its variance; and CE(X) is its certainty-equivalent value (i.e., the deterministic value that is considered equivalent in value to the uncertain prospect) (Infanger, 2006, p. 208). Consider three events, A, B, and C, with identical probabilities or frequencies and having normally distributed consequences (on some outcome scale) with respective means of 1, 2, and 3 and respective variances of 0, 1, and 2. The certainty equivalents of prospects A, B, and C are:

$$CE(A) = 1$$
$$CE(B) = 2 - k$$
$$CE(C) = 3 - 2k.$$

For a risk-neutral decisionmaker (for whom $k = 0$), the ordering of the prospects from largest to smallest certainty equivalent value is therefore: C > B > A. For a risk-averse decisionmaker with $k = 1$, all three prospects have the same certainty equivalent value of 1. For a more risk-averse decisionmaker with $k = 2$, the ordering of the prospects is: A > B > C. Thus, the certainty equivalents of the severities of the prospects are oppositely ordered by decisionmakers with different degrees of risk aversion. There is no objectively correct ordering of prospect severity certainty equivalents independent of subjective attitudes toward risk. But risk matrices typically do not specify or record the risk attitudes of those who use them. Users with different risk attitudes might have opposite orderings, as in this example. Neither is objectively (independent of subjective risk attitude) more correct than the other. As a result there is no objective way to classify the relative severities of such prospects with uncertain consequences.

5.5. Example: Pragmatic Limitations of Guidance from Standards

In practice, various standards provide written guidance on how to classify severities for use in risk matrices. For example, Table VIII shows the severity ratings suggested in a 1998 General Accounting Office report on "Combating Terrorism," based on the widely cited Military Standard 882C (https://crc.army.mil/guidance/system_safety/882C.pdf). As that standard notes: "These hazard severity categories provide guidance to a wide variety of programs. However, adaptation to a particular program is generally required to provide a mutual understanding ... as to the meaning of the terms used in the category definitions. The adaptation must define what constitutes system loss, major or minor system or environmental damage, and severe and minor injury and occupational illness." Even with these caveats, the guidance in Table VIII does not resolve the type of ambiguity in the previous example. For example, it offers no guidance on how to rate a consequence that is zero with probability 90% but catastrophic otherwise (perhaps depending on wind direction or crowding of a facility or of evacuation routes at the time of a terrorist attack). Moreover,

Table VIII. Severity Levels of Undesired Event Consequences for Combating Terrorism

Severity Level	Characteristics
I Catastrophic	Death, system loss, or severe environmental damage
II Critical	Severe injury, severe occupational illness, major system or environmental damage
III Marginal	Minor injury, minor occupational illness, or minor system or environmental damage
IV Negligible	Less than minor injury, occupational illness, or less than minor system or environmental damage

Source: GAO (1998).

it introduces other ambiguities. For example, how should one rate the severity of a consequence that consists of 1 death and 1 severe injury compared to that of a consequence of 0 deaths but 50 severe injuries? The answer is not obvious from Table VIII.

The discrete qualitative categories provided in guidance such as Table VIII are also inconsistent with the continuous quantitative nature of many physical hazards. For example, should a condition that causes "negligible" environmental damage on each occurrence (e.g., leaking 1 ounce of jet fuel per occurrence) but that causes a high frequency of these small events (e.g., averaging 5 events per hour) truly have a lower severity rating than a second condition that causes more damage per occurrence (e.g., leaking 10 pounds of jet fuel per occurrence) but that causes less frequent occurrences (e.g., once per week)? (Both would be assigned the highest possible frequency rating by Military Standard 882C.) If so, then the risk matrix analysis could give lower priority to eliminating a threat of leaking 52.5 pounds per week (= 5 ounces per hour × 24 hours/day × 7 days per week) than to eliminating a threat of leaking only 10 pounds per week, due to the greater "severity" of 10 pounds than 1 ounce and the equal "frequency" rating of common events (an example of range compression). In such cases, the idea of rating severity independently from frequency appears flawed.

Focusing on applying qualitative rating criteria, rather than on more quantitative comparisons of risks, can create irrational risk management priorities. The following example illustrates how uncritical application of risk matrix guidance might promote misperceptions and misrankings of the relative risks of different strategic investment opportunities.

5.6. Example: Inappropriate Risk Ratings in Enterprise Risk Management (ERM)

Suppose that a company must choose between the following two risky investment strategies for responding to major and pervasive uncertainties, such as climate change risks.

- Strategy A has probability 0.001 of leading to a small growth rate that barely meets shareholder expectations; otherwise (probability 99.9%) shareholder value and growth will increase by a negligible amount (e.g., $< 0.00001\%$), disappointing shareholders and failing to meet their expectations.
- Strategy B has probability 50% of causing rapid and sustained growth that greatly exceeds shareholder expectations; otherwise (e.g., if the outcome of a crucial R&D project is unsuccessful), shareholder value and growth will not grow (growth rate = 0%).

Which strategy, A or B, better matches a responsible company's preferences (or "risk appetite") for risky strategic investments?

Commonsense might suggest that Strategy B is obviously better than Strategy A, as it offers a 50% probability of greatly exceeding expectations instead of a 0.1% probability of barely meeting them, with no significant difference in downside risk. However, uncritical application of risk matrices suggested as examples for enterprise risk management (ERM) systems could rate B as more risky than A. For example, Australia published a risk management "guide for business and government . . . [that] is consistent with the Australian and New Zealand Standard for Risk Management, AS/NZS 4360:2004, which is widely used in the public and private sectors to guide strategic, operational and other forms of risk management. The Guide describes how the routine application of the Standard can be extended to include the risks generated by climate change impacts" (Australian Government, 2006). The illustrative risk matrix and category definitions for a commercial business (Tables 10–12 of the Guide) could be used to assign a "*medium*" risk priority to Strategy A but a "*high*" risk to strategy B, making B appear to be less attractive than A. (For A, the likelihood of the adverse consequence, 99.9%, is classified as "almost certain." The consequence is described as "Growth would be achieved but it would fail to meet expectations," which is classified as a "minor" consequence. The risk matrix example in Figure 12 of the Guide categorizes the likelihood-consequence pair (*almost certain*, *minor consequence*) as a "*medium*" risk. For B, the likelihood of the adverse consequence is classified as "likely," the consequence is described as "There would be no growth," and this is classified as a "moderate" consequence. The combination (*likely*, *moderate consequence*) is categorized as a "*high*" risk.) Thus, a tight focus on implementing the discrete categorization criteria in the guidance could distract attention from the fact that most shareholders would gladly trade a negligible increase in adverse consequences for a large increase in the probability of a much better outcome. In the terminology of multicriteria decision making, the discrete categorization of consequences and probabilities inherent in risk matrices can produce noncompensatory decision rules that do not reflect the risk trade-off preferences of real decisionmakers and stakeholders.

Quantitative risk assessment was developed in part to help prevent the types of paradoxes illustrated in these examples. Even if the quantities in the fuel leaking example were quite uncertain (e.g., an average of 1–10 ounces every few minutes in the first case and 0–100 pounds every few months in the second), a rough quantitative calculation would reveal that the first threat is much more severe than the second. Similarly, even a rough quantitative comparison of strategies A and B in the enterprise risk management example would show that B is much more attractive than A. By contrast, qualitative or semiquantitative risk assessments based on ordered categories do not necessarily prevent rating reversals and misallocations of resources, as in these examples—and may even unintentionally encourage them, by directing risk management effort and attention away from the key quantitative comparisons involved and toward the (often inherently subjective) task of categorizing frequency and severity components.

6. DISCUSSION AND CONCLUSIONS

The theoretical results in this article demonstrate that, in general, quantitative and semiquantitative risk matrices have limited ability to correctly reproduce the risk ratings implied by quantitative models, especially if the two components of risk (e.g., frequency and severity) are negatively correlated. Moreover, effective risk management decisions cannot in general be based on mapping ordered categorical ratings of frequency and severity into recommended risk management decisions or priorities, as optimal resource allocation may depend crucially on other quantitative information, such as the costs of different countermeasures, the risk reductions that they achieve, budget constraints, and possible interactions among risks or countermeasures (such as when fixing a leak protects against multiple subsequent adverse events).

Categorizing severity may require inherently subjective judgments (e.g., reflecting the rater's personal degree of risk aversion, if severity is modeled as a random variable) and/or arbitrary decisions about how far to aggregate multiple small and frequent events into fewer and less frequent but more severe events. The need for such judgments, and the potential for inconsistencies in how they are made by different people, implies that there may be no objectively correct way to fill out a risk matrix.

Conversely, the meaning of a risk matrix may be far from transparent, despite its simple appearance. In general, there is no unique way to interpret the comparisons in a risk matrix that does not require explanations—seldom or never provided in practice— about the risk attitude and subjective judgments used by those who constructed it. In particular, if some consequence severities are random variables with sufficiently large variances, then there may be no guarantee that risks that receive higher risk ratings in a risk matrix are actually greater than risks that receive lower ratings.

In summary, the results and examples in this article suggest a need for caution in using risk matrices. Risk matrices do not necessarily support good (e.g., better-than-random) risk management decisions and effective allocations of limited management attention and resources. Yet, the use of risk matrices is too widespread (and convenient) to make cessation of use an attractive option. Therefore, research is urgently needed to better characterize conditions under which they are most likely to be helpful or harmful in risk management decision making (e.g., when frequencies and severities are positively or negatively correlated, respectively) and that develops methods for designing them to maximize potential decision benefits and limit potential harm from using them. A potentially promising research direction may be to focus on placing the grid lines in a risk matrix to minimize the maximum loss from misclassified risks.

We hope to present some positive results from this optimization-based approach soon.

APPENDIX: PROOF OF THEOREM 1

By definition, the lower left-most cell is green. Consistent coloring implies that any contour must be green if it lies below/to the left of the one passing through the upper right corner of this lower left-most cell (i.e., the contour through the points (0.04, 1), (0.2, 0.2), (1, 0.04) in the numerical example in Table IV), since (a) it passes through the lower left-most cell (which is green by definition); and (b) none of the cells that it passes through is red (by Lemma 2). By construction, such a green contour passes through all cells in the left-most column and in the bottom row.

Now, consider the cell directly above the lower left-most cell (i.e., the cell containing the point (0.1, 0.3) in Table IV). Suppose that, contrary to the claimed result, this cell is not green. It cannot be red, by Lemma 2. For it to be an intermediate color (not green), it must contain at least one red contour (by color consistency and the fact that a green contour passes through it). This cell cannot be "between" a red and a green cell, since it is on an edge of the matrix, so it cannot acquire an intermediate color that way. This red color neither comes from the cell above it in the left-most column (which is nonred, by Lemma 2), nor from any cell in the bottom row (again by Lemma 2). Since contours are downward-sloping, the only remaining possibility is for the cell to its right (the cell containing (0.3, 0.3) in Table IV) to be red. But this would violate betweenness (at the point (0.2, 0.2) in Table IV). Therefore, the assumption that the cell directly above the lower left-most cell is not green leads to a contradiction. Hence, it must be green. By a symmetrical argument, the cell directly to the right of the lower left-most cell (the cell containing (0.3, 0.1) in Table IV) must also be green.

Next, suppose that the third cell in the left-most column (the one containing (0.1, 0.5) in Table IV) is not green. Since green contours pass through it (as it is in the left-most column), it can only be nongreen if some red contour also passes through it (by color consistency and the fact that it is an edge cell). This red contour could not come from a red cell below it in the left-most column, or in the bottom row (by Lemma 2), nor from the cell directly to its southeast (containing (0.3, 0.3) in Table IV) (since if that were red, it would violate Lemma 1 and betweenness for the cells so far proved to be green). The only remaining possibility is that the cell to its right (the one containing (0.3, 0.5) in Table IV) is red. But this would violate betweenness (with the second cell in the left-most column, the cell containing (0.1, 0.3) in Table IV, which we have proved above must be green). Hence, the assumption that the third cell in the left-most column is not green implies a contradiction. So, it must be green. Symmetrically, the third cell in the bottom row must be green. This construction (showing that a cell directly above a green cell in the first column, with only nonred cells to its southeast, must itself be green) can be iterated for all remaining cells in the left-most column, thus establishing that they all must be green; symmetrically, all remaining cells in the bottom row must be green. This proves part (a). Part (b) is then an immediate consequence of part (a) and Lemma (2). QED

Comment: This proof does not depend on the number of rows or columns in the table. Therefore, its conclusion (that the left-most column and bottom row consist entirely of green cells) holds for risk matrices of any size, under the stated conditions of weak consistency, betweenness, and consistent coloring.

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APPENDIX D

Limitations of the Entomological Operational Risk Assessment. Using Probabilistic and Deterministic Analyses

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Limitations of the Entomological Operational Risk Assessment Using Probabilistic and Deterministic Analyses

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ABSTRACT The Entomological Operational Risk Assessment (EORA) is used by the U.S. military to estimate risks posed by arthropod-vectored pathogens that produce human diseases. Our analysis demonstrated that the EORA matrix is formatted so that a small change in probability results in a discontinuous jump in risk. In addition, we show the overlap of different risk categories with respect to their probability of occurrence. Our results reveal that the fundamental mathematical problems associated with the EORA process may not provide estimates that are better than random chance. To ameliorate many of the problems associated with the EORA, we suggest more robust methods for performing qualitative and semiquantitative risk assessments when it is difficult to obtain the probability that an adverse event will occur and when the knowledge of experts can aid the process.

INTRODUCTION

Insect-vectored pathogens that produce diseases such as malaria, dengue, yellow fever, plague, typhus, and leishmanisis have affected military objectives for hundreds of years.[1–3] The role of military entomologists is to protect soldiers, materials, and facilities from pests. To assist in this protection, the Entomological Operational Risk Assessment (EORA) was created to aid preventive medicine experts in the U.S. military with identifying entomological and disease hazards to personnel in deployed areas.[3] Risk assessment is an integral part of risk management and provides the scientific information needed during the decision-making process.

The EORA involves three steps used to generate an overall risk estimate for the entomological hazard. The first step in the EORA is to identify the entomological hazard. An entomological hazard is any arthropod pathogen vector that can affect a soldier's ability to accomplish a mission.[3] The EORA process proceeds by using risk matrices that incorporate hazard severity and hazard probability. The hazard severity is estimated by integrating endemicity and maximum expected rates of infection into a risk matrix, whereas hazard probability incorporates exposure to insect vectors and force protection measures. The hazard probability is estimated on the basis of definitions such as "frequent," "likely," "occasional," and "seldom."[3] After the hazard severity and probability are estimated, they are integrated into the risk assessment matrix, which gives the overall risk estimate. For example, a hazard severity of "marginal" and a hazard probability of "occasional" give an overall risk estimate of "moderate," which corresponds to a definition on how the entomological hazard may affect mission objectives.

The basis for the estimation of hazard probability is dependent on five definitions. Each definition is subject to another set of definitions, unintentionally adding another layer of complexity. For example, to generate the exposure estimate of the hazard probability, EORA practitioners must take into account vector habits and habitat, billeting, seasonality, recent weather conditions, density of vectors, and infection rate.

The EORA utilizes risk matrices, which are meant to be an intuitive interpretation of risks. Similar approaches are used by the U.S. Navy and Marines in operational risk management documents, which rely on similar matrix and category assignment schemes.[4,5] Risk matrices are a qualitative risk assessment methodology and are used when information is not readily available to perform a quantitative risk assessment.[6,7] There are two major limitations of qualitative risk assessments: reversed rankings and uninformative ratings.[7] Reversed rankings occur when assigning a higher qualitative risk rating to situations that have a lower quantitative risk, and uninformative ratings occur when frequently assigning the most severe qualitative risk label to situations with arbitrarily small quantitative risks and also by assigning risks that differ by many orders of magnitude. Another issue with qualitative risk assessments involves the subjective judgments by stakeholders and experts who are susceptible to a range of influences that may have little to do with objective data.[8]

Risk matrices are relatively easy-to-use tools that provide a convenient document for prioritizing risks with relatively simple inputs.[6] Although risk matrices are easy to use, if designed improperly they can give unrealistic estimates of the risks.[6] Very little information exists addressing the limitations of risk matrices, but Cox Jr.[6] has outlined many of the errors currently made when designing risk matrices. Not only are many techniques in qualitative risk assessments mathematically problematic, but risk assessments based on these methodologies do not necessarily outperform a purely random decision-making process.[6,9] In this article, we examine fundamental limitations of the EORA and provide recommendations for improving the EORA process.

APPROACH

Human-health risk can be described in quantitative terms as a function of effect and exposure.[10] Risk assessment is a formalized process in which the assumptions and uncertainties in

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estimating risk are clearly defined. It proceeds in a stepwise fashion with five distinct steps: problem formulation, hazard identification, effects assessment, exposure assessment, and risk characterization. Risk characterization is the integration of the effect and exposure assessments. To characterize risk, the EORA integrates the hazard severity and probability (which can also be thought of as effect and exposure, respectively) to generate a risk estimate (Table I). Because risk is ultimately a probability, the final risk categorization of the EORA (or any risk matrix) is meant to represent some underlying quantitative value associated with the findings.[6]

To generate quantitative values for use in the current analysis, we assigned probability ranges to each category in the risk assessment matrix (Table II). The calculation of risk is the probability of adverse effects occurring, so risk matrices should provide an approximation to a more detailed but unknown underlying quantitative probability of adverse effects occurring.[6] Therefore, we assumed that hazard severity and probability have underlying quantitative risks associated with them. Because it is beyond the scope of this article to determine the underlying variability associated with each input parameter, we assumed that they had uniform distributions. Both hazard severity and probability have interval values between 0 and 1, where 0 is the minimum risk and 1 is the maximum risk possible. Because no data exist about the distributions of the risk categories, we defined our boundaries on the basis of uniform distributions evenly spaced for each category (Table II). To define the quantitative risk for any combination of hazard severity and probability, the product is

$$\text{Entomological Risk Score} = \text{Hazard Severity} \times \text{Hazard Probability.}$$

TABLE I. The Risk Assessment Matrix Reproduced From Wells[3]

Hazard Severity	Hazard Probability: Frequent	Likely	Occasional	Seldom	Unlikely
Catastrophic	Extremely High	Extremely High	High	High	Moderate
Critical	Extremely High	High	High	Moderate	Low
Marginal	High	Moderate	Moderate	Low	Low
Negligible	Moderate	Low	Low	Low	Low

We performed deterministic calculations to determine whether small increases in probability could result in discontinuous jumps in risk and to assess whether an entomological risk score could encompass more than one risk category. In addition, to determine the potential magnitude of any problems identified, we performed a probabilistic assessment using Monte Carlo simulation (Crystal Ball 7.3; Decisioneering, Denver, CO) with the above entomological risk score and uniform distributions to generate the probability of an entomological risk score occurring for each matrix cell. Probabilistic analysis differs from deterministic by using the probabilities of occurrence for the entomological risk score as a result of incorporating iterative sampling from the uniform distribution of each input variable used to calculate it. Each of the input variables was sampled 20,000 times so that its distribution shape was reproduced. Then, the variability for each input was propagated into the output of the model so that the model output reflected the probability of entomological risk scores that could occur for each matrix cell.

RESULTS AND DISCUSSION

Ideally, risk matrices should provide an approximate qualitative representation of underlying quantitative risk, which implies that arbitrarily small increases in probability should not result in discontinuous jumps in risk (i.e., a jump from low to high risk).[6] However, the EORA matrix is formatted so that a small change in probability results in a discontinuous jump in risk. For example, a hazard severity of marginal and a hazard probability of likely ($0.5 \times 0.8 = 0.4$) results in an entomological risk score categorization of moderate risk (Table II). However, a hazard severity of critical and a hazard probability of frequent ($0.81 \times 0.51 = 0.41$) results in an entomological risk score categorization of extremely high risk (Table II). Additionally, a hazard severity of negligible and a hazard probability of likely ($0.80 \times 0.25 = 0.2$) results in an entomological risk score categorization of low risk (Table II). However, a hazard severity of marginal and a hazard probability of frequent ($0.81 \times 0.26 = 0.21$) results in an entomological risk score categorization of moderate risk (Table II). In both of the above cases, a small increase in probability results in a large increase in qualitative risk.

In addition to discontinuous jumps in risk, risk matrices can correctly and unambiguously compare only a small fraction

TABLE II. The Risk Assessment Matrix Reproduced From Wells[3] With Probabilities Assigned to Each Cell

		Hazard Probability				
		Frequent	Likely	Occasional	Seldom	Unlikely
Hazard Severity	Probability	0.81–1	0.61–0.8	0.41–0.6	0.21–0.4	0.01–0.2
Catastrophic	1–0.76	Extremely High	Extremely High	High	**High**	**Moderate**
Critical	0.75–0.51	Extremely High	High	High	**Moderate**	Low
Marginal	0.5–0.26	High	Moderate	**Moderate**	**Low**	Low
Negligible	0.25–0.01	**Moderate**	**Low**	Low	Low	Low

To define the quantitative risk for any combination of hazard severity and probability, the product is Entomological Risk Score (ERS) = Hazard Severity × Hazard Probability. Cells that are bold have an equal ERS but encompass three different risk categories.

of randomly selected pairs of hazards and can assign identical ratings to quantitatively very different risks.[6] Table II shows the seven cells that could have the same entomological risk score based on the probabilities of occurring, but encompass three different risk ranking levels (i.e., low, medium, and high). This is seen when risk matrices have too many risk categorizations that give spurious resolution.[6]

Using Monte Carlo probabilistic analysis, the results reveal that the EORA currently is formatted so that different risk categorizations overlap in their probability of occurrence. Figure 1 and Table III demonstrate that many of the risk categorizations overlap in their occurrence. The probabilistic analysis shows that the assumption that the categorizations represent some underlying increase in risk is not supported because of the overlap in probability of occurring (Fig. 1). There is an underlying increase in risk from low to extremely high, but there are no clear delineations between the groupings, which leads to ambiguous categorization of the entomological risk (Fig. 1, Table III).

We also conducted the same probabilistic analysis using triangular distributions, which more heavily weights the values of the distribution at the midpoint. Despite reduction in overlap between certain cells, the results support the findings using uniform distributions (data not shown).

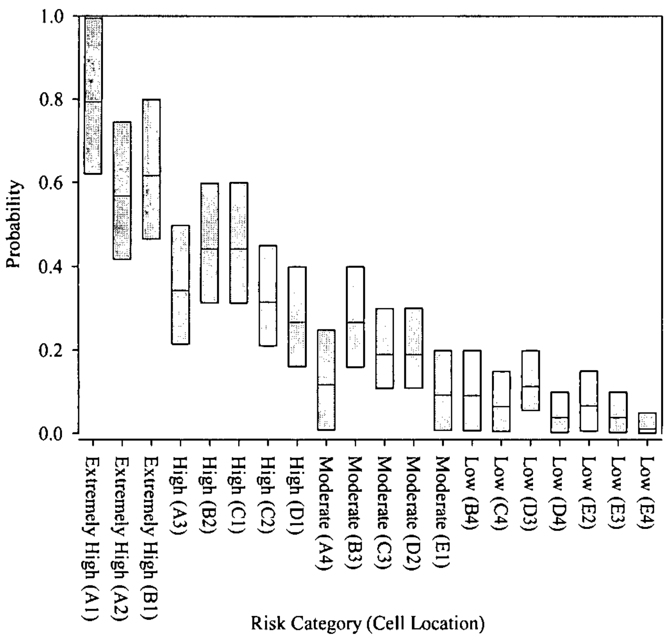

FIGURE 1. The probabilistic output at the 5th, 50th, and 95th percentiles demonstrating the overlap of the different risk categories relating to the cell locations in Table III.

Additionally, the definitions are vague and subject to bias depending on who is performing the risk assessment. For example, the definition of seldom is the "exposure to hazard possible, but not expected to occur during a specific mission or operation. This is a subjective definition, which is left up to expert opinion. Expert opinions from different people inevitably provide different judgments on the same subject.[11] Additionally, there is no clear definition of what is meant by "exposure to hazard possible and isolated incidents of noncompliance"[3]. If personnel are deployed to a country where leishmanisis is endemic, there is always a possibility that an encounter with a sand fly carrying the pathogen could occur. Another problem with the current definition scheme is that there are many situations for which it cannot categorize. For instance, exposure to hazard is expected to occur continuously or very often during a mission or operation. However, a full range of force protection measures are available with good compliance. This situation uses the exposure estimate of frequent and the force protection estimate of unlikely, which should have an overall hazard probability estimate between those two. Intuitively, the categorization should be occasional, but the definition of occasional is "exposure may occur during a specific mission or operation but not often. Basic force protection measures in use but compliance level sporadic."[3]

To remedy the outlined problems, we recommend using a more robust categorizing scheme, which uses the number of force protection measures available against the vector and indices of vector populations like number of vectors per light trap night to reduce the amount of bias present in estimating the hazard probability. In addition, the heading "hazard probability" should be changed to hazard estimate, because probability is a measure of how likely it is that some event will occur. Currently, as "hazard probability" is used in the EORA, it is not estimating the probability that a soldier will become ill given that they encounter a vector carrying a pathogen.

The EORA currently does not contain an uncertainty analysis. People often are confronted by uncertainty, which is a result of lack of information, in particular, inaccuracy of measurements or lack of knowledge, which is common in risk assessment.[12] The most important feature of a risk assessment that separates it from a hazard or impact assessment is the emphasis on characterizing and quantifying uncertainty. Because uncertainty is inherent in all risk assessments, the EORA should include a formal uncertainty analysis. The importance of uncertainty analysis in risk assessment derives from its importance in the decision-making process.[13] Risk

TABLE III. The Cell Locations of Figure 1 Related to the Cell Location Within in the Risk Matrix of Wells[3]

	Hazard Probability				
Hazard Severity	Frequent	Likely	Occasional	Seldom	Unlikely
Catastrophic	A1: Extremely High	B1: Extremely High	C1: High	D1: High	E1: Moderate
Critical	A2: Extremely High	B2: High	C2: High	D2: Moderate	E2: Low
Marginal	A3: High	B3: Moderate	C3: Moderate	D3: Low	E3: Low
Negligible	A4: Moderate	B4: Low	C4: Low	D4: Low	E4: Low

managers need to have an understanding of the uncertainties associated with the scientific information on which they are basing their decisions.

Uncertainty analysis also provides direction in identifying data gaps that may exist in the current assessment. A formalized uncertainty analysis would benefit the EORA and would add to the transparency of the assessment. Uncertainty analysis can be performed using quantitative methods like sensitivity analysis or by a qualitative discussion of the different assumptions in the risk assessment where data are insufficient or nonexistent.[11,14,15] Sensitivity analysis is a powerful tool in risk analysis because it shows to what extent the viability of parameters like vector abundance influence the estimate of risk. Sensitivity analysis can dictate resource allocation to reduce the uncertainty if a parameter contributes a large amount of variability to risk estimate. For example, if a parameter like vector abundance is unknown (uncertain) and sensitivity analysis shows that it is highly influential in the estimate of risk, studies can take place to determine the actual abundance. Methods like probability theory, fuzzy logic, and Bayesian analysis techniques are formal methods for quantitatively addressing uncertainty in risk assessments.[12,16,17]

For example, if fuzzy logic is used, many of the qualitative assumptions associated with the EORA can become quantitative. Fuzzy methods are especially efficient in areas where quantitative risk assessment methods are difficult to use and where the knowledge of experts can aid the process.[18] Fuzzy logic or fuzzy sets can work with uncertainty and imprecision to solve problems where there are no sharp boundaries because of a lack of knowledge.[16,19,20] These sets provide mathematical formulations that can characterize uncertain parameters within the EORA.[16] Fuzzy sets permit the quantification of values, beliefs, and inherently imprecise or uncertain terms such as "frequent," "likely," and "catastrophic."[21] Using fuzzy logic or a similar technique could sufficiently enhance the EORA process by providing a quantitative framework that can quantify uncertainty and guide future research needs for refining the estimated risk to personnel.

We realize that the current EORA was designed to provide a simple and rapid way of determining the risks, and adding a technique such as fuzzy logic would add a layer of complexity to the process. However, results from the current EORA process may not be better than random chance, and once the fuzzy logic algorithms have been constructed, input assumptions are all that may be needed to generate an entomological risk score, which is the same amount of information that would be needed to generate the current entomological risk score. Additionally, a more advanced model that does not use risk matrices can take into account all of the parameters that may influence an entomological risk (i.e., degree days, time of year, etc.) where humans have a difficult time integrating large numbers of parameters.[21] Another important feature of models that utilize fuzzy logic or Bayesian is that they can be calibrated and verified against historic data, which would increase the reliability of the model. Models utilizing fuzzy logic or Bayesian analysis techniques can also assign a probability to an event occurring, which provides a better understanding of the risks and the uncertainties surrounding the estimates of risk.[22,23]

All branches of the military have a distinct need for a formalized risk assessment process to accurately assess the risks of entomological hazards to personnel. Troops will be deployed where they are needed regardless of the entomological risk, but a risk assessment for the deployment area will aid military entomologists in prioritizing control measures to reduce the risk of disease transmission. An accurate risk assessment would inform risk managers of the risks so appropriate measures can be taken, which would most likely reduce the costs associated with instituting emergency control measures and excessive disease incidences (cost of treatment and lost duty days). In addition, other agencies that use similar matrices like those found in the EORA should consider the results of the current analysis and Cox Jr.[6] when assessing risks using matrices.

When troops are deployed to areas where few data exist about the disease risks, expert elicitation may be the best way of generating a risk assessment. With the changes outlined above and the future use of more advanced modeling techniques, the EORA could be improved considerably by reducing and quantifying uncertainty and subjectivity in the process, leading to more informed decisions about the entomological hazards that may be experienced during deployment.

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APPENDIX E

Qualitative criteria for consequence, likelihood and Risk Matrix proposed for use in Fingerboards EES

Impacts were defined as the change to a value (either negative or positive) that will, or could, occur as a result of a project-related activity or hazard.

2.3 Assess risk of environmental harm

The risk of environmental harm associated with each impact was assessed using a combination the likelihood of the impact occurring, and the consequence of environmental harm or damage should it occur, where *risk = likelihood x consequence*.

Likelihood and consequence were defined as:

- **Likelihood:** The probability that an environmental, socioeconomic or cultural value will be impacted by a project activity (hazard) having regard to the event that would release/mobilise the hazard and the pathway for the value to contact or be exposed to the hazard.
- **Consequence:** The magnitude or severity of the impact on the identified value, which is usually a factor of the extent and/or duration of the predicted change to the value.

The general criteria used for determining different levels of likelihood and consequence are set out in Table 2 and Table 3 respectively.

Table 2 Qualitative criteria for likelihood

Descriptor	Description
Rare	A hazard, event and pathway are theoretically possible on this project and has occurred once elsewhere, but not anticipated over the duration of the project activity, project phase or project life.
Unlikely	A hazard, event and pathway exist and harm has occurred in similar environments and circumstances elsewhere but is unlikely to occur over the duration of the project activity, project phase or project life.
Possible	A hazard, event and pathway exist and harm has occurred in similar environments and circumstances elsewhere and may occur over the duration of the project activity, project phase or project life.
Likely	A hazard, event and pathway exist and harm has occurred in similar environments and circumstances elsewhere and is likely to occur at least once over the duration of the project activity, project phase or project life.
Almost certain	A hazard, event and pathway exist and harm has occurred in similar environments and circumstances elsewhere and is expected to occur more than once over the duration of the project activity, project phase or project life.

Table 3 Qualitative criteria for consequence

Descriptor	Description
Negligible	A temporary or short-term (less than one year) and localised impact that is limited to the project footprint, is barely detectable, does not reduce the viability/capacity of the value, and will resolve itself without intervention.
Minor	A temporary or short-term (less than five years) and localised impact largely within the project footprint.

Descriptor	Description
Moderate	A short- to medium-term (e.g., 5 to 15 years) impact that extends beyond the area of disturbance to the surrounding area. The viability of the value will be reduced to a limited extent only and will recover over time. Specific management measures may be required to effectively manage the impact. A long-term (e.g., greater than 20 years) and localised impact largely within the project footprint.
Major	A medium to long term (e.g., 15 to 20 years) impact, that is severe (e.g., viability of the value is reduced to some extent) and widespread (e.g., extends beyond the study area, but stays within the catchment). Specific management measures are required to effectively manage the impact.
Extreme	A long-term (e.g., greater than 20 years) and potentially irreversible impact (e.g., severely affecting the viability of the value) that is widespread (e.g., extending well beyond the study area, possibly at a catchment-wide and/or regional scale). Design modification is required to eliminate the impact or specific management measures are required to reduce the likelihood of occurrence of the impact.
Positive	An impact that enhanced the viability, capacity or quality of a value, over the short- or long-term.

Consistent with the requirements of AS/NZS 31000:2018 (and its companion documents), the technical specialists revised the criteria descriptions, where appropriate, to reflect the specific objectives of their study. Proposed changes were reviewed to ensure the revised criteria were consistent with the model criteria; that is, the descriptions adequately differentiated the levels of risk. The likelihood and consequence criteria and risk matrices used by the technical specialists are described in the relevant specialist study reports appended to the EES.

The risk of harm to the identified environmental, socioeconomic and cultural values were determined by applying the assessed likelihood and consequence in accordance with the risk matrix in Table 4. Positive risks (benefits) are also described where relevant.

Table 4 Risk matrix

		Likelihood				
		Rare	Unlikely	Possible	Likely	Almost certain
Consequence	Negligible	Very low	Very low	Very low	Low	Moderate
	Minor	Very low	Low	Low	Moderate	Moderate
	Moderate	Low	Low	Moderate	High	High
	Major	Low	Moderate	High	Major	Major
	Extreme	Moderate	High	Major	Major	Major

2.4 Manage impacts

Mitigation measures (based on a hierarchy of avoid, minimise, manage, offset) were proposed to address the identified impacts. The aim of the measures is to protect identified values and meet the evaluation objectives.

Measures will be implemented through project design, construction methods, operating procedures, and during closure activities.

APPENDIX F

Mt Moornarna Wind Events

Date	Minimum	Maximum	Rainfall (	Evaporat	Sunshine	Direction	max. wind gust (km/h)	Time of maximum wi	
2019-11-21	16	39.1	0			NNW	93	12:25	1
2019-09-21	17.4	22	0			NNW	91	10:19	1
2019-10-25	21.2	27.1	0			NW	91	06:56	1
2020-08-27	4.6	17.6	0			WSW	81	19:11	1
2020-08-27	4.6	17.6	0			WSW	81	19:11	1
2019-11-7	8.1	18.3	0.2			NW	80	13:31	1
2019-10-26	8.7	14.1	0.8			NW	76	09:44	1
2019-11-6	7.9	23	0			WNW	76	12:45	1
2019-11-12	10.6	18	0			NNW	76	03:22	1
2019-09-12	10.3	22.2	0			W	74	12:20	1
2019-09-15	9.1	24.7	0.6			NW	74	15:31	1
2020-04-11	9.1	12.3	0			WSW	74	14:21	1
2019-10-6	10.9	32.1	0			NW	69	10:45	1
2020-01-22	11.7	30.5	0			NNW	67	18:34	1
2020-02-26	13	18.5	0			WSW	67	11:04	1
2019-09-27	8.4	22.6	0			NW	65	15:26	1
2019-12-3	6.9	19.6	0.6			WNW	65	15:03	1
2019-12-30	20	42.1	0			NNW	65	11:16	1
2020-04-5	6.1	18.4	0.2			NW	65	11:00	1
2020-05-2	7.1	11.4				W	65	16:15	1
2019-11-1	18.6	33.6	0			NW	63	11:37	1
2019-09-7	5.7	11.2	8.4			WSW	61	15:39	1
2019-12-4	10.4	22.6	0			W	61	23:06	1
2020-04-20	8.4	20.9				NNW	61	09:01	1
2020-07-19	5.9	18.2	0.2			W	61	20:36	1.0
2019-11-2	14.1	24.5	0			NNW	59	02:58	1
2019-11-8	7	11.7	10.4			SW	59	15:16	1
2019-12-2	5.8	13.4	3.8			WSW	59	15:42	1
2020-02-1	22.6	36.7	0			WNW	59	12:58	1
2020-05-1	5.7	11.8				NW	59	14:12	1
2020-05-30	5.8	16.4				NNW	59	22:58	1
2020-07-20	7.3	14.3	0.6	5.6		W	59	14:39	1.0
2020-08-28	4.1	14.2	4.2			W	59	00:19	1
2020-08-28	4.1	14.2	4.2			W	59	00:19	1
2019-11-26	8.7	12	5.4			SSW	57	15:09	1
2020-07-13	9.1	14.4	25.8	13		E	57	07:16	1.0
2020-08-5	1.7	8.3	3			W	57	06:14	1
2020-08-5	1.7	8.3	3			W	57	06:14	1
2019-09-9	1.7	10.6	9.2			WSW	56	09:02	1
2020-02-3	11.5	16.3	0			SW	56	12:12	1
2020-03-13	15.8	28	0			SW	56	18:40	1
2019-10-18	5.5	22.1	1.2			NW	54	17:34	1
2019-11-13	4.5	18.8	1			W	54	14:28	1
2020-01-15	20	33.6	0			SW	54	19:17	1
2020-04-4	10.4	13.8	0.2			WNW	54	19:08	1
2020-04-17	8.1	18				W	54	15:20	1
2020-05-3	7	12.8				WSW	54	02:53	1
2020-07-4	3.7	13.6	8.4			W	54	15:16	1.0
2020-08-21	4.8	11.2	0.2			WNW	54	11:19	1
2020-08-23	1.3	8.7	11.2			WSW	54	15:48	1
2020-08-21	4.8	11.2	0.2			WNW	54	11:19	1
2020-08-23	1.3	8.7	11.2			WSW	54	15:48	1
2019-09-8	4.7	14.8	0.6			W	52	22:04	1
2019-12-6	8.4	23.1	0			W	52	16:02	1
2020-04-29	11	21.6				SW	52	17:14	1
2020-06-3	6.5	9.8				SW	52	03:30	1
2020-08-30	10.5	21.5	0			WNW	52	21:21	1
2020-08-30	10.5	21.5	0			WNW	52	21:21	1
2019-12-28	14.7	31.8	0			NW	50	07:53	1
2020-01-10	16.1	34.9	0			SSE	50	15:49	1
2020-01-20	14.9	17.4	24			W	50	11:44	1
2020-03-20	13.1	24.8	0			SW	50	00:13	1
2020-06-15	6.9	16.9				WNW	50	13:53	1
2020-07-5	7.7	13.8	0			W	50	13:24	1
2020-07-9	-0.1	14.9	0.2			WNW	50	10:52	1.0
2019-09-6	8.3	13.8	2.4			NNW	48	13:06	65
2019-10-17	5.5	15.1	4.4			W	48	12:24	
2019-10-19	7.3	16.5	0			WNW	48	13:32	
2019-11-9	3.5	11.9	6			W	48	13:11	
2020-01-4	13.4	34.9	0			S	48	14:02	
2020-02-19	11.9	14.6	0.2			SW	48	16:26	
2020-03-2	11.1	17.8	0			SW	48	06:43	
2020-03-19	17.5	31	0			NNW	48	21:07	
2020-06-13	6.4	15				NNW	48	20:42	
2019-11-15	9.6	23.2	0			WSW	46	17:21	
2020-01-31	23.2	43.3	0			NW	46	15:55	
2020-02-14	17.5	29.2	4.6			WSW	46	17:25	
2020-06-1	8.5	11.5				SW	46	22:15	
2020-08-4	0.3	8.3	2.8			WNW	46	13:13	
2020-08-16	7.8	9.2	18.2			WSW	46	15:54	
2020-08-20	5.9	13.7	0.6			NNW	46	18:12	
2020-08-22	2.1	9	0.4			WNW	46	13:17	
2020-08-4	0.3	8.3	2.8			WNW	46	13:13	
2020-08-16	7.8	9.2	18.2			WSW	46	15:54	
2020-08-20	5.9	13.7	0.6			NNW	46	18:12	
2020-08-22	2.1	9	0.4			WNW	46	13:17	
2019-09-1	7.5	17.3	0			WNW	44	19:13	
2019-09-24	5.7	15.7	0.2			WSW	44	15:18	
2019-10-8	5.8	12.8	6.8			SW	44	16:22	
2019-12-9	10.7	36.6	0			SW	44	22:33	
2020-04-26	11.7	18.2				SW	44	12:23	
2020-05-7	12.3	21.5				NW	44	09:59	
2020-05-31	9	15.8				NNW	44	05:13	
2020-06-2	4.6	13.5				SW	44	00:40	
2020-06-16	10.4	17.9				NW	44	15:44	
2020-07-22	3.4	13.8	0.2			WSW	44	11:51	
2020-07-27	9.4	12.6	10			SSE	44	18:36	
2020-07-28	10.7	14	21.8			S	44	12:16	
2020-08-31	4.4	10.7	1.4			SW	44	04:22	
2020-08-31	4.4	10.7	1.4			SW	44	04:22	
2019-09-28	4.9	13.9	1.4			W	43	01:09	
2019-12-12	9.7	19.7	0			WSW	43	14:19	
2020-01-11	9.8	20.3	13.2			SSW	43	15:45	
2020-01-23	13.6	22.7	8.6			WNW	43	18:51	
2020-02-8	16.5	24.2	0			ESE	43	16:32	
2020-05-9	11	15				WNW	43	13:25	
2020-07-3	3	14	0			SSW	43	17:29	
2020-07-30	6.5	14.5	0.2			W	43	03:45	
2020-08-18	6.9	16.3	0			NW	43	22:13	
2020-08-24	3.7	10.7	2.6			WSW	43	02:19	
2020-08-18	6.9	16.3	0			NW	43	22:13	
2020-08-24	3.7	10.7	2.6			WSW	43	02:19	
2019-09-16	4.9	9.8	15.4			SW	41	05:38	
2019-11-10	5.5	18.6	1.6			WSW	41	09:46	
2019-12-31	12.9	22.5	0			SSW	41	00:56	
2020-02-9	15.3	16.7	0			ESE	41	12:14	
2020-07-21	4.7	13.1	0	1.4		W	41	00:13	
2019-09-29	6.3	15.5	0			SSW	39	13:21	
2019-10-3	15.5	31.4	0			NNW	39	15:57	
2019-10-20	7.1	16.4	0			SW	39	14:49	
2019-11-4	7.1	18.8	9.6			SSW	39	14:40	
2019-11-14	9.6	23.4	0			WNW	39	15:26	
2019-12-1	7.2	17.2	0			NNW	39	22:00	
2019-12-5	8.2	25.9	0			W	39	14:24	
2020-01-17	10.3	13.7	0.2			ENE	39	17:37	
2020-03-6	12.3	19.1	0			SW	39	08:44	
2020-03-22	9.6	18.2	0			SSW	39	13:01	
2020-03-29	15.6	26.7	0			NNW	39	13:31	
2020-04-28	6.4	20.8				NNW	39	21:17	
2020-05-10	3.9	10.8				W	39	11:28	
2020-05-20	7.5	15.8				N	39	00:14	
2020-06-14	6.1	14.1				WNW	39	07:44	
2019-09-13	5.7	16	0			SW	37	23:29	
2019-09-19	8.1	25.4	0			NNW	37	13:32	
2019-11-5	5.1	17.5	0.8			SW	37	02:17	
2019-11-18	6.6	26.8	0			W	37	18:25	
2019-11-25	11.4	32.2	0			NNE	37	21:16	
2019-12-7	7.9	22.9	0			S	37	18:19	
2019-12-21	17.3	24.2	0			SW	37	01:27	
2020-02-10	15	19.7	20.4			ESE	37	12:24	
2020-04-12	6	15.3	0.2			W	37	02:26	
2020-04-30	6.6	9.2				NW	37	23:30	
2020-08-2	6.9	17.8	0			N	37	04:12	
2020-08-2	6.9	17.8	0			N	37	04:12	
2019-10-27	6.4	16	3.6			WNW	35	23:18	
2019-10-29	10.7	31	0			SW	35	15:40	
2019-11-11	8.5	28	0			NNW	35	21:39	
2019-11-30	7.3	16.6	20			SSW	35	14:14	
2020-03-14	6.9	15.9	0			SW	35	23:26	
2020-04-16	15.3	19.4				SSW	35	19:49	
2020-06-20	10.4	15.6				NNW	35	12:20	
2020-06-23	5.4	11.1				WSW	35	19:55	
2020-07-16	6.5	12.6	2	1.6		SSW	35	13:30	
2020-08-7	2.4	8.1	0			E	35	12:21	
2020-08-8	6.1	9.8	6			ESE	35	03:26	
2020-08-7	2.4	8.1	0			E	35	12:21	
2020-08-8	6.1	9.8	6			ESE	35	03:26	
2019-09-2	6	16.3	3.8			NNW	33	22:55	
2019-10-31	17.5	34.5	0			NNW	33	10:17	
2019-11-27	4.8	22.4	20.4			WSW	33	23:13	
2019-12-8	8.1	24.5	0			ESE	33	14:58	
2019-12-10	12.6	22.1	0			SSW	33	23:10	
2020-01-16	14.7	16.1	2.4			SSW	33	15:48	
2020-02-20	9.6	17.7	3.8			WSW	33	10:22	
2020-03-1	12.7	29.9	0			NW	33	22:57	
2020-04-10	12.3	22.7	0.2			NNW	33	07:22	
2020-04-15	11.6	24.6	0.2			NNW	33	18:54	
2020-04-18	9.8	16.8				WNW	33	04:08	
2020-04-25	11	19.3				NW	33	21:55	
2020-06-19	8.5	16				NNW	33	14:12	
2020-06-30	4.2	14				NNW	33	22:40	
2020-07-6	7.3	13.9	0.2			W	33	10:30	
2020-07-12	8.3	12.9	2.6			SE	33	17:16	
2020-08-6	3.4	10.1	0.8			W	33	05:44	
2020-08-19	6.8	12.9	0			W	33	21:42	
2020-08-6	3.4	10.1	0.8			W	33	05:44	
2020-08-19	6.8	12.9	0			W	33	21:42	
2019-09-20	15.9	27.6				NNW	31	00:18	
2019-09-22	5.1	17.7	0.6			SE	31	15:08	
2019-09-30	5.8	13.9	0			WSW	31	00:30	
2019-10-9	4.5	13.6	3			WSW	31	23:34	
2019-12-14	10.4	23.4	0			SSE	31	10:45	
2019-12-20	15.8	39.6	0			NNW	31	22:41	
2020-01-18	11.8	18.2	10.2			E	31	02:08	
2020-02-18	13.7	22.8	0.4			SW	31	16:26	
2020-02-27	7.1	19.2	0			W	31	22:21	
2020-03-7	10.2	19.4	0			ESE	31	19:17	
2020-03-8	10.4	16.4	0			E	31	01:14	
2020-03-18	14.8	28.4	0			N	31	07:27	
2020-04-2	13.2	22.6	0			N	31	16:03	
2020-04-13	7.3	14.3	0			N	31	21:31	
2020-04-23	8	18.3				N	31	23:01	
2020-05-6	9.2	18				N	31	21:39	
2020-05-8	12.6	20.1				NW	31	00:39	
2020-05-12	7	12.7				NNW	31	22:07	
2020-05-13	7.7	10.5				NNW	31	00:16	
2020-07-7	7.8	13.9	0			WSW	31	00:12	
2020-07-14	6.6	12.7	5.6	0.8		S	31	09:55	
2020-08-17	7.8	13.4	16.8			WSW	31	04:35	
2020-08-17	7.8	13.4	16.8			WSW	31	04:35	
2019-09-3	9.2	19.7	0			WNW	30	01:33	
2019-09-11	4.3	20.5	0			N	30	23:49	
2019-09-14	5.9	18.9	0			SSW	30	00:11	
2019-09-23	5.7	14.3	0.2			W	30	21:13	
2019-10-7	9.1	11.9	0			SSW	30	01:04	
2019-10-24	15.2	33.7	0			ESE	30	17:17	
2019-10-30	16.8	30.8	0			N	30	00:55	
2019-11-16	6.5	18.5	0.6			S	30	15:45	
2019-11-20	10.1	31	0			N	30	22:53	
2019-12-19	19.8	30.4	0			S	30	11:09	
2019-12-22	7.5	23.7	0			WSW	30	00:14	
2020-01-21	11.9	22	138.8			WSW	30	00:53	
2020-01-26	14.4	28.2	0			SSW	30	13:27	
2020-02-25	17.8	30.9	0			NNW	30	12:07	
2020-04-3	13.1	20.4	0.2			N	30	20:24	
2020-04-22	10.9	17.8				WNW	30	06:32	
2020-05-21	6.1	7.9				NNW	30	02:15	
2020-07-15	6.9	12.7	5.2	1		SE	30	12:17	
2020-08-3	8.1	13.4	0			NNW	30	05:45	
2020-08-9	6.8	10.2	15.6			SE	30	11:17	
2020-08-14	9.3	16	0.4			NNW	30	00:04	
2020-08-29	7.4	20.4	0.2			N	30	23:37	
2020-08-3	8.1	13.4	0			NNW	30	05:45	
2020-08-9	6.8	10.2	15.6			SE	30	11:17	
2020-08-14	9.3	16	0.4			NNW	30	00:04	
2020-08-29	7.4	20.4	0.2			N	30	23:37	
2019-09-10	4.6	13	0			SW	28	01:51	
2019-10-5	5.8	23.8	2.2			N	28	21:28	
2019-10-11	6.8	13.4	0			ESE	28	14:42	
2019-10-16	9.3	18.2	0.2			NNW	28	17:21	
2019-10-28	5.7	22.3	0			WSW	28	00:48	
2019-11-24	9.3	23.8	0			SE	28	14:05	
2019-11-28	7.6	24.2	0			SE	28	15:12	
2019-11-29	9.6	26.2	0			SE	28	14:37	
2019-12-18	17.3	38.1	0			N	28	00:21	
2019-12-24	12.1	22.6	1.4			SE	28	14:02	
2020-01-2	11.6	27.9	0			SE	28	14:14	
2020-01-12	9.1	22.3	0			WSW	28	11:17	
2020-02-16	13.5	15.2	35			ESE	28	01:30	
2020-03-10	10	20.2	0			E	28	16:18	
2020-03-21	9.2	18	0			WSW	28	00:23	
2020-03-26	8.9	19.7	0			ESE	28	16:30	
2020-03-28	14	25.3	0			N	28	08:05	
2020-05-4	6.7	11.7				W	28	06:46	
2020-05-19	9.4	18.3				N	28	12:05	
2020-06-25	6.6	15				WNW	28	14:52	
2020-06-26	5.4	10.8				W	28	03:27	
2020-07-2	8.7	15.7	3.4			WNW	28	08:12	
2020-08-1	5.3	16	0.2			N	28	21:49	
2020-08-12	7.3	12.8	0			N	28	12:14	
2020-08-13	9.1	17.2	0			N	28	23:12	
2020-08-15	8.5	12.7	3			SW	28	21:35	
2020-08-25	3.7	11.2	0.2			W	28	20:34	
2020-08-1	5.3	16	0.2			N	28	21:49	
2020-08-12	7.3	12.8	0			N	28	12:14	
2020-08-13	9.1	17.2	0			N	28	23:12	
2020-08-15	8.5	12.7	3			SW	28	21:35	
2020-08-25	3.7	11.2	0.2			W	28	20:34	
2019-09-17	2.6	11.6	0.2			ESE	26	18:23	
2019-11-17	7.5	18.7	0			WSW	26	08:44	
2019-11-23	8.6	24	0			S	26	17:28	
2019-12-26	13.7	27.4	0			SSE	26	14:59	
2020-01-14	13.3	32.3	0			ESE	26	18:39	
2020-02-2	12	23.7	10.2			S	26	16:37	
2020-02-21	10.1	18.1	3.2			SW	26	23:21	
2020-02-28	10.1	20.2	0			SW	26	09:18	
2020-03-3	8.7	17.4	0			E	26	20:48	
2020-03-12	14.1	29.1	0			N	26	06:40	
2020-03-17	11	24.6	0			NNW	26	06:35	
2020-04-6	7.3	14.3	0.2			W	26	10:29	
2020-04-14	9.6	19.5	0.2			N	26	00:58	
2020-05-22	5.6	9.4				W	26	01:38	
2020-06-22	5.2	10.8				W	26	15:44	
2020-08-11	4.8	14.1	0.2			E	26	18:30	
2020-08-11	4.8	14.1	0.2			E	26	18:30	
2019-09-5	6.6	16.8	0			ESE	24	15:27	
2019-09-18	3.9	16.7	0			N	24	06:48	
2019-10-12	6.9	15.5	0.2			ESE	24	16:14	
2019-11-19	10.1	23.4	0			SW	24	13:28	
2019-12-27	11.2	30.4	0			SE	24	14:58	
2019-12-29	20	36.6	0			SE	24	13:59	
2020-01-1	10.7	26.4	2.4			SSE	24	14:52	
2020-01-24	11.1	23.8	6.8			SW	24	12:36	
2020-01-25	13	25.9	0			SE	24	16:10	
2020-01-30	16	37.3	0			ESE	24	17:04	
2020-02-4	6.8	20.5	0.8			WSW	24	23:11	
2020-02-12	16.5	20.4	16.8			SSE	24	14:30	
2020-02-23	12.8	29.6	0.6			N	24	06:00	
2020-02-24	17.2	28.9	0.2			NNW	24	23:10	
2020-03-5	12.6	20.6	0			N	24	11:49	
2020-03-9	10.4	16.2	0			E	24	20:03	
2020-03-15	5.8	17.1	0			E	24	19:26	
2020-03-23	7.2	16.9	0			WSW	24	00:01	
2020-03-27	10	23.9	0			N	24	06:29	
2020-04-24	12.9	21.9				WNW	24	03:42	
2020-05-11	6	15.2				N	24	23:23	
2020-05-23	5.5	11.3				W	24	07:51	
2020-05-28	9.7	17.7				NW	24	11:13	
2020-06-17	6.1	10.4				SW	24	00:21	
2020-08-10	6	12.3	5.8			E	24	18:58	
2020-08-10	6	12.3	5.8			E	24	18:58	
2019-10-4	9.5	16.3	0			SSW	22	15:42	
2019-10-23	8	27.5	0			N	22	02:56	
2019-11-3	13.5	18.4	10			S	22	15:50	
2019-11-22	9.4	22.4	0.2			SE	22	15:30	
2019-12-13	7.3	21.1	0			S	22	11:19	
2019-12-16	10	23.9	0			SE	22	17:34	
2019-12-25	13.1	28.9	0			SSE	22	16:00	
2020-01-5	10.2	13.5	0			SSW	22	00:07	
2020-01-27	12.9	24.2	0			SE	22	15:35	
2020-02-5	9.4	22.4	0			SE	22	16:09	
2020-02-6	11.6	25.6	0			E	22	00:53	
2020-02-7	15.6	28	0			SSE	22	16:13	
2020-02-11	16.3	25.7	0			ESE	22	17:38	
2020-02-15	17	24.9	35.4			S	22	13:33	
2020-03-4	10	19.3	0			ENE	22	23:01	
2020-03-16	8.2	20.8	0			ESE	22	17:07	
2020-03-25	9	14.7	0			WSW	22	11:10	
2020-03-30	13	18.3	0			N	22	02:13	
2020-04-19	9.1	15				E	22	18:18	
2020-04-21	9.4	17.7				NW	22	23:54	
2020-05-27	8	16.3				N	22	01:57	
2020-05-29	6.6	15.7				N	22	06:00	
2020-06-5	4	12.8				N	22	05:12	
2020-06-9	2.2	12.2				N	22	22:11	
2020-07-17	7.1	14	1.8	0.8		SE	22	15:44	
2020-07-18	1.7	13.7	0.2			NNW	22	22:57	
2020-07-23	5	11.6	0	2.8		WNW	22	11:55	
2020-07-26	3.3	12.9	0.2			ENE	22	14:23	
2020-07-29	7.9	15.9	1.2			WSW	22	20:16	
2020-08-26	3.6	12.1	0.8			WNW	22	07:48	
2020-08-26	3.6	12.1	0.8			WNW	22	07:48	
2019-09-25	6.3	15.4	0			SW	20	01:04	
2019-10-2	10	25.9	0			SE	20	16:05	
2019-10-14	10.1	23.7	0			N	20	04:21	
2019-10-22	6.7	20.6	0			SSE	20	12:10	
2019-12-15	11.4	20.3	0			S	20	19:00	
2019-12-23	8.2	26	0			SE	20	14:10	
2020-01-7	9.5	22	3.2			SW	20	15:55	
2020-01-28	13.4	26	0			S	20	15:11	
2020-02-17	12.3	17.9	5.4			E	20	01:05	
2020-03-11	11.8	25.8	0			NNW	20	08:10	
2020-05-5	6.3	15.6				N	20	23:29	
2020-05-18	6.8	15.5				N	20	23:43	
2020-05-26	5.5	13.9				N	20	22:53	
2020-06-12	5.2	14.3				N	20	20:08	
2020-06-21	5.7	11.4				SW	20	20:48	
2020-07-1	3.9	20	0.4			N	20	21:01	
2020-07-25	-1.2	13.2	0			SSE	20	13:03	
2019-09-4	9	18.8	0			W	19	12:05	
2019-09-26	6.1	18	0			SSE	19	16:57	
2019-10-13	5.5	19.4	0			NE	19	20:19	
2019-10-15	9.5	14.4	0			SW	19	01:07	
2019-10-21	6.7	20.1	0			S	19	14:13	
2019-12-17	11.7	30.1	0			ESE	19	15:50	
2020-01-3	12.2	29.6	0			SE	19	14:22	
2020-01-6	7.8	15.1	13.2			NE	19	03:05	
2020-01-9	15.2	28.1	1			SE	19	14:53	
2020-02-22	10.1	21.9	2			SSE	19	16:05	
2020-02-29	10.8	21.6	0			ESE	19	18:46	
2020-03-31	11	19.3	0.2			ESE	19	18:06	
2020-04-8	8.9	15.4	0			ENE	19	21:26	
2020-04-9	10	18.7	0.2			ESE	19	13:36	
2020-05-24	6.5	11.3				W	19	03:08	
2020-05-25	7.2	10.7				NE	19	21:26	
2020-06-4	5.9	10.3				W	19	01:20	
2020-06-18	4.4	14.2				N	19	20:49	
2020-06-29	2.6	11.2				N	19	23:01	
2020-07-24	-1.3	11.9	0			W	19	11:54	
2020-07-31	2	14.4	0.2			NW	19	00:21	
2019-10-1	4.2	19.4	0			S	17	13:45	
2020-01-8	14	19.4	0			SE	17	13:54	
2020-01-13	10.1	26.7	0			ENE	17	23:14	
2020-01-19	13.4	24.5	2.2			SSE	17	15:14	
2020-01-29	12.2	29.1	0			SSE	17	16:01	
2020-02-13	16.6	20.9	27.6			SE	17	12:53	
2020-04-1	12.2	21.9	0			SE	17	16:24	
2020-05-15	4.7	13.1				N	17	06:17	
2020-05-16	5.5	13.8				N	17	03:42	
2020-05-17	7.9	14.1				E	17	18:28	
2020-06-7	3.8	9.1				SW	17	05:49	
2020-06-10	5.4	14.4				N	17	22:48	
2020-06-11	6.2	12.2				N	17	22:10	
2020-06-24	6.7	12.9				S	17	00:15	
2020-06-27	3.2	10.7				N	17	07:38	
2020-07-8	1	14.3	0			E	17	14:38	
2020-07-11	5	13.7	0			WNW	17	01:27	
2019-10-10	5.5	12.7	1.4			SE	15	15:49	
2019-12-11	8.8	18.5	0			ENE	15	20:56	
2020-04-27	6.4	15.3				N	15	02:25	
2020-06-28	3	9.3				N	15	08:05	
2020-07-10	2	12.8	0			ESE	15	14:11	
2020-03-24	7.8	16.5	0			SE	13	13:39	
2020-04-7	8.3	14.9	0.2			SW	13	23:05	
2020-06-6	6.3	12.7				SSW	13	19:53	
2020-06-8	2.5	10				N	13	21:35	
2020-05-14	4.8	11.5				W	11	02:14	
Daily Weather Observations for Mount Moornapa, Victoria for September 2019									130

Prepared at 13:01 UTC on Saturday 12 September 2020 IDCJDW3057.201909

Observations were drawn from Mount Moornapa {station 085296}

Daily Weather Observations for Mount Moornapa, Victoria for October 2019

Prepared at 13:01 UTC on Friday 11 September 2020 IDCJDW3057.201910

Observations were drawn from Mount Moornapa {station 085296}

	Date	Minimum	Maximum	Rainfall (	Evaporat	Sunshine	Direction	Speed of	Time of r	9am Tem	9am rela	9am clou	9am wind	9am wind	9am MSL	3pm Tem	3pm rela	3pm clou	3pm wind	3pm wind	3pm MSL
	2019-10-	4.2	19.4	0			S	17	13:45	10.2	68		0	Calm		17.9	44		SE	6	
	2019-10-	10	25.9	0			SE	20	16:05	17.6	36		NNW	6		24.4	22		SSE	7	
	2019-10-	15.5	31.4	0			NNW	39	15:57	22.7	27		N	11		29.9	15		NNW	20	
	2019-10-	9.5	16.3	0			SSW	22	15:42	11.9	77		WSW	7		13	64		S	7	
	2019-10-	5.8	23.8	2.2			N	28	21:28	11.1	77		NE	4		18.1	52		ESE	6	
	2019-10-	10.9	32.1	0			NW	69	10:45	23.8	33		NNW	22		29.5	17		WNW	17	
	2019-10-	9.1	11.9	0			SSW	30	01:04	9.3	93		S	7		11.2	76		SE	2	
	2019-10-	5.8	12.8	6.8			SW	44	16:22	5.9	99		SW	11		10.8	82		SSW	9	
	2019-10-	4.5	13.6	3			WSW	31	23:34	7.2	83		WSW	7		12.4	59		S	4	
	2019-10-	5.5	12.7	1.4			SE	15	15:49	7	94		WSW	4		11.7	61		SSE	6	
	2019-10-	6.8	13.4	0			ESE	28	14:42	9	92		SE	2		9.6	89		SE	9	
	2019-10-	6.9	15.5	0.2			ESE	24	16:14	8.9	75		ESE	6		12.7	60		SE	9	
	2019-10-	5.5	19.4	0			NE	19	20:19	10.1	72		ENE	4		18.5	40		SSE	9	
	2019-10-	10.1	23.7	0			N	20	04:21	13.1	60		N	11		22.3	35		S	6	
	2019-10-	9.5	14.4	0			SW	19	01:07	9.7	98		SSE	4		13.5	77		SSE	4	
	2019-10-	9.3	18.2	0.2			NNW	28	17:21	11.1	90		SE	2		13.7	81		NW	7	
	2019-10-	5.5	15.1	4.4			W	48	12:24	6	93		NW	20		11.4	63		W	13	
	2019-10-	5.5	22.1	1.2			NW	54	17:34	10.3	60		NE	6		20.6	25		WNW	17	
	2019-10-	7.3	16.5	0			WNW	48	13:32	9.6	61		WNW	9		13.1	32		W	15	
	2019-10-	7.1	16.4	0			SW	39	14:49	11	56		SW	4		15.1	53		SSW	7	
	2019-10-	6.7	20.1	0			S	19	14:13	9.6	82		S	4		19.5	52		S	6	
	2019-10-	6.7	20.6	0			SSE	20	12:10	8.4	100		SSE	2		19.1	47		SE	7	
	2019-10-	8	27.5	0			N	22	02:56	17.5	54		0	Calm		27.2	18		S	7	
	2019-10-	15.2	33.7	0			ESE	30	17:17	21.8	24		N	13		32.3	10		WNW	9	
	2019-10-	21.2	27.1	0			NW	91	06:56	24.7	30		NNW	26		13.3	87		SSE	6	
	2019-10-	8.7	14.1	0.8			NW	76	09:44	11.8	43		WNW	22		11	57		WNW	30	
	2019-10-	6.4	16	3.6			WNW	35	23:18	9.6	63		NW	6		14.9	47		WNW	6	
	2019-10-	5.7	22.3	0			WSW	28	00:48	10.8	67		NNE	6		21.4	19		S	7	
	2019-10-	10.7	31	0			SW	35	15:40	19.1	23		NNE	4		28.7	9		WSW	7	
	2019-10-	16.8	30.8	0			N	30	00:55	17.7	32		0	Calm		29	24		SE	9	
	2019-10-	17.5	34.5	0			NNW	33	10:17	25.2	19		NNW	13		31	13		NNE	6	

Daily Weather Observations for Mount Moornapa, Victoria for November 2019																					
Prepared at 13:01 UTC on Thursday 10 September 2020 IDCJDW3057.201911																					
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Observations were drawn from Mount Moornapa {station 085296}																					
	Date	Minimum	Maximum	Rainfall (	Evaporat	Sunshine	Direction	Speed of	Time of r	9am Tem	9am rela	9am clou	9am wind	9am wind	9am MSL	3pm Tem	3pm rela	3pm clou	3pm wind	3pm wind	3pm MSL
	2019-11-	18.6	33.6	0			NW	63	11:37	25.3	28		N	9		31.6	20		NW	13	
	2019-11-	14.1	24.5	0			NNW	59	02:58	16.6	70		NNE	7		19.1	71		SW	6	
	2019-11-	13.5	18.4	10			S	22	15:50	14.8	100		E	6		15.8	97		S	6	
	2019-11-	7.1	18.8	9.6			SSW	39	14:40	10.1	84		W	4		17.7	47		SW	4	
	2019-11-	5.1	17.5	0.8			SW	37	02:17	8	66		WSW	11		15.9	42		SSW	4	
	2019-11-	7.9	23	0			WNW	76	12:45	16.5	43		N	6		21.1	32		NW	20	
	2019-11-	8.1	18.3	0.2			NW	80	13:31	11.8	49		NW	22		15.8	42		NW	33	
	2019-11-	7	11.7	10.4			SW	59	15:16	7.2	92		NW	11		8.8	80		WSW	11	
	2019-11-	3.5	11.9	6			W	48	13:11	6.8	70		WSW	11		9.6	74		WNW	9	
	2019-11-	5.5	18.6	1.6			WSW	41	09:46	11	75		WSW	11		17.6	57		SSW	11	
	2019-11-	8.5	28	0			NNW	35	21:39	16.5	48		WNW	4		26.8	21		WSW	9	
	2019-11-	10.6	18	0			NNW	76	03:22	10.9	78		SSW	13		16.4	44		SW	15	
	2019-11-	4.5	18.8	1			W	54	14:28	9.6	57		W	13		16.7	36		W	19	
	2019-11-	9.6	23.4	0			WNW	39	15:26	14.9	55		WNW	7		22.1	34		WNW	17	
	2019-11-	9.6	23.2	0			WSW	46	17:21	12.6	72		SSW	6		19.7	33		WNW	11	
	2019-11-	6.5	18.5	0.6			S	30	15:45	10.4	52		SW	7		17.2	39		S	7	
	2019-11-	7.5	18.7	0			WSW	26	08:44	11.2	63		WSW	6		17.2	45		SSE	9	
	2019-11-	6.6	26.8	0			W	37	18:25	13.2	52		NNE	6		24.8	27		S	6	
	2019-11-	10.1	23.4	0			SW	24	13:28	15	43		SSW	4		22.1	45		S	6	
	2019-11-	10.1	31	0			N	30	22:53	16.5	67		E	2		26.3	36		SE	11	
	2019-11-	16	39.1	0			NNW	93	12:25	30.9	16		NNW	24		37.1	14		NW	30	
	2019-11-	9.4	22.4	0.2			SE	22	15:30	11.5	78		SW	2		21.2	41		S	6	
	2019-11-	8.6	24	0			S	26	17:28	14.2	65		N	2		23	38		SSW	9	
	2019-11-	9.3	23.8	0			SE	28	14:05	14.8	63		ESE	2		21.6	44		SE	13	
	2019-11-	11.4	32.2	0			NNE	37	21:16	21.6	25		NNW	6		31.1	14		W	13	
	2019-11-	8.7	12	5.4			SSW	57	15:09	9.1	100		SW	13		8.2	99		WSW	17	
	2019-11-	4.8	22.4	20.4			WSW	33	23:13	10.7	52		NE	6		21.6	34		SSW	6	
	2019-11-	7.6	24.2	0			SE	28	15:12	11.9	78		SSE	6		23.1	42		SE	9	
	2019-11-	9.6	26.2	0			SE	28	14:37	16.4	66		SE	4		25.3	45		SSE	9	
	2019-11-	7.3	16.6	20			SSW	35	14:14	7.5	100		SW	6		13.8	63		S	7	

Daily Weather Observations for Mount Moornapa, Victoria for December 2019																					
Prepared at 13:01 UTC on Wednesday 9 September 2020 IDCJDW3057.201912																					
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Observations were drawn from Mount Moornapa {station 085296}																					
	Date	Minimum	Maximum	Rainfall (	Evaporat	Sunshine	Direction	Speed of	Time of r	9am Tem	9am rela	9am clou	9am wind	9am wind	9am MSL	3pm Tem	3pm rela	3pm clou	3pm wind	3pm wind	3pm MSL
	2019-12-	7.2	17.2	0			NNW	39	22:00	8.2	85		NW	4		14.6	54		NW	13	
	2019-12-	5.8	13.4	3.8			WSW	59	15:42	7.2	98		WSW	9		8.8	76		WSW	17	
	2019-12-	6.9	19.6	0.6			WNW	65	15:03	12.6	58		WNW	19		18.2	44		NW	24	
	2019-12-	10.4	22.6	0			W	61	23:06	12.1	67		WSW	6		20.7	35		WNW	13	
	2019-12-	8.2	25.9	0			W	39	14:24	13.1	80		S	6		23.3	40		SSE	11	
	2019-12-	8.4	23.1	0			W	52	16:02	14	65		SW	7		21.2	32		WSW	11	
	2019-12-	7.9	22.9	0			S	37	18:19	13.3	53		SW	4		22.4	41		SSW	7	
	2019-12-	8.1	24.5	0			ESE	33	14:58	10.8	83		ENE	4		23.1	36		SE	9	
	2019-12-	10.7	36.6	0			SW	44	22:33	24.4	31		N	7		32.3	17		SE	7	
	2019-12-	12.6	22.1	0			SSW	33	23:10	13.3	86		S	6		20.9	51		S	7	
	2019-12-	8.8	18.5	0			ENE	15	20:56	11.4	81		SSE	2		15	71		NW	4	
	2019-12-	9.7	19.7	0			WSW	43	14:19	11.6	86		S	6		18.2	51		S	11	
	2019-12-	7.3	21.1	0			S	22	11:19	11.4	69		S	4		18.4	43		SSW	6	
	2019-12-	10.4	23.4	0			SSE	31	10:45	14.8	67		WSW	6		22.4	47		S	11	
	2019-12-	11.4	20.3	0			S	20	19:00	13.4	93		NNE	2		18	69		S	4	
	2019-12-	10	23.9	0			SE	22	17:34	12.3	85		WSW	2		22	43		SSW	7	
	2019-12-	11.7	30.1	0			ESE	19	15:50	17.9	62		S	4		28.4	25		SSE	6	
	2019-12-	17.3	38.1	0			N	28	00:21	24.5	33		SSE	2		35.6	18		SSW	6	
	2019-12-	19.8	30.4	0			S	30	11:09	22.8	47		S	7		28	26		SSW	9	
	2019-12-	15.8	39.6	0			NNW	31	22:41	24	27		ESE	4		38.7	13		SE	7	
	2019-12-	17.3	24.2	0			SW	37	01:27	17.7	76		SSW	11		22.3	42		S	11	
	2019-12-	7.5	23.7	0			WSW	30	00:14	12	64		SW	4		21.5	30		SE	9	
	2019-12-	8.2	26	0			SE	20	14:10	12.4	72		SSW	6		24.9	44		SSE	7	
	2019-12-	12.1	22.6	1.4			SE	28	14:02	13.4	96		SE	4		20.2	65		SE	13	
	2019-12-	13.1	28.9	0			SSE	22	16:00	15.8	87		0	Calm		27.9	43		SSE	11	
	2019-12-	13.7	27.4	0			SSE	26	14:59	17.9	79		SSE	7		26	45		S	7	
	2019-12-	11.2	30.4	0			SE	24	14:58	14.7	75		E	4		26.5	38		SE	7	
	2019-12-	14.7	31.8	0			NW	50	07:53	30.2	24		NW	24		29.8	29		NW	13	
	2019-12-	20	36.6	0			SE	24	13:59	24.1	35		NNE	6		34.6	26		SE	11	
	2019-12-	20	42.1	0			NNW	65	11:16	33.4	17		NNW	13		41.8	10		NNW	22	
	2019-12-	12.9	22.5	0			SSW	41	00:56	13.3	78		S	7		15.2	73		NW	6	

Daily Weather Observations for Mount Moornapa, Victoria for January 2020

Prepared at 13:01 UTC on Tuesday 8 September 2020 IDCJDW3057.202001

Observations were drawn from Mount Moornapa {station 085296}

	Date	Minimum	Maximum	Rainfall (	Evaporat	Sunshine	Direction	Speed of	Time of r	9am Tem	9am rela	9am clou	9am wind	9am wind	9am MSL	3pm Tem	3pm rela	3pm clou	3pm wind	3pm wind	3pm MSL
	2020-01-	10.7	26.4	2.4			SSE	24	14:52	12.6	73		N	4		24	28		SSW	6	
	2020-01-	11.6	27.9	0			SE	28	14:14	15.3	60		E	2		27.6	29		SE	7	
	2020-01-	12.2	29.6	0			SE	19	14:22	13.7	72		S	2		25.8	47		SE	7	
	2020-01-	13.4	34.9	0			S	48	14:02	29.5	20		N	17		26.6	49		S	19	
	2020-01-	10.2	13.5	0			SSW	22	00:07	11.8	75		SSW	2		11.3	94		N	6	
	2020-01-	7.8	15.1	13.2			NE	19	03:05	10	100		SW	4		12	100		N	13	
	2020-01-	9.5	22	3.2			SW	20	15:55	14.1	93		NW	4		19.6	73		S	6	
	2020-01-	14	19.4	0			SE	17	13:54	15.5	94		0	Calm		17.7	97		SE	7	
	2020-01-	15.2	28.1	1			SE	19	14:53	16.4	100		ENE	2		26.1	60		ESE	7	
	2020-01-	16.1	34.9	0			SSE	50	15:49	28	36		NW	15		33.5	26		NNW	13	
	2020-01-	9.8	20.3	13.2			SSW	43	15:45	13.8	74		SW	9		18.8	53		S	11	
	2020-01-	9.1	22.3	0			WSW	28	11:17	12.5	71		SW	4		20.8	41		S	6	
	2020-01-	10.1	26.7	0			ENE	17	23:14	13.4	71		NNW	7		25.8	37		S	6	
	2020-01-	13.3	32.3	0			ESE	26	18:39	22.4	44		0	Calm		31.1	26		SE	9	
	2020-01-	20	33.6	0			SW	54	19:17	21.8	43		N	11		32.5	29		SE	6	
	2020-01-	14.7	16.1	2.4			SSW	33	15:48	14.8	100		S	6		15.5	82		SSW	7	
	2020-01-	10.3	13.7	0.2			ENE	39	17:37	12.3	75		ENE	4		12.9	100		ESE	7	
	2020-01-	11.8	18.2	10.2			E	31	02:08	13.5	100		ENE	2		17.6	88		SSE	2	
	2020-01-	13.4	24.5	2.2			SSE	17	15:14	16.3	94		0	Calm		18.7	92		ESE	2	
	2020-01-	14.9	17.4	24			W	50	11:44	16.4	100		ENE	2		15	100		SW	6	
	2020-01-	11.9	22	138.8			WSW	30	00:53	12.6	100		S	4		20.5	67		SSE	6	
	2020-01-	11.7	30.5	0			NNW	67	18:34	19.5	65		N	11		29.2	30		NNW	15	
	2020-01-	13.6	22.7	8.6			WNW	43	18:51	14	100		SSW	4		18.6	67		NW	7	
	2020-01-	11.1	23.8	6.8			SW	24	12:36	14	59		NW	7		22.3	40		S	7	
	2020-01-	13	25.9	0			SE	24	16:10	17.1	60		NNW	2		24.4	44		S	6	
	2020-01-	14.4	28.2	0			SSW	30	13:27	17.5	65		SSW	2		25.9	50		SSE	13	
	2020-01-	12.9	24.2	0			SE	22	15:35	14.7	95		NW	2		21.8	60		SSW	4	
	2020-01-	13.4	26	0			S	20	15:11	14.9	97		SW	2		24.4	49		S	7	
	2020-01-	12.2	29.1	0			SSE	17	16:01	16.5	82		SSW	2		27.4	39		SE	6	
	2020-01-	16	37.3	0			ESE	24	17:04	23.6	47		N	13		36.5	22		SSE	6	
	2020-01-	23.2	43.3	0			NW	46	15:55	28.8	26		N	17		40.5	18		NNW	11	

Daily Weather Observations for Mount Moornapa, Victoria for February 2020

Prepared at 13:01 UTC on Thursday 8 October 2020 IDCJDW3057.202002

Observations were drawn from Mount Moornapa {station 085296}

	Date	Minimum	Maximum	Rainfall (	Evaporat	Sunshine	Direction	Speed of	Time of r	9am Tem	9am rela	9am clou	9am wind	9am wind	9am MSL	3pm Tem	3pm rela	3pm clou	3pm wind	3pm wind	3pm MSL
	2020-02-	22.6	36.7	0			WNW	59	12:58	29.1	53		NNW	9		35.6	34		WNW	11	
	2020-02-	12	23.7	10.2			S	26	16:37	12.9	100		ESE	4		21.5	60		S	7	
	2020-02-	11.5	16.3	0			SW	56	12:12	14.4	59		W	7		12.4	65		WSW	15	
	2020-02-	6.8	20.5	0.8			WSW	24	23:11	10.1	71		NW	6		19.1	43		SSE	6	
	2020-02-	9.4	22.4	0			SE	22	16:09	12.9	81		ENE	2		21.3	54		SE	7	
	2020-02-	11.6	25.6	0			E	22	00:53	15.9	85		E	4		22.8	63		S	4	
	2020-02-	15.6	28	0			SSE	22	16:13	19.1	81		0	Calm		27.3	54		SE	7	
	2020-02-	16.5	24.2	0			ESE	43	16:32	17.1	98		ESE	11		23.7	61		ESE	15	
	2020-02-	15.3	16.7	0			ESE	41	12:14	16.1	92		E	7		16	100		ESE	11	
	2020-02-	15	19.7	20.4			ESE	37	12:24	16.5	100		ESE	7		17.8	100		ESE	9	
	2020-02-	16.3	25.7	0			ESE	22	17:38	18.5	100		NNW	4		22.6	87		SSE	6	
	2020-02-	16.5	20.4	16.8			SSE	24	14:30	16.8	100		NW	4		19.8	99		S	2	
	2020-02-	16.6	20.9	27.6			SE	17	12:53	17.7	100		SE	4		20.1	100		SE	7	
	2020-02-	17.5	29.2	4.6			WSW	46	17:25	20.8	91		N	4		28.7	67		SE	6	
	2020-02-	17	24.9	35.4			S	22	13:33	19.7	85		SSW	4		20.2	89		S	7	
	2020-02-	13.5	15.2	35			ESE	28	01:30	14.2	100		ESE	7		14.1	100		ESE	7	
	2020-02-	12.3	17.9	5.4			E	20	01:05	13.9	98		0	Calm		17.1	87		SE	4	
	2020-02-	13.7	22.8	0.4			SW	31	16:26	16	100		NNW	6		18.6	96		SSW	7	
	2020-02-	11.9	14.6	0.2			SW	48	16:26	12.1	100		WSW	11		14.2	97		SW	2	
	2020-02-	9.6	17.7	3.8			WSW	33	10:22	11.7	79		WSW	13		16.1	69		S	6	
	2020-02-	10.1	18.1	3.2			SW	26	23:21	12.1	84		W	4		15.1	74		S	6	
	2020-02-	10.1	21.9	2			SSE	19	16:05	12.9	79		ESE	4		21.1	63		SSE	6	
	2020-02-	12.8	29.6	0.6			N	24	06:00	17.9	74		N	13		28.3	45		SSE	6	
	2020-02-	17.2	28.9	0.2			NNW	24	23:10	18.4	85		0	Calm		23.7	74		SSE	9	
	2020-02-	17.8	30.9	0			NNW	30	12:07	21.1	70		N	13		30.1	46		NNW	7	
	2020-02-	13	18.5	0			WSW	67	11:04	15.1	92		E	2		15.9	62		WSW	22	
	2020-02-	7.1	19.2	0			W	31	22:21	10.1	72		NNE	6		18.7	55		S	7	
	2020-02-	10.1	20.2	0			SW	26	09:18	12.5	90		SSW	4		19.9	61		S	7	
	2020-02-	10.8	21.6	0			ESE	19	18:46	13.4	88		SE	4		20.4	65		SE	6	

Daily Weather Observations for Mount Moornapa, Victoria for March 2020																					
Prepared at 16:01 UTC on Wednesday 7 October 2020 IDCJDW3057.202003																					
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Observations were drawn from Mount Moornapa {station 085296}																					
	Date	Minimum	Maximum	Rainfall (	Evaporat	Sunshine	Direction	Speed of	Time of m	9am Tem	9am rela	9am clou	9am wind	9am wind	9am MSL	3pm Tem	3pm rela	3pm clou	3pm wind	3pm wind	3pm MSL
	2020-03-	12.7	29.9	0			NW	33	22:57	17.1	75		N	9		28.1	37		SSE	2	
	2020-03-	11.1	17.8	0			SW	48	06:43	11.2	94		SSW	13		16	56		SSW	6	
	2020-03-	8.7	17.4	0			E	26	20:48	10.3	82		NNE	2		15	62		SE	6	
	2020-03-	10	19.3	0			ENE	22	23:01	12.6	78		0	Calm		16.9	78		0	Calm	
	2020-03-	12.6	20.6	0			N	24	11:49	19.1	83		NNE	7		19.5	94		NNW	7	
	2020-03-	12.3	19.1	0			SW	39	08:44	13.4	100		SW	9		17.6	86		SSW	6	
	2020-03-	10.2	19.4	0			ESE	31	19:17	11.7	79		WSW	2		17	72		SE	6	
	2020-03-	10.4	16.4	0			E	31	01:14	11.7	94		ESE	4		13.2	92		SE	9	
	2020-03-	10.4	16.2	0			E	24	20:03	11.9	95		ESE	4		15.2	75		SE	7	
	2020-03-	10	20.2	0			E	28	16:18	12.5	88		ENE	4		19.3	68		SE	9	
	2020-03-	11.8	25.8	0			NNW	20	08:10	14.1	85		N	11		23	55		SSE	6	
	2020-03-	14.1	29.1	0			N	26	06:40	17.9	64		N	17		28.3	31		NNE	6	
	2020-03-	15.8	28	0			SW	56	18:40	19.1	52		NNW	15		25.8	40		NW	6	
	2020-03-	6.9	15.9	0			SW	35	23:26	8.3	75		WSW	7		12.9	64		SSE	4	
	2020-03-	5.8	17.1	0			E	24	19:26	8.8	78		0	Calm		16	55		SE	7	
	2020-03-	8.2	20.8	0			ESE	22	17:07	11.5	83		ENE	6		20	59		SE	6	
	2020-03-	11	24.6	0			NNW	26	06:35	14.9	71		N	13		23.8	48		S	2	
	2020-03-	14.8	28.4	0			N	31	07:27	17.7	59		N	20		26.3	37		WNW	9	
	2020-03-	17.5	31	0			NNW	48	21:07	21.9	46		N	6		29.8	37		NNW	9	
	2020-03-	13.1	24.8	0			SW	50	00:13	13.5	80		SSE	4		24.2	32		WNW	11	
	2020-03-	9.2	18	0			WSW	28	00:23	10.5	83		W	6		16.3	62		SW	6	
	2020-03-	9.6	18.2	0			SSW	39	13:01	11.2	86		N	7		15.3	67		SSW	9	
	2020-03-	7.2	16.9	0			WSW	24	00:01	8.9	81		NW	4		16.2	50		S	2	
	2020-03-	7.8	16.5	0			SE	13	13:39	9.7	91		0	Calm		15.4	72		SSE	4	
	2020-03-	9	14.7	0			WSW	22	11:10	9.3	99		W	6		13.2	72		SSW	6	
	2020-03-	8.9	19.7	0			ESE	28	16:30	10	77		N	7		19.1	53		ESE	6	
	2020-03-	10	23.9	0			N	24	06:29	14.2	70		N	15		23	49		SE	4	
	2020-03-	14	25.3	0			N	28	08:05	15.9	65		N	19		24.5	38		0	Calm	
	2020-03-	15.6	26.7	0			NNW	39	13:31	17.4	57		N	11		25.6	43		NNW	15	
	2020-03-	13	18.3	0			N	22	02:13	14.6	94		0	Calm		16.9	81		S	4	
	2020-03-	11	19.3	0.2			ESE	19	18:06	13	85		SSE	4		17.6	65		SE	2	

Daily Weather Observations for Mount Moornapa, Victoria for April 2020

Prepared at 13:01 UTC on Tuesday 6 October 2020 IDCJDW3057.202004

Observations were drawn from Mount Moornapa {station 085296}

	Date	Minimum	Maximum	Rainfall (	Evaporat	Sunshine	Direction	Speed of	Time of r	9am Tem	9am rela	9am clou	9am wind	9am wind	9am MSL	3pm Tem	3pm rela	3pm clou	3pm wind	3pm wind	3pm MSL
	2020-04-	12.2	21.9	0			SE	17	16:24	13.4	85		E	4		21.1	54		SE	4	
	2020-04-	13.2	22.6	0			N	31	16:03	13.6	100		E	7		19.1	88		NNW	15	
	2020-04-	13.1	20.4	0.2			N	30	20:24	14.3	88		NE	6		18.8	74		NNW	6	
	2020-04-	10.4	13.8	0.2			WNW	54	19:08	10.9	100		WNW	11		9.8	97		SW	7	
	2020-04-	6.1	18.4	0.2			NW	65	11:00	11.3	62		NNW	22		17.1	56		NW	17	
	2020-04-	7.3	14.3	0.2			W	26	10:29	8.7	97		W	7		13.2	66		SW	6	
	2020-04-	8.3	14.9	0.2			SW	13	23:05	10.4	71		0	Calm		12.9	74		SSE	6	
	2020-04-	8.9	15.4	0			ENE	19	21:26	11	85		0	Calm		14.8	67		ENE	2	
	2020-04-	10	18.7	0.2			ESE	19	13:36	14.1	89		E	4		17	79		SE	7	
	2020-04-	12.3	22.7	0.2			NNW	33	07:22	13.9	84		N	13		19.1	61		SSW	2	
	2020-04-	9.1	12.3	0			WSW	74	14:21	9.7	88		WSW	19		7.4	86		W	26	
	2020-04-	6	15.3	0.2			W	37	02:26	8.9	99		WSW	15		12.6	72		S	6	
	2020-04-	7.3	14.3	0			N	31	21:31	11	81		N	4		13.3	80		0	Calm	
	2020-04-	9.6	19.5	0.2			N	26	00:58	12.2	89		N	11		18.3	57		0	Calm	
	2020-04-	11.6	24.6	0.2			NNW	33	18:54	17.3	55		N	11		23.7	46		0	Calm	
	2020-04-	15.3	19.4				SSW	35	19:49	17.5	62		SE	4		17.4	73		S	7	
	2020-04-	8.1	18				W	54	15:20	11.9	62		NW	13		17.5	46		W	19	
	2020-04-	9.8	16.8				WNW	33	04:08	11.2	74		WSW	7		15.6	64		S	6	
	2020-04-	9.1	15				E	22	18:18	10.6	90		0	Calm		14.6	66		SE	6	
	2020-04-	8.4	20.9				NNW	61	09:01	14.8	63		NW	20		17.7	53		W	13	
	2020-04-	9.4	17.7				NW	22	23:54	12	77		N	11		16.1	64		SSE	6	
	2020-04-	10.9	17.8				WNW	30	06:32	14	64		W	9		16.7	60		S	6	
	2020-04-	8	18.3				N	31	23:01	13	73		0	Calm		17	61		NNW	4	
	2020-04-	12.9	21.9				WNW	24	03:42	14.4	82		S	4		20.4	54		SW	6	
	2020-04-	11	19.3				NW	33	21:55	14.3	71		WNW	4		17.3	64		SSE	2	
	2020-04-	11.7	18.2				SW	44	12:23	12.4	97		NNW	13		11.8	94		SW	9	
	2020-04-	6.4	15.3				N	15	02:25	10.6	60		0	Calm		13.6	68		SSE	6	
	2020-04-	6.4	20.8				NNW	39	21:17	10.9	66		N	11		17.5	61		NNW	11	
	2020-04-	11	21.6				SW	52	17:14	14.2	92		N	6		18.4	75		0	Calm	
	2020-04-	6.6	9.2				NW	37	23:30	6.9	100		WSW	6		7.8	93		NNW	9	

Daily Weather Observations for Mount Moornapa, Victoria for May 2020																					
Prepared at 13:01 UTC on Monday 5 October 2020 IDCJDW3057.202005																					
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Observations were drawn from Mount Moornapa {station 085296}																					
	Date	Minimum	Maximum	Rainfall (	Evaporat	Sunshine	Direction	Speed of	Time of r	9am Tem	9am rela	9am clou	9am wind	9am wind	9am MSL	3pm Tem	3pm rela	3pm clou	3pm wind	3pm wind	3pm MSL
	2020-05-	5.7	11.8				NW	59	14:12	7.5	66		NW	19		9.8	57		NW	20	
	2020-05-	7.1	11.4				W	65	16:15	9	67		W	17		9.3	72		WSW	22	
	2020-05-	7	12.8				WSW	54	02:53	8.5	79		WSW	11		12.6	66		WSW	11	
	2020-05-	6.7	11.7				W	28	06:46	7.7	90		WNW	4		11.1	84		NW	2	
	2020-05-	6.3	15.6				N	20	23:29	9.4	80		N	7		15.2	78		SE	4	
	2020-05-	9.2	18				N	31	21:39	12.8	60		NNE	9		15.9	77		0	Calm	
	2020-05-	12.3	21.5				NW	44	09:59	15.3	52		NNW	13		19.7	46		NNW	9	
	2020-05-	12.6	20.1				NW	31	00:39	14.8	65		N	7		17.3	61		E	4	
	2020-05-	11	15				WNW	43	13:25	13.4	70		N	13		9.4	86		WNW	6	
	2020-05-	3.9	10.8				W	39	11:28	6.1	73		W	13		9.9	66		WSW	7	
	2020-05-	6	15.2				N	24	23:23	9.6	66		NW	9		14.5	57		WSW	7	
	2020-05-	7	12.7				NNW	31	22:07	9.3	69		N	9		11.3	62		NNW	6	
	2020-05-	7.7	10.5				NNW	31	00:16	9.5	70		N	4		7.9	99		NW	4	
	2020-05-	4.8	11.5				W	11	02:14	7	71		NW	4		10.9	60		SW	2	
	2020-05-	4.7	13.1				N	17	06:17	7.1	78		NNW	6		11.1	71		SE	4	
	2020-05-	5.5	13.8				N	17	03:42	9.8	73		0	Calm		13	69		SE	4	
	2020-05-	7.9	14.1				E	17	18:28	10.4	73		WSW	6		13	71		SSE	2	
	2020-05-	6.8	15.5				N	20	23:43	10.9	72		N	7		14.1	68		SE	6	
	2020-05-	9.4	18.3				N	28	12:05	13.6	58		E	4		15.6	62		ENE	6	
	2020-05-	7.5	15.8				N	39	00:14	11.3	78		N	7		15.7	57		NW	6	
	2020-05-	6.1	7.9				NNW	30	02:15	7.8	83		0	Calm		6.9	99		WSW	6	
	2020-05-	5.6	9.4				W	26	01:38	6.7	93		WSW	7		8.7	86		WSW	6	
	2020-05-	5.5	11.3				W	24	07:51	6.6	86		W	11		9.5	84		WSW	7	
	2020-05-	6.5	11.3				W	19	03:08	8.1	94		SSW	2		9.2	87		SSE	7	
	2020-05-	7.2	10.7				NE	19	21:26	7.9	100		SSE	6		9.4	100		ESE	4	
	2020-05-	5.5	13.9				N	20	22:53	8.4	88		NNE	6		12.3	84		E	6	
	2020-05-	8	16.3				N	22	01:57	11.9	72		N	7		15.3	77		E	4	
	2020-05-	9.7	17.7				NW	24	11:13	11.3	71		NNW	11		16.3	53		NW	9	
	2020-05-	6.6	15.7				N	22	06:00	8.9	78		NNE	9		14.2	57		0	Calm	
	2020-05-	5.8	16.4				NNW	59	22:58	9.1	65		N	15		16	44		NNW	15	
	2020-05-	9	15.8				NNW	44	05:13	11.9	64		NNW	19		11.9	79		0	Calm	

Daily Weather Observations for Mount Moornapa, Victoria for June 2020																					
Prepared at 13:01 UTC on Sunday 4 October 2020 IDCJDW3057.202006																					
Copyright 2003 Commonwealth Bureau of Meteorology																					
Observations were drawn from Mount Moornapa {station 085296}																					
	Date	Minimum	Maximum	Rainfall (	Evaporat	Sunshine	Direction	Speed of	Time of r	9am Tem	9am rela	9am clou	9am wind	9am wind	9am MSL	3pm Tem	3pm rela	3pm clou	3pm wind	3pm wind	3pm MSL
	2020-06-	8.5	11.5				SW	46	22:15	9.8	70		N	13		10.3	87		NW	6	
	2020-06-	4.6	13.5				SW	44	00:40	7.8	76		W	9		12.9	69		W	7	
	2020-06-	6.5	9.8				SW	52	03:30	7.4	87		SW	13		9	76		SW	7	
	2020-06-	5.9	10.3				W	19	01:20	6.2	83		NW	4		10	71		0	Calm	
	2020-06-	4	12.8				N	22	05:12	7	73		W	4		10	73		S	2	
	2020-06-	6.3	12.7				SSW	13	19:53	7.3	78		N	9		10.5	82		S	2	
	2020-06-	3.8	9.1				SW	17	05:49	5.7	78		W	7		8.5	63		WNW	4	
	2020-06-	2.5	10				N	13	21:35	5.5	77		NNW	4		9.6	66		0	Calm	
	2020-06-	2.2	12.2				N	22	22:11	5.5	70		N	9		9.5	77		SSE	4	
	2020-06-	5.4	14.4				N	17	22:48	10.9	49		E	4		11.3	61		SSE	6	
	2020-06-	6.2	12.2				N	17	22:10	8	89		NNE	11		10.8	84		SSE	4	
	2020-06-	5.2	14.3				N	20	20:08	6.4	82		N	9		11.6	72		SE	4	
	2020-06-	6.4	15				NNW	48	20:42	14	53		0	Calm		13.6	65		NNW	9	
	2020-06-	6.1	14.1				WNW	39	07:44	6.9	92		WNW	11		13.7	47		NW	9	
	2020-06-	6.9	16.9				WNW	50	13:53	10.9	75		NNW	15		15.9	56		WNW	17	
	2020-06-	10.4	17.9				NW	44	15:44	13.1	65		N	4		14.6	53		WNW	17	
	2020-06-	6.1	10.4				SW	24	00:21	6.8	94		N	7		9.1	75		0	Calm	
	2020-06-	4.4	14.2				N	19	20:49	9.3	74		ENE	2		12.2	78		ESE	4	
	2020-06-	8.5	16				NNW	33	14:12	11.5	69		N	13		14.4	67		NNW	9	
	2020-06-	10.4	15.6				NNW	35	12:20	11.1	85		ESE	4		15	69		NNW	9	
	2020-06-	5.7	11.4				SW	20	20:48	7.6	82		N	4		10.3	83		SW	4	
	2020-06-	5.2	10.8				W	26	15:44	7	77		NW	9		9.1	76		WNW	6	
	2020-06-	5.4	11.1				WSW	35	19:55	6.8	96		W	11		10.7	82		WSW	9	
	2020-06-	6.7	12.9				S	17	00:15	9.9	100		S	2		12.5	90		WSW	4	
	2020-06-	6.6	15				WNW	28	14:52	8.7	84		N	9		13.5	62		WNW	9	
	2020-06-	5.4	10.8				W	28	03:27	6.7	72		NW	6		9.8	82		SW	4	
	2020-06-	3.2	10.7				N	17	07:38	4.8	87		N	9		7.6	78		SSE	4	
	2020-06-	3	9.3				N	15	08:05	4.8	83		N	6		8.4	77		SE	4	
	2020-06-	2.6	11.2				N	19	23:01	4.2	88		N	9		8.9	84		SSE	4	
	2020-06-	4.2	14				NNW	33	22:40	8.7	61		N	6		13.6	56		NNW	9	

Daily Weather Observations for Mount Moornapa, Victoria for July 2020

Prepared at 13:01 UTC on Saturday 3 October 2020 IDCJDW3057.202007

Observations were drawn from Mount Moornapa {station 085296}

	Date	Minimum	Maximum	Rainfall (	Evaporat	Sunshine	Direction	Speed of	Time of r	9am Tem	9am rela	9am clou	9am wind	9am wind	9am MSL	3pm Tem	3pm rela	3pm clou	3pm wind	3pm wind	3pm MSL
	2020-07-	7.5	16.8							11.5	67		NNE	13		15.7	48		NNW	26	
	2020-07-2																				
	2020-07-3																				
	2020-07-4																				
	2020-07-5																				
	2020-07-6																				
	2020-07-7																				
	2020-07-8																				
	2020-07-9																				
	2020-07-10																				
	2020-07-11																				
	2020-07-12																				
	2020-07-13																				
	2020-07-14																				
	2020-07-15																				
	2020-07-16																				
	2020-07-17																				
	2020-07-18																				
	2020-07-19																				
	2020-07-20															8.8	84		W	11	
	2020-07-21		11.8				WSW	33	00:37	6.8	83		WSW	15		11.4	81		0	Calm	
	2020-07-	4.6	10.7	0			W	26	21:09	6.3	91		N	7		9.2	76		SSE	4	
	2020-07-	4.7	8.7	0			W	22	02:34	5.6	77		NW	7		8.4	69		S	2	
	2020-07-	1.6	8.7	0			NNE	17	18:03	4.4	85		NNW	2		8.2	78		SSE	2	
	2020-07-	2.8	10.7	0			N	20	02:25	7.7	58		NNW	6		8.6	78		SE	6	
	2020-07-	6.2	11.4	0.6			E	19	15:32	7.9	100		NNW	4		10	95		E	6	
	2020-07-	7.5	9.6	8.8			SSE	41	21:25	8.2	100		S	6		9.2	100		SSE	15	
	2020-07-	8.1	10.3	32.6			S	39	12:20	9.1	100		SSE	9		9.4	100		SSE	6	
	2020-07-	6.8	13.1	12.2			WNW	19	22:05	7.6	100		N	7		12.5	79		SW	2	
	2020-07-	6.6	11.2	0.2			WSW	30	04:48	7.7	91		WSW	9		9.2	72		0	Calm	
	2020-07-	3.5	13	0			N	24	22:30	5.4	77		N	9		11.1	72		SSE	2	

Daily Weather Observations for Mount Moornapa, Victoria for August 2020

Prepared at 16:01 UTC on Friday 2 October 2020 IDCJDW3057.202008

Observations were drawn from Mount Moornapa {station 085296}

	Date	Minimum	Maximum	Rainfall (	Evaporat	Sunshine	Direction	Speed of	Time of r	9am Tem	9am rela	9am clou	9am wind	9am wind	9am MSL	3pm Tem	3pm rela	3pm clou	3pm wind	3pm wind	3pm MSL
	2020-08-	5.3	16	0.2			N	28	21:49	7.6	71		N	13		15.2	49		0	Calm	
	2020-08-	6.9	17.8	0			N	37	04:12	9.8	64		NNW	17		16.7	54		0	Calm	
	2020-08-	8.1	13.4	0			NNW	30	05:45	8.5	71		E	4		10.8	83		SSE	4	
	2020-08-	0.3	8.3	2.8			WNW	46	13:13	1.7	99		WSW	11		6.8	60		WNW	9	
	2020-08-	1.7	8.3	3			W	57	06:14	5.8	78		WSW	24		7.9	77		W	13	
	2020-08-	3.4	10.1	0.8			W	33	05:44	5.3	76		WSW	9		9.4	66		SW	6	
	2020-08-	2.4	8.1	0			E	35	12:21	6.7	89		E	7		7.6	84		ESE	9	
	2020-08-	6.1	9.8	6			ESE	35	03:26	7.6	99		E	6		9	100		ESE	6	
	2020-08-	6.8	10.2	15.6			SE	30	11:17	7.5	100		SE	9		8.5	99		SE	7	
	2020-08-	6	12.3	5.8			E	24	18:58	8.3	96		NNE	6		11	73		ESE	4	
	2020-08-	4.8	14.1	0.2			E	26	18:30	8.2	67		NNE	9		12	61		E	4	
	2020-08-	7.3	12.8	0			N	28	12:14	9.4	73		NNE	7		11.6	76		NNW	11	
	2020-08-	9.1	17.2	0			N	28	23:12	11.7	74		N	9		14.9	73		0	Calm	
	2020-08-	9.3	16	0.4			NNW	30	00:04	10.9	77		N	13		13.9	75		NNW	9	
	2020-08-	8.5	12.7	3			SW	28	21:35	9.6	87		WSW	7		11.3	87		SSW	2	
	2020-08-	7.8	9.2	18.2			WSW	46	15:54	8.5	100		WSW	13		8.8	100		WSW	17	
	2020-08-	7.8	13.4	16.8			WSW	31	04:35	8.9	84		W	7		12.2	79		S	4	
	2020-08-	6.9	16.3	0			NW	43	22:13	10	75		N	13		14.1	58		NW	9	
	2020-08-	6.8	12.9	0			W	33	21:42	8.3	74		N	11		12.3	63		WNW	11	
	2020-08-	5.9	13.7	0.6			NNW	46	18:12	8	76		W	9		13.1	56		WNW	15	
	2020-08-	4.8	11.2	0.2			WNW	54	11:19	5.3	95		S	6		10	58		NW	15	
	2020-08-	2.1	9	0.4			WNW	46	13:17	5.9	64		NW	7		1.4	99		W	17	
	2020-08-	1.3	8.7	11.2			WSW	54	15:48	5.2	91		W	17		5.1	99		WSW	15	
	2020-08-	3.7	10.7	2.6			WSW	43	02:19	5.4	84		WSW	11		8.2	76		SW	6	
	2020-08-	3.7	11.2	0.2			W	28	20:34	6.7	68		NW	6		9.5	96		SSW	4	
	2020-08-	3.6	12.1	0.8			WNW	22	07:48	6.9	66		WNW	7		11.1	62		S	2	
	2020-08-	4.6	17.6	0			WSW	81	19:11	9.6	71		NNW	17		15.6	49		NNW	17	
	2020-08-	4.1	14.2	4.2			W	59	00:19	8.5	69		W	11		13.6	59		SSW	4	
	2020-08-	7.4	20.4	0.2			N	30	23:37	11.1	55		N	13		19.1	38		ESE	4	
	2020-08-	10.5	21.5	0			WNW	52	21:21	13.9	44		N	15		19.4	31		NNW	13	
	2020-08-	4.4	10.7	1.4			SW	44	04:22	6.3	74		WSW	13		9.7	69		SSW	6	

Daily Weather Observations for Mount Moornapa, Victoria for September 2020

Prepared at 13:01 UTC on Wednesday 7 October 2020   IDCJDW3057.202009

Observations were drawn from Mount Moornapa {station 085296}

	Date	Minimum	Maximum	Rainfall (	Evaporat	Sunshine	Direction	Speed of	Time of r	9am Tem	9am rela	9am clou	9am wind	9am wind	9am MSL	3pm Tem	3pm rela	3pm clou	3pm wind	3pm wind	3pm MSL
	2020-08-	5.3	16	0.2			N	28	21:49	7.6	71		N	13		15.2	49		0	Calm	
	2020-08-	6.9	17.8	0			N	37	04:12	9.8	64		NNW	17		16.7	54		0	Calm	
	2020-08-	8.1	13.4	0			NNW	30	05:45	8.5	71		E	4		10.8	83		SSE	4	
	2020-08-	0.3	8.3	2.8			WNW	46	13:13	1.7	99		WSW	11		6.8	60		WNW	9	
	2020-08-	1.7	8.3	3			W	57	06:14	5.8	78		WSW	24		7.9	77		W	13	
	2020-08-	3.4	10.1	0.8			W	33	05:44	5.3	76		WSW	9		9.4	66		SW	6	
	2020-08-	2.4	8.1	0			E	35	12:21	6.7	89		E	7		7.6	84		ESE	9	
	2020-08-	6.1	9.8	6			ESE	35	03:26	7.6	99		E	6		9	100		ESE	6	
	2020-08-	6.8	10.2	15.6			SE	30	11:17	7.5	100		SE	9		8.5	99		SE	7	
	2020-08-	6	12.3	5.8			E	24	18:58	8.3	96		NNE	6		11	73		ESE	4	
	2020-08-	4.8	14.1	0.2			E	26	18:30	8.2	67		NNE	9		12	61		E	4	
	2020-08-	7.3	12.8	0			N	28	12:14	9.4	73		NNE	7		11.6	76		NNW	11	
	2020-08-	9.1	17.2	0			N	28	23:12	11.7	74		N	9		14.9	73		0	Calm	
	2020-08-	9.3	16	0.4			NNW	30	00:04	10.9	77		N	13		13.9	75		NNW	9	
	2020-08-	8.5	12.7	3			SW	28	21:35	9.6	87		WSW	7		11.3	87		SSW	2	
	2020-08-	7.8	9.2	18.2			WSW	46	15:54	8.5	100		WSW	13		8.8	100		WSW	17	
	2020-08-	7.8	13.4	16.8			WSW	31	04:35	8.9	84		W	7		12.2	79		S	4	
	2020-08-	6.9	16.3	0			NW	43	22:13	10	75		N	13		14.1	58		NW	9	
	2020-08-	6.8	12.9	0			W	33	21:42	8.3	74		N	11		12.3	63		WNW	11	
	2020-08-	5.9	13.7	0.6			NNW	46	18:12	8	76		W	9		13.1	56		WNW	15	
	2020-08-	4.8	11.2	0.2			WNW	54	11:19	5.3	95		S	6		10	58		NW	15	
	2020-08-	2.1	9	0.4			WNW	46	13:17	5.9	64		NW	7		1.4	99		W	17	
	2020-08-	1.3	8.7	11.2			WSW	54	15:48	5.2	91		W	17		5.1	99		WSW	15	
	2020-08-	3.7	10.7	2.6			WSW	43	02:19	5.4	84		WSW	11		8.2	76		SW	6	
	2020-08-	3.7	11.2	0.2			W	28	20:34	6.7	68		NW	6		9.5	96		SSW	4	
	2020-08-	3.6	12.1	0.8			WNW	22	07:48	6.9	66		WNW	7		11.1	62		S	2	
	2020-08-	4.6	17.6	0			WSW	81	19:11	9.6	71		NNW	17		15.6	49		NNW	17	
	2020-08-	4.1	14.2	4.2			W	59	00:19	8.5	69		W	11		13.6	59		SSW	4	
	2020-08-	7.4	20.4	0.2			N	30	23:37	11.1	55		N	13		19.1	38		ESE	4	
	2020-08-	10.5	21.5	0			WNW	52	21:21	13.9	44		N	15		19.4	31		NNW	13	

APPENDIX G

Table of stockpiled Sands PM20 and Thorium content

	≤PM20 percentage	Thorium content mg/kg	Reference
Gravelly (upper) Sands	21%	21	AOO4 Appx C
Fine Sands	44%	60	A002 p.30