DOHERTY MODELLING –FINAL REPORT TO NATIONAL CABINET

5TH NOVEMBER 2021

Table of contents

Attachments

Key Messages

Work Package 1 – Modelling to inform review and refinement of public health response measures

- Streamlined and focussed test-trace-isolate-quarantine (TTIQ) processes (supported by PHSMs) will be required for future public health responses to be effective and sustainable
- We have previously shown that case-initiated contact tracing can support timely quarantine in times of system stress
- Reduced contact tracing intensity and differential management of vaccinated individuals will help to ensure sustainable responses as caseloads increase
- Focussed TTIQ with wrap around support will be needed in communities that remain at risk of higher transmission and/or clinical impacts
- Ongoing data collection is advised to enable evaluation of TTIQ responses for situation assessment

Work Package 2 – Optimise vaccination at sub-jurisdictional level

1. First Nations Australians
    - High vaccine coverage can reduce transmission and health impacts in urban and remote communities
    - Reactive vaccination is a useful adjunct to community engaged and led outbreak response
    - Providing access to effective treatments will further promote health outcomes
2. Local Government and small area effects
    - Baseline transmission potential (TP) differs by small area, as do vaccine and PHSM impacts (ability to work from home)
    - Focussed TTIQ and wrap around supports will be needed to constrain TP in high-risk areas and may include additional measures in schools and workplaces
3. Schools
    - Early infection detection and high vaccine coverage markedly reduce outbreak risk
    - Allowing ongoing school attendance for class contacts of a case through a 'test to stay' strategy achieves equivalent outbreak containment to home quarantine and enables face to face learning
    - School based measures will have maximum utility in areas with higher than average transmission
    - Regular screening of students in areas at risk of outbreaks can result in even fewer infections and in-person teaching days lost

Work Package 3 – Review border measures and arrivals pathways

- Vaccination reduces the risk of infected people being released from quarantine into the community, mitigating against shorter duration
- These importations do not materially impact on established epidemics or lead to large outbreaks at the defined Phase C coverage threshold of 80%, when combined with 'low' PHSMs
- *These findings assume consistent vaccine protection and virus characteristics identical to those assumed for the Delta variant (ie no more transmissible, and equally preventable by vaccines)*

Revisions to parameter assumptions

- Mixing, vaccine effectiveness and clinical severity parameters have been updated for this phase of work, based on latest available evidence
- Previous recommendations of 70 and 80% vaccine coverage thresholds for National Plan transition phases remain robust

Background

On 30 July 2021, National Cabinet considered advice from the Doherty Institute and Commonwealth Treasury to inform the National Plan to Transition Australia's National COVID Response (National Plan). The combined modelling/Treasury conclusion was that where an outbreak occurs strict lockdowns were likely to be required to manage outbreaks until completed coverage of 70% or more had been achieved and that a 'low case' strategy was likely to be lower economic cost than managing higher transmission within the community. Additional recommendations of that work were that:

- Ongoing public health test, trace, isolate, quarantine (TTIQ) responses combined with public health and social measures (PHSMs) were critical interventions to achieve this low case strategy as vaccination alone would be insufficient;
- Achievement of vaccine coverage targets at small area level would be critical to ensure equity of program impact, as ongoing outbreaks in undervaccinated populations are reasonably anticipated from international experience;
- Ongoing situational assessment of measured transmission potential and circulating SARS-CoV-2 variants in the Australian population over coming months would allow benchmarking of these hypothetical scenarios to guide real time policy decision making about the transition to Phases B and C of the National Plan.

The consortium was subsequently tasked with a second phase of work to support implementation of the Plan, which was approved by National Cabinet on the 13th August 2021:

- Work Package 1: Modelling to inform review and refinement of public health response measures for optimal utility and sustainability in Phase B and beyond;
- Work Package 2: Optimise vaccination at sub-jurisdictional level, including attention to key populations and risk settings (First Nations, CALD and low SES communities, and schools);
- Work Package 3: Review border measures and arrivals pathways in context of revised risk tolerance.

Ongoing consultation has informed iterative revision of questions and outputs to inform key decisions as the local and international landscape changes. We have also revised several critical parameters as needed, based on emerging evidence from Australia and elsewhere.

Key Findings Work Package 1: Modelling to inform review and refinement of public health response measures for optimal utility and sustainability in Phase B and beyond

Key question: What are the most effective and sustainable strategies for test, trace, isolate, quarantine (TTIQ) to manage COVID as vaccination rates increase in Phase A then Phases B and C to achieve the aim of strong suppression and avoid lockdown requirement?

Through Department of Health-led consultations with the Communicable Diseases Network of Australia (CDNA) and Australian Health Protection Principal Committee (AHPPC), strategies have been identified to simplify and streamline TTIQ responses during the transition into a phase of established community transmission of COVID-19, with increasing caseloads and high vaccine coverage. Models were used to assess risks associated with proposed changes to measures, informing revisions of national guidelines. We have previously shown that case-initiated contact tracing can support timely quarantine in times of system stress. Reduced contact tracing intensity and differential management of vaccinated individuals will further help to ensure sustainable responses. Focussed TTIQ with wrap around support will be needed in communities that remain at risk of higher transmission and/or clinical impacts. Ongoing data collection is advised to enable evaluation of TTIQ responses for situational assessment of transmission potential.

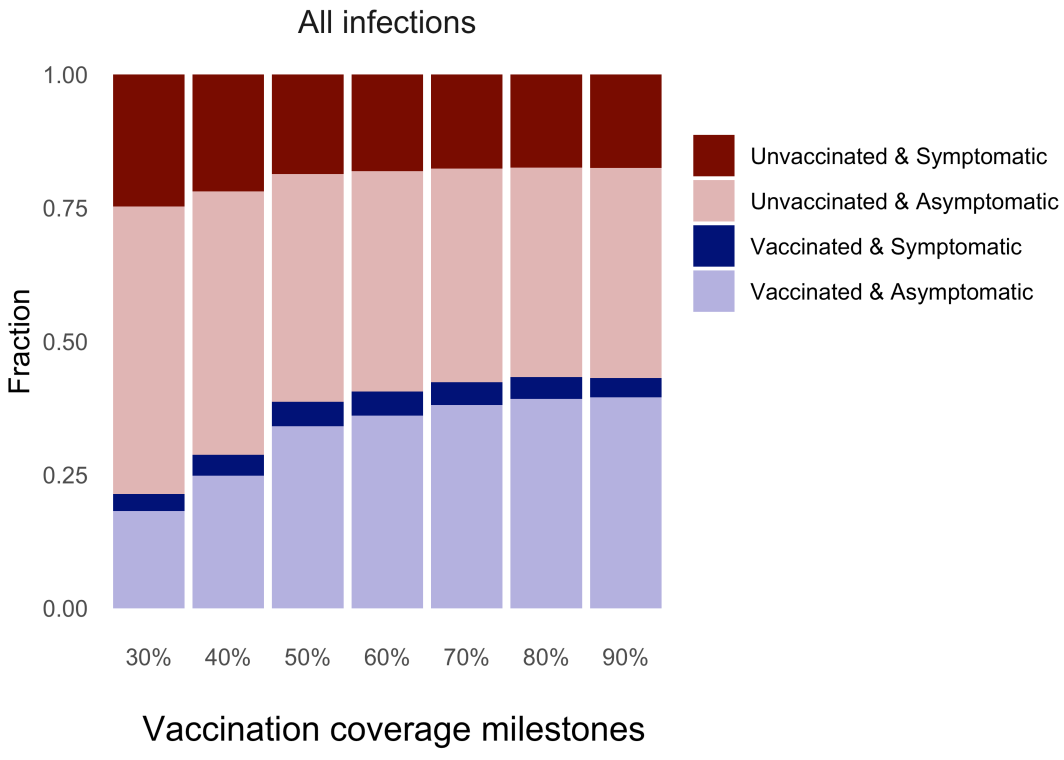
The current report focuses on some key findings and their implications for epidemic control, along with the importance of ongoing evaluation.

When considering streamlining of TTIQ processes for sustainable future responses, it is important to note that the impact of even minor changes in TP on the local epidemiology depends critically on how close TP is to the national strategic objective of maintaining a control threshold of 1. If TP at the population level is very close to 1, even a small change can be sufficient to enable escalation of the local epidemic.

Vaccine coverage and asymptomatic infections

As vaccine coverage increases, the proportion of all infections that occur in vaccinated people will increase, because they will represent a majority proportion of the population (Figure 1.1). Such cases are likely to be less symptomatic and infectious, supporting public health responses and limiting clinical impacts.

Figure 1.1: Proportion of all infections in vaccinated and unvaccinated individuals over time as coverage increase in the population, and related symptomatic fraction



Management of vaccinated cases and contacts

Doherty modelling is supporting risk appraisal to assess the impact on transmission potential (TP) of changing the management of cases and contacts in a highly vaccinated population. Understanding which measures can be safely altered as part of routine practice, and which are the most important to continue in times of system stress, will help to inform reduced intensity of case and contact management during the transition to living with COVID. Options include differential management of vaccinated individuals presenting either as index cases or contacts.

Figure 1.2.1 is an example of a change in routine management of vaccinated cases that has minimal impact on the overall impact of the public health response. Reducing the duration of isolation for vaccinated cases from the current guideline recommendation of 14 days to 7 days contributes only a 1% increase in TP, meaning that such a change poses a very low risk.

Figure 1.2.1 Reduced duration of isolation for vaccinated COVID positive cases. The left panel reports outputs from a simulation model estimating the reduction in transmission potential achieved by isolating fully vaccinated cases for 14 days (left) or 7 days (right). The small 'by eye' difference seen here is confirmed in the rightmost plot, which shows an overall increase in TP of approximately 1% for 7 days.

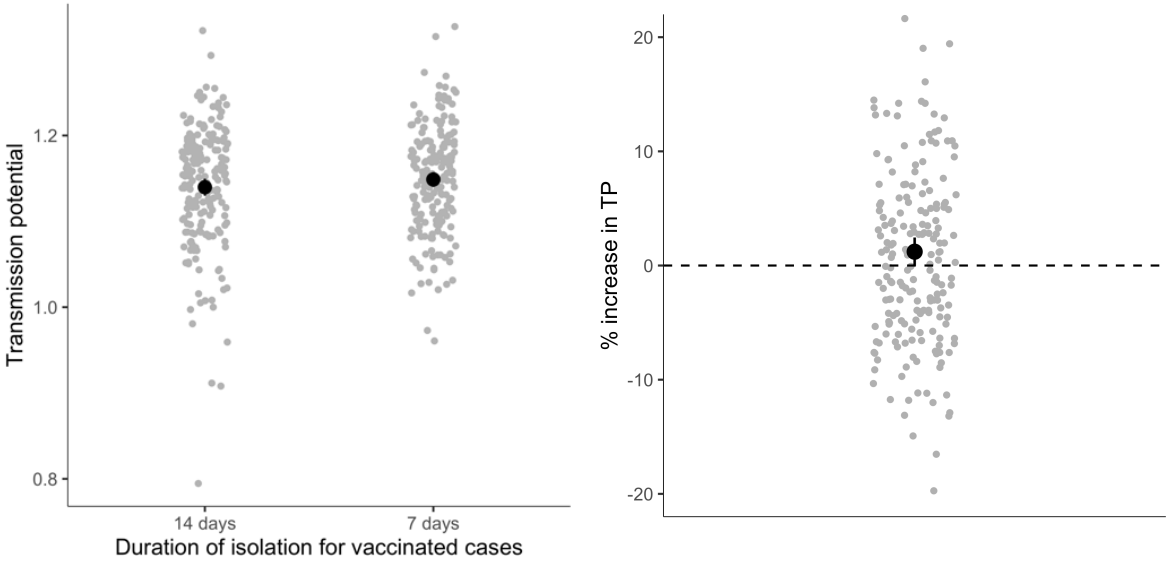


Figure 1.2.2 draws on the experience of NSW during the 2021 outbreak to demonstrate the utility of asking cases to notify their own primary close contacts (PCCs) and asking them to isolate, hastening the time to contact isolation as public health response efforts become less timely under system stress. We have developed a simulation approach to consider the likely impact of this strategy on transmission potential, given some assumptions about compliance and the proportion of contacts that can be ascertained by this means. The model was used to replicate three scenarios for NSW:

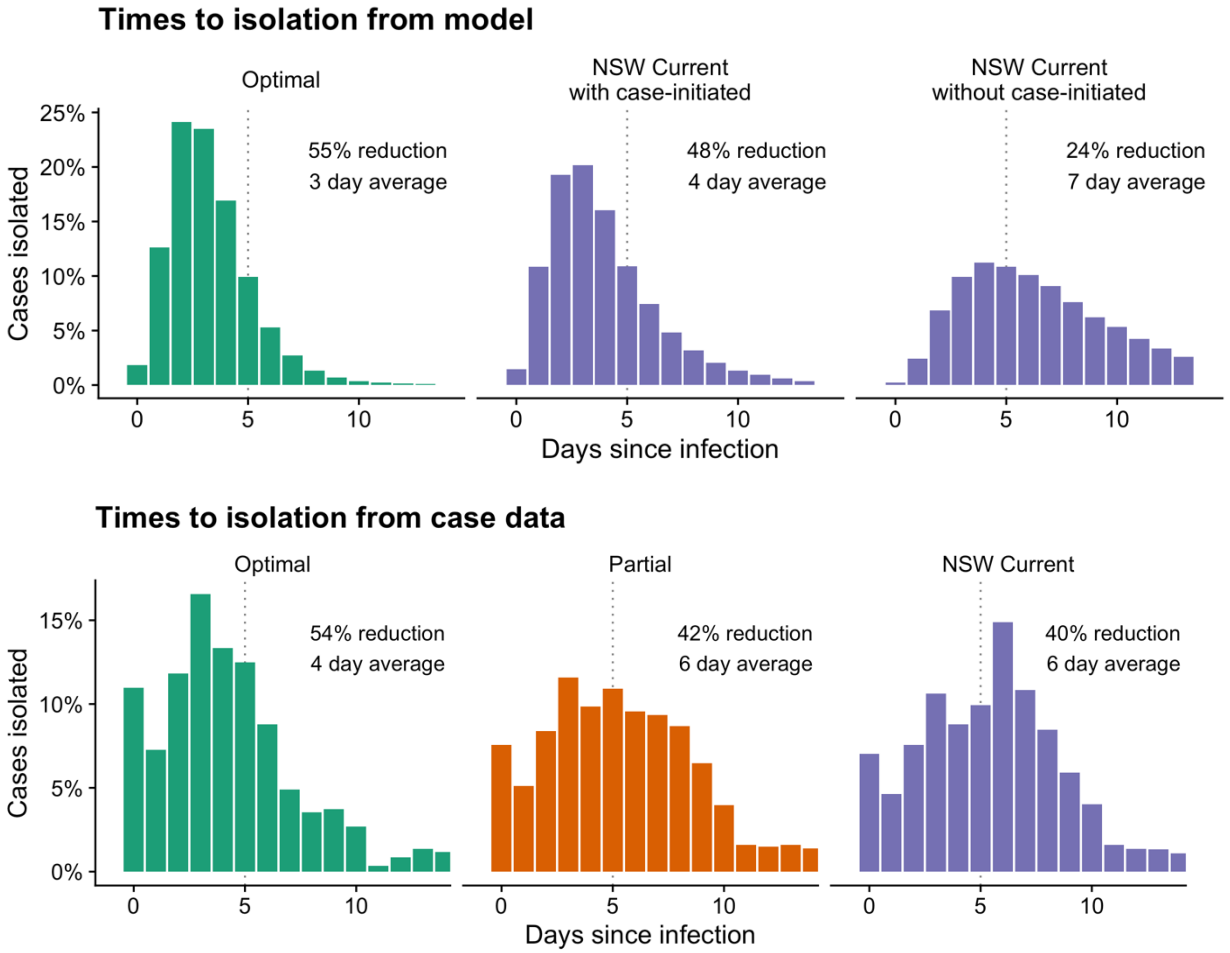
- Optimal TTIQ – the period from July 2020-February 2021 presented in our previous work;
- Current TTIQ – a four-week period commencing August 15 2021, without case initiated tracing;
- Current with case-initiated TTIQ – as above, but assuming 80% of contacts are case-notified.

Optimal and Current scenarios use assumptions about the time from case notification to interview based on data reported by public health units during the time periods above. The interview is the first timepoint at which public health units can identify contacts and ask them to test and quarantine. From these inputs, the model reports time delays to isolation of all cases, including those found through contact tracing.

The left most panel of the upper figure shows that our model can reproduce the TP reduction calculated from observed distributions of times from infection to isolation for 'optimal TTIQ' as estimated in Phase 1 of the National Plan Modelling (54% reduction). The middle panel shows that if we assume a high level of case-initiated contact tracing, NSW should still achieve similar reductions in TP to 'partial TTIQ' as estimated in Phase 1 of the National Plan Modelling (42% reduction). The right most panel shows that the

reported contact tracing delays in NSW would be predicted to result in a much smaller reduction in TP if case-initiated contact tracing (or other strategies to reduce times to isolation) were not in place.

Figure 1.2.2 Case initiated contact tracing – comparison of simulation model outputs (upper panel) with observed times to isolation from case duration during periods of Optimal and Partial TTIQ as defined in previous reporting, compared with NSW observations from mid-August to mid-September 2021



The lower panel of the figure displays estimates of times from infection to isolation from case data. The right most panel (NSW current) shows that between mid-August and mid-September 2021, TTIQ responses in NSW were reducing TP by 40%. This estimate is much higher than would be expected based on public health unit contact tracing alone (right most panel of the 'model' figure). It supports the hypothesis that a substantial proportion of cases did self-identify contacts, who complied with the recommendation to quarantine. *These findings further confirm the effectiveness of TTIQ responses to constrain Delta.*

Ongoing evaluation of the impacts of TTIQ on TP

Assessment of the continuing impact of TTIQ on transmission will be an important component of ongoing weekly situational assessment given its impact on TP in the population. A monitoring system needs to measure the overall impact of TTIQ, as well as the components that underpin system performance, to allow identification of reduced timeliness or completeness of response actions. The overall indicator of system performance is defined as the **TTIQ effect** as shown in Figure 1.3.1, which is the percentage reduction in transmission potential due to TTIQ. This effect is the product of two components: the impact on *detected* infections, and the overall proportion of infections detected (case ascertainment). Figure 1.3.2 demonstrates that our current estimates of TTIQ performance are based on a very high level of infection ascertainment, likely in the order of 90-100%. In future, if the proportion of all infections that can be identified falls substantially because of a higher asymptomatic fraction (as in Figure 1.1) or complacency, the impacts of TTIQ measures on TP will similarly decline.

Figure 1.3.1: Elements required to estimate the TTIQ effect (percentage reduction in TP due to TTIQ).

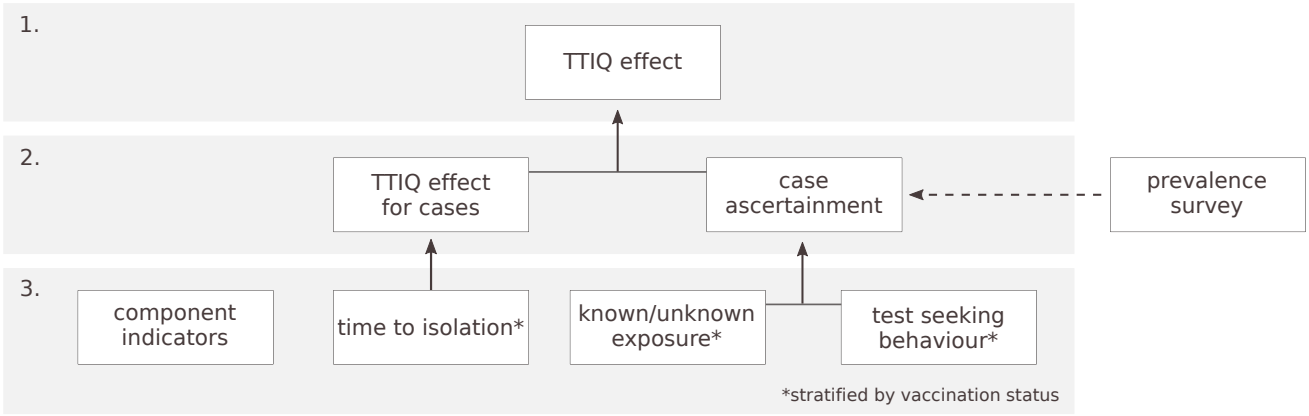
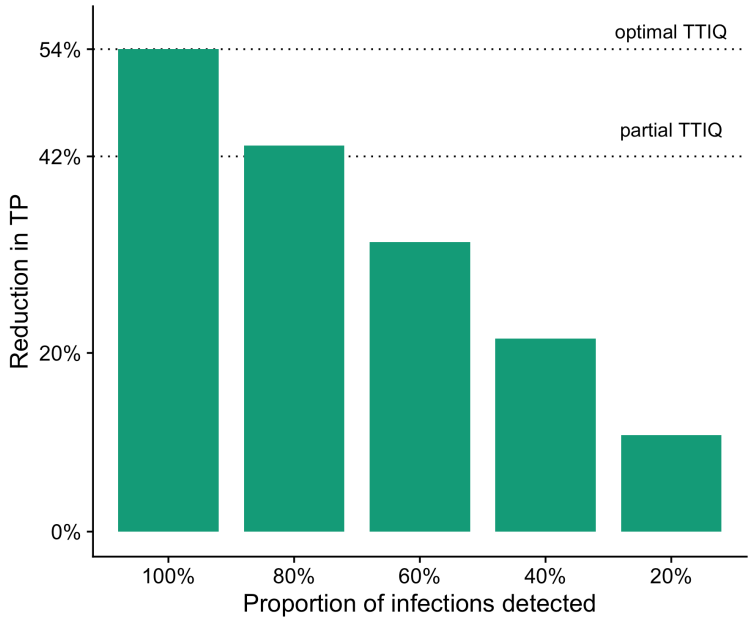


Figure 1.3.2: Relationship between case ascertainment and the proportional reduction in TP that has previously been observed in the Australian population (noting that historical ascertainment is likely somewhere between 80 and 100% of cases). Should ascertainment fall, these proportional reductions in TP will only apply to the proportion of infections that have been identified, initiating TTIQ responses.



Estimation of the proportion of all infections that are detected is critical to assessment of TTIQ impact and would ideally be informed by regular prevalence surveys. In their absence, modelling approaches may be used to infer the fraction of infections ascertained over time, but these estimates would be less accurate and difficult to validate.

Maintaining low case numbers through maintenance of ongoing PHSMs will further assist to constrain TP and support TTIQ.

Key Findings Work Package 2: Optimise vaccination at sub-jurisdictional level, including attention to key populations and risk settings

Key questions: What coverage targets are appropriate for populations at higher risk of transmission and disease impacts? What is the role of reactive vaccination in response should outbreaks occur in such localised groups and settings in the context of suboptimal coverage? What additional public health response measures will be most useful to regain control of transmission should outbreaks occur?

This report defines some of the key population characteristics, measurable in census and survey data, that allow identification of baseline increased risk of transmission in small areas and settings. The impacts on transmission potential (TP) of vaccination and public health and social measures may also be less than average in some of these groups. Enhanced public health focus including community engagement, strong TTIQ responses (including supports for isolation and quarantine) and heightened attention to transmission in schools will be required in such areas to improve health and social outcomes. Providing access to effective treatments will further promote health outcomes in populations at high risk of severe disease.

1. *First Nations Australians*

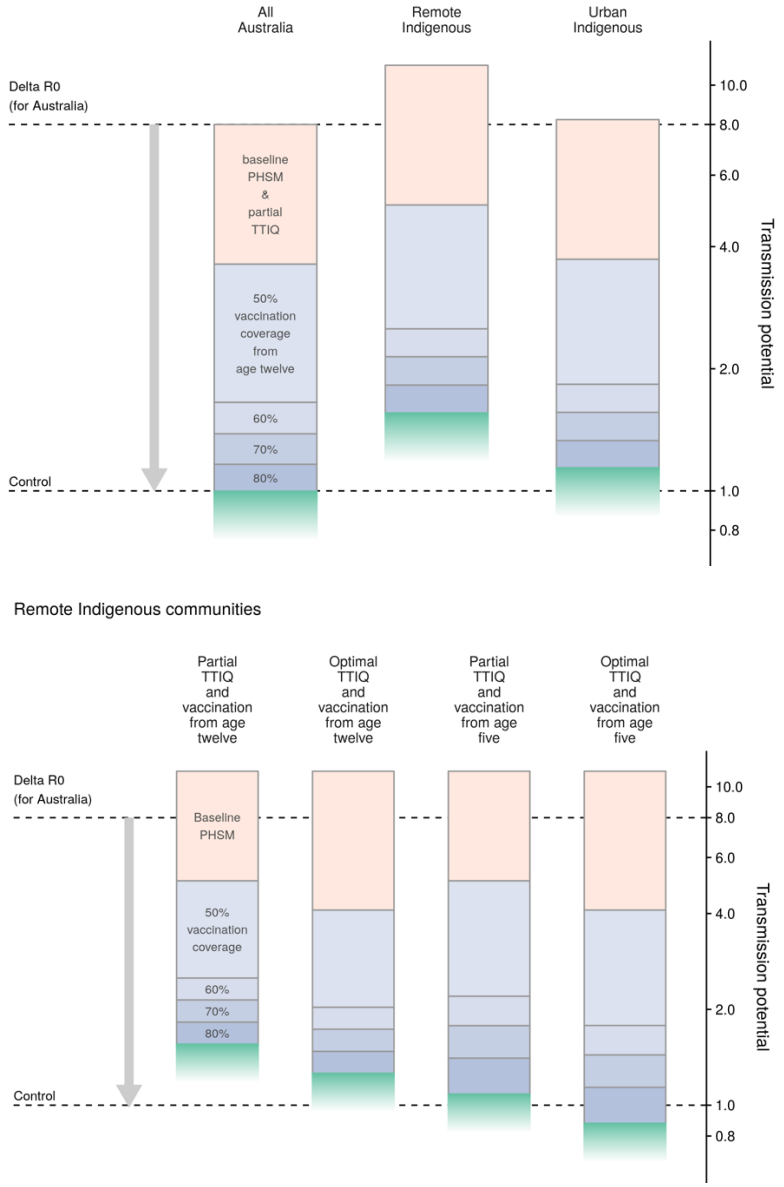
High vaccine coverage can reduce transmission and health impacts in urban and remote communities. Reactive vaccination is a useful adjunct to community engaged and led outbreak response, and can reduce health impacts, particularly in larger communities with low initial vaccine coverage. Providing access to effective treatments will further promote health outcomes, particularly where clinical access is limited.

Figure 2.1.1 indicates that 80% coverage of the 12+ population combined with PHSMs and partial TTIQ should be sufficient to reduce transmission potential (TP) to the control threshold of 1 for urban Indigenous communities. At this coverage level and even with optimal TTIQ, additional PHSMs will be needed to control outbreaks in remote settings. The figure illustrates how the baseline reproduction number (R_0) and the effects of vaccination coverage (for the population aged 12+ years) vary between population groups with different demographic profiles. Each column in the left panel of the figure represents a group with different age and household structure, estimated from population data and for the two rightmost columns, the Northern Territory Aboriginal Birth Cohort Study.

R_0 is increased when the proportion of adults aged 20-39 years is higher than the Australian average (29%). Indigenous populations in northern Australia also have a higher proportion of children less than 12 years and larger household sizes than the national average (3 x for remote, 1.7 times for urban). This intense household mixing drives the higher R_0 estimated for remote Indigenous communities. Vaccination of 12+ years has less effect on TP when children under 12 make up a larger proportion of the total population and live in larger households. Both factors increase their contribution to transmission despite lower susceptibility and infectiousness than adults. Lowering the age of immunisation to 5+ years is anticipated to substantially reduce TP in this context (right panel).

Note that the figure assumes baseline protective behaviours/PHSMs and TTIQ responses are equally achievable in all settings. The potential for responsive PHSMs to further reduce transmission in outbreak settings is indicated by the green shading in the Figure and would vary with measures employed. The effectiveness of community engaged and led responses to support TTIQ and distancing strategies has been clearly demonstrated in the recent Western NSW outbreaks. Note, however, that Figure 2.1.1 only considers impacts on transmission and not health outcomes, which are further mitigated by vaccine.

Figure 2.1.1: Transmission potential (TP) for Delta variant accounting for demography and household structure for remote living and urban Indigenous populations. 'Baseline' public health and social measures (PHSMs) and partial TTIQ public health responses are assumed. The figures report impacts on TP of 50-80% vaccine coverage* among individuals aged 12+ years (upper) and 5+ years (lower). Further TP reductions may be achievable in remote communities by vaccinating 5-11 year olds, even with partial TTIQ. Potential additional impacts of PHSMs are indicated by the green shading.



**Coverage at 70-80% includes some additional single doses at the two-dose threshold*

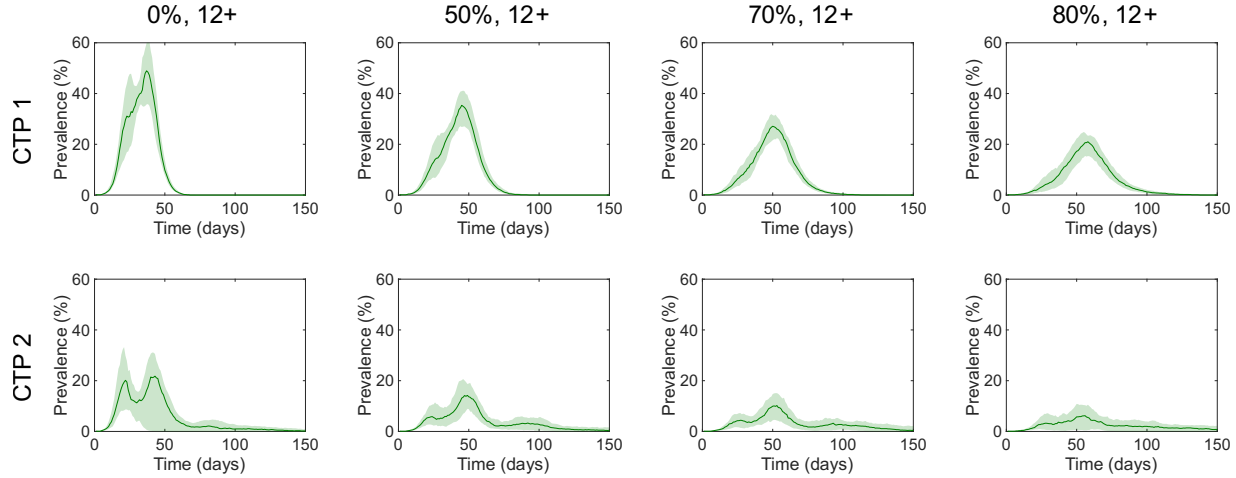
Attachment B reports findings from an agent-based model that captures key features of age structure, household composition and social connections in remote Aboriginal communities of different sizes. The model reports outbreak trajectories following silent introduction of infection in the context of different levels of prior vaccine coverage and given different response measures including reactive vaccination.

Modelled infections are translated into anticipated clinical outcomes using the clinical pathways model employed in our earlier phase work, with updated assumptions. Given the high prevalence of underlying health risk determinants in remote Indigenous communities we assume that the increasing likelihood of severe health outcomes by age commences from the age of 20 years and in each cohort thereafter maps to the non-Indigenous population 10 years older. This starting assumption has been approved by the Aboriginal and Torres Strait Islander Advisory group and benchmarked as reasonable against available data from NSW which demonstrates a higher prevalence of severe outcomes for Indigenous Australians.

Impact of pre-emptive vaccination on outbreak size and clinical outcomes

Figure 2.1.2 quantifies the impact of achieved uniform two-dose vaccine coverage of 50, 70 and 80% for ages 12+ on the magnitude and timing of an outbreak following silent introduction of infection into a remote community of size 1,000. Following identification of the first case, families are required to stay at home for 14 days, during which time all individuals are tested twice to enable case finding and household contact identification. All scenarios assume that cases, once identified, are isolated out of community. Upper and lower panels in the Figure compare currently recommended outbreak response strategies for management of contacts, quarantined either on (CTP1) or away from (CTP2) community. The lower panels show that the CTP2 strategy is demonstrably more effective at reducing outbreak size at all coverage levels.

Figure 2.1.2: Daily infection prevalence* in a remote Indigenous community of size 1,000 over time following initiation of an outbreak. Outputs compare different pre-emptive vaccine coverage levels and outbreak response management approaches. Results assume a starting TP of 10.7, and 90% compliance with stay at home orders implemented during the first 14 days following initial case detection.



**Solid lines: median prevalence, shaded regions: interquartile range of 100 simulations.*

Clinical outcomes of these observed infections will vary, depending on age and vaccination status of the individuals infected. Table 2.1.1 reports modelled health outcomes based on the clinical pathways model, noting the earlier assumption of a ten-year downward age shift in severity compared with the non-Indigenous population, based on the high prevalence of underlying clinical risk determinants in remotely living Indigenous Australians. Findings shown are for the less optimistic CTP1 strategy, reflecting feedback that quarantining of contacts away from community is noted to be challenging in many settings, but where it can be achieved, as in the Wilcannia outbreak, health outcomes are improved (the CTP2 strategy).

Table 2.1.1: Average cumulative symptomatic infections, ward admissions and ICU admissions over the course of outbreaks for achieved two dose vaccine threshold targets of 50, 70, and 80% for ages 12+. Results presented assume 90% level of compliance with lockdown and response policy CTP1, as in the top panel of Figure 2.1.2 above.

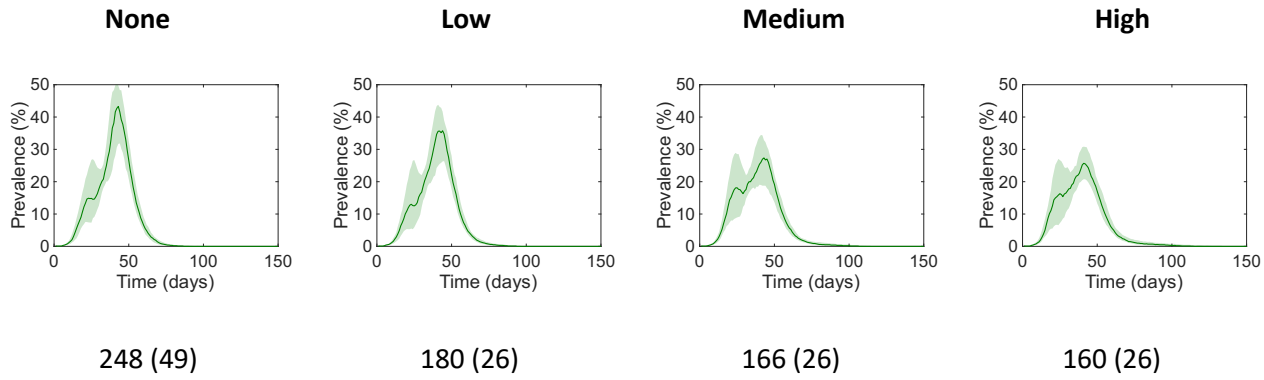
	Achieved coverage scenario	<15 yrs		15-39 yrs		40-59 yrs		60+ yrs	
		Vacc'd	Unvac	Vacc'd	Unvac	Vacc'd	Unvac	Vacc'd	Unvac
Symptomatic infections	50%	0	64	7	56	6	45	5	20
	70%	1	56	8	32	7	26	6	11
	80%	0	49	8	19	7	16	6	7
Ward admissions	50%	0	1	0	4	1	15	4	17
	70%	0	1	0	2	1	8	4	10
	80%	0	1	0	1	1	5	4	6
ICU admissions	50%	0	0	0	1	0	6	1	8
	70%	0	0	0	1	0	3	1	4
	80%	0	0	0	0	0	2	1	3

Impact of reactive vaccination in conjunction with other outbreak response measures

We further assessed the impact on transmission and clinical outcomes of a targeted immunisation program initiated as part of outbreak response. Outbreaks were simulated in communities of differing sizes and baseline coverage, based on case studies identified by the Aboriginal and Torres Strait Islander Advisory Group. The full set of outputs are included in Attachment B.

Findings for a community of size ~1,000 with low initial vaccine coverage are shown below and demonstrate the greatest benefits observed in the simulations. We consider how vaccines rolled out at different rates might augment the public health response in such a community. Rates of achievable delivery are based on advice from the Northern Territory, assuming different numbers of teams deployed for implementation. High acceptance is assumed among individuals not infected in the outbreak, with refusal of only 7%. This figure is concordant with recent experience from the Wilcannia outbreak.

Figure 2.1.3 Impact of reactive immunisation approaches as an adjunct to 'CTP1' response measures in a remote community of size 1,018. Baseline 2 dose immunisation coverage is ~50% for >50 years, ~25% for 40-49 years and <10% for eligible individuals <40 years. The reactive program is delivered at a low (30 doses/day for 13 days), medium (75 doses/day for 5 days) or high (120 doses/day for 3 days) rate. Clinical outcomes are reported below each panel as cumulative symptomatic infections over the course of the outbreak, with hospitalisations in parentheses.



In this scenario, reactive vaccination at any rate approximately halves severe outcomes, noting that vaccine protection against disease commences 2 weeks after a first dose, and increases further 5 days after a second dose.

Effects on transmission following the first dose begin a week later, rise over the subsequent fortnight and continue to increase after the second dose. In this example, lockdown measures are only maintained for 14 days. Differences in community size, baseline coverage and acceptance may increase the time taken to immunize communities effectively. In such cases it may be desirable to extend stay at home measures beyond the 14 days duration to slow down spread and maximise benefits of immunisation.

Beyond the National Cabinet reporting, we are continuing to work with the Advisory Group to develop extended narrative case studies of combined vaccine and other public health measures that may be feasible and implementable in remote settings with different starting vaccination coverage by age to maximise outbreak response impacts. Providing access to effective treatments will further promote health outcomes, particularly given limitations of clinical services in regional and remote Australia.

2. *Local Government and small area effects*

As shown for First Nations communities, demographic and social differences are anticipated to result in varying baseline transmission rates of COVID-19 across the Australian population more broadly. Drivers include larger mean household size (leading to more household contacts), larger working-age populations (leading to more workplace contacts) and social determinants such as housing quality and crowding. These factors tend to be geographically clustered and are often reported at the LGA-level. Such variation also influences likely vaccine impacts at subpopulation level as LGAs with a higher proportion of children will be more likely to observe ongoing transmission in those aged less than 12 years, who are currently ineligible for vaccination. In addition, inability to work from home reduces the impact of public health stay at home orders, and often correlates with higher baseline and post-vaccination transmission potential. Focussed TTIQ responses and augmented school and workplace measures will be needed in such areas, not lockdowns.

Figure 2.2.1 shows how population characteristics influence baseline transmission potential and vaccine impacts. Compared with the 'all Australian' population, small area TP and vaccine impacts will be heterogeneous, as demonstrated by five exemplar LGAs each for greater Melbourne and Sydney. Kingston (left panel) and Sutherland Shire (right panel) are most 'typical' of the national average. Affluent areas comprised of small households and a high proportion of working age adults (Port Phillip, Stonnington, North Sydney, Mosman) have an average baseline TP but larger than average vaccine change impacts. Areas like Greater Dandenong and Fairfield have a higher than average proportion of working age adults, which accounts for a higher starting TP but also marked reductions achieved following vaccination. Murrindindi and Oberon both have lower baseline transmission potential and vaccine impacts arising from higher proportions of children and older adults than the national average, respectively.

Experience has also shown that the ability of lockdowns to modify mixing and so reduce transmission are inequitable across geographical areas. While a number of behavioural changes result in PHSM impacts, the ability to work from home can be anticipated with reasonable certainty based on occupation and have been validated on the basis of survey data. In some LGAs, there is a high proportion of people whose work cannot be done remotely and are considered 'essential', who will continue to have workplace contacts even under the most restrictive of PHSMs. Varying ability to work from home is reflected in the differences between the green components of Figure 2.2.1. Port Phillip, Stonnington, North Sydney and Mosman have large population proportions in professional occupations that are amenable to stay at home working. Greater Dandenong and Oberon each have higher than the national average proportion of machinery operators and labourers, who cannot work from home. Murrindindi and Fairfield have a larger than average proportion of children who are not in employment, lessening the impact of work from home requirements on overall levels of mixing in these areas under public health orders.

Even within LGAs, the ability to work from home may be heterogeneous, resulting in subpopulation 'pockets' in which heightened transmission can occur. Such effects were notable in Western and South-West Sydney during the 2021 outbreak response. Figure 2.2.2 reports variation at SA2 level in the ability to work from home within different LGAs in NSW and VIC.

Figure 2.2.3 maps geographical variation in these described measures of baseline transmission potential, vaccine change impacts and overlaid work from home measures for Melbourne and Sydney. These figures show how the distribution of relative risk of transmission may change following vaccination due to variable vaccine change impacts. Anticipation of such shifts should guide enhanced surveillance and response efforts through the transition phase.

Full outputs for this work package are included in Attachment C. The main conclusion of this work is that stay at home orders will not necessarily mitigate importation and outbreak risks in many LGAs that would be anticipated to have higher than average ongoing risks of transmission, even with high 12+ vaccine coverage. Focussed TTIQ responses, wrap around supports and school and workplace measures are more likely to effectively reduce transmission and disease impacts in these settings.

Figure 2.2.1: Baseline transmission potential (TP) for the Delta variant accounting for demography and household structure across exemplar Melbourne and Sydney LGAs with differing population characteristics. The figure reports the impact on TP of 50-80% vaccine coverage for the 12+ years population. It further shows variables reductions in transmission achievable through work from home requirements under stay at home orders, based on predominant occupations within each LGA.

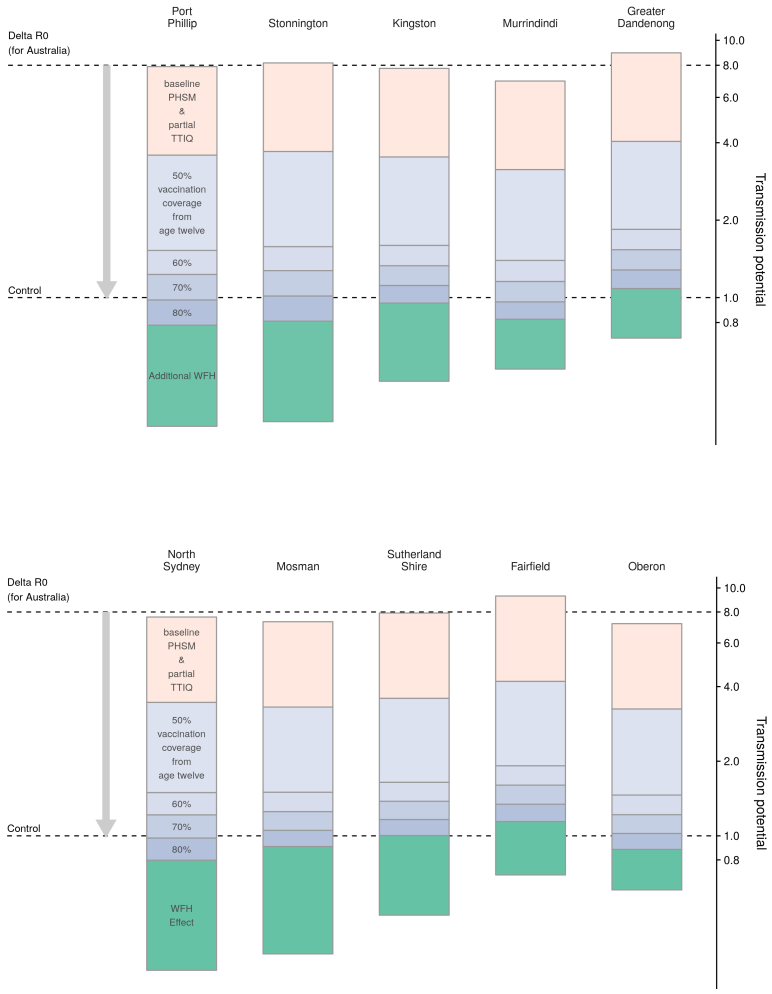


Figure 2.2.2 Proportion (with 95% Confidence Intervals) of residents with the ability to work from home based on ABS occupations data, calculated for each SA2 within listed LGAs

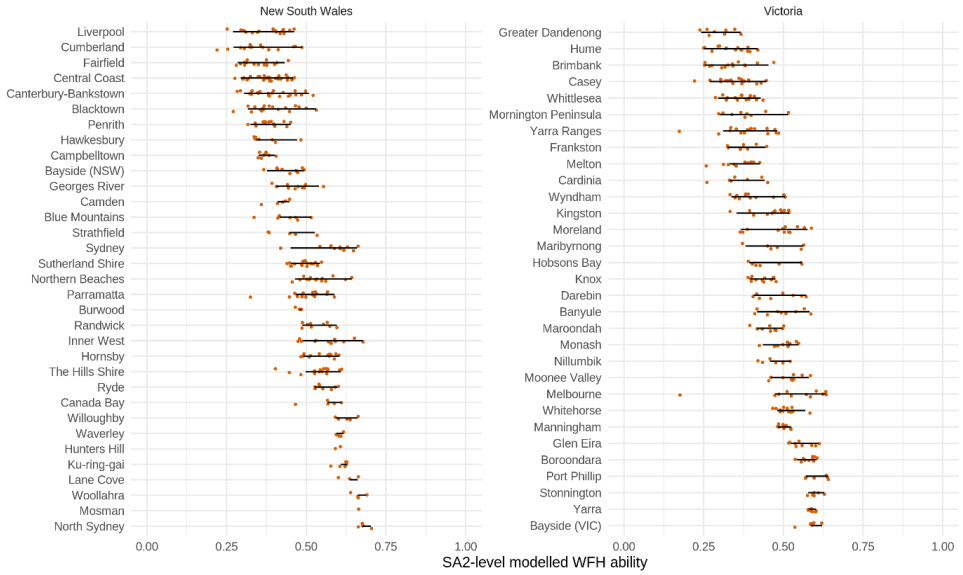
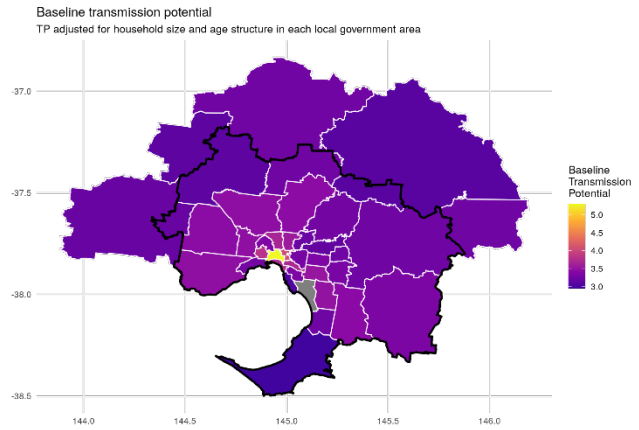
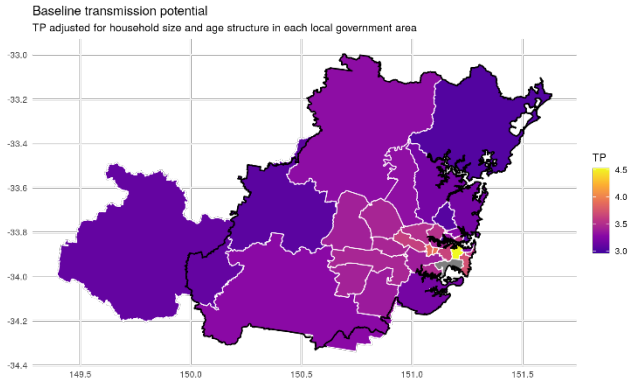
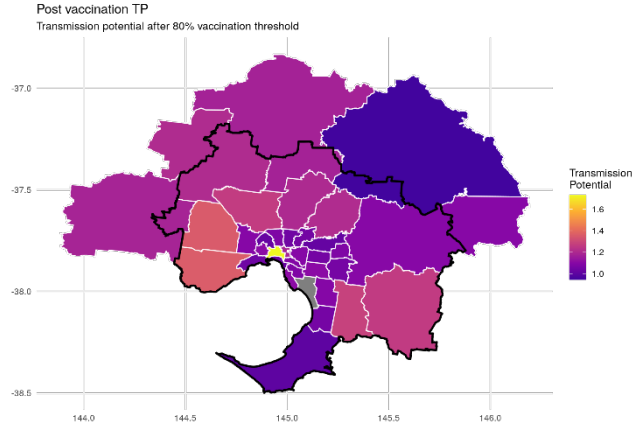
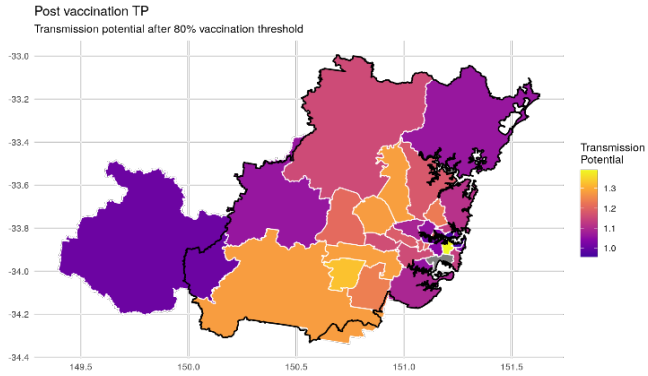


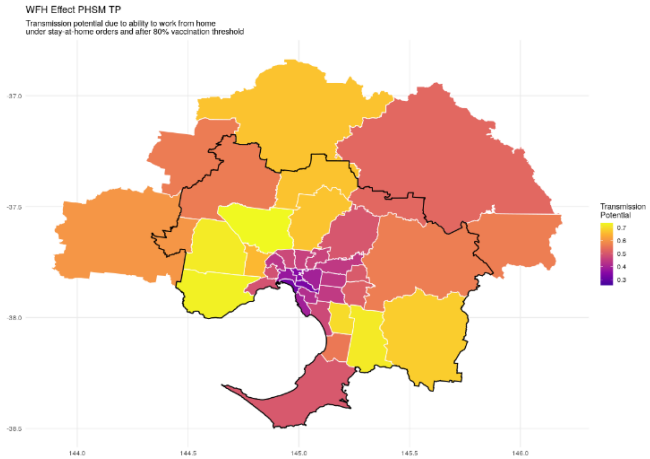
Figure 2.2.3 Mapped estimates of baseline TP, absolute reduction post vaccination, and absolute reduction following vaccination and overlaid work from home orders, by LGA, for Melbourne and Sydney

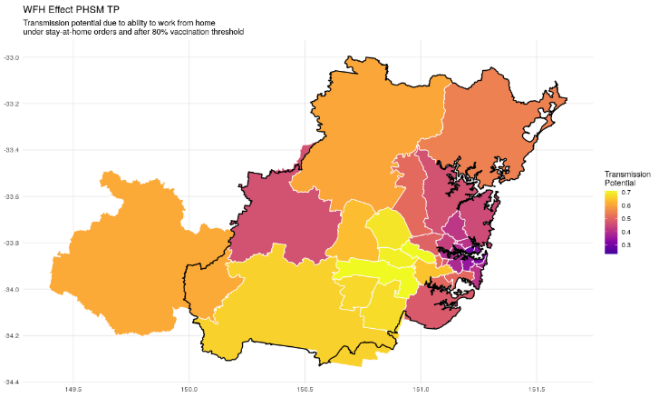












3. *Schools*

As community transmission becomes established, incursions into school settings will be inevitable. Returning students to in-person learning and keeping schools open safely during this phase has been identified as a national priority. Early detection of infections through surveillance testing substantially reduces the risk that incursions will lead to outbreaks and if feasible, may be an appropriate strategy in areas with high levels of ongoing transmission. Daily rapid antigen testing of contacts, with exclusion only if positive, is as effective for outbreak prevention as 14-day contact quarantine and dramatically reduces days of missed face to face learning.

We have used a model of primary and secondary schools within the context of a community to consider the likely consequences of incursions, for different screening and testing strategies, vaccination coverage and contact management approaches. As Figure 2.3.1 demonstrates, in the absence of screening or any form of contact tracing or management, between 37-47% of incursions will 'die out' given the heterogeneous nature of COVID transmission. But between one third to one half of introductions will result in 20 or more infections and sometimes as many as 50. These figures show the case for both high schools, where we assume that 80% of students and staff are vaccinated and primary schools where children are too young to be immunized. Our sensitivity analysis confirms that higher student vaccine coverage in high schools substantially reduces the risk of large outbreaks. Teacher vaccination has less influence on transmission within the school, even at 100% uptake, but would be anticipated to materially impact on importation risk.

Figure 2.3.1 further explores the ability of different routine surveillance strategies to minimize spread and days of face to face learning lost in schools. If symptomatic students are diagnosed and sent home early, on average only tens of teaching days will be lost per incursion over the reporting period. Screening teachers twice weekly regardless of symptoms with rapid antigen (RAT) testing makes little difference to school-based outbreaks, as there are relatively few teachers in the school. Twice weekly testing of students markedly increases the chances of nipping an outbreak in the bud. There is a small increase in average school days lost because we are looking harder for infections and so detect asymptomatic individuals, but far fewer large outbreaks. These findings are for a single infection introduction – as shown in Attachment D, the relative utility of this approach increases with the number of incursions over time.

Figure 2.3.1 Impact of twice weekly rapid antigen testing (RAT) surveillance of teachers and students on size of outbreaks following incursion and days of face to face learning lost. No contact tracing is assumed. All outputs are the results of 1,000 simulations.

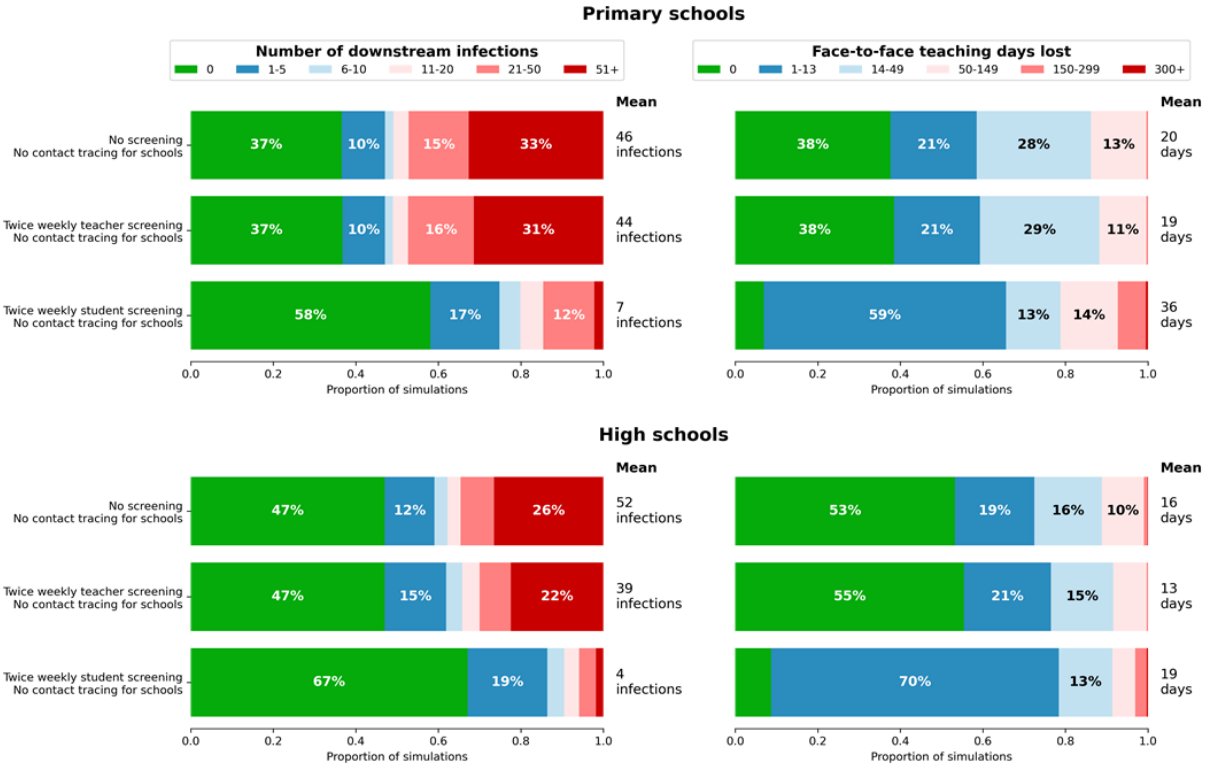
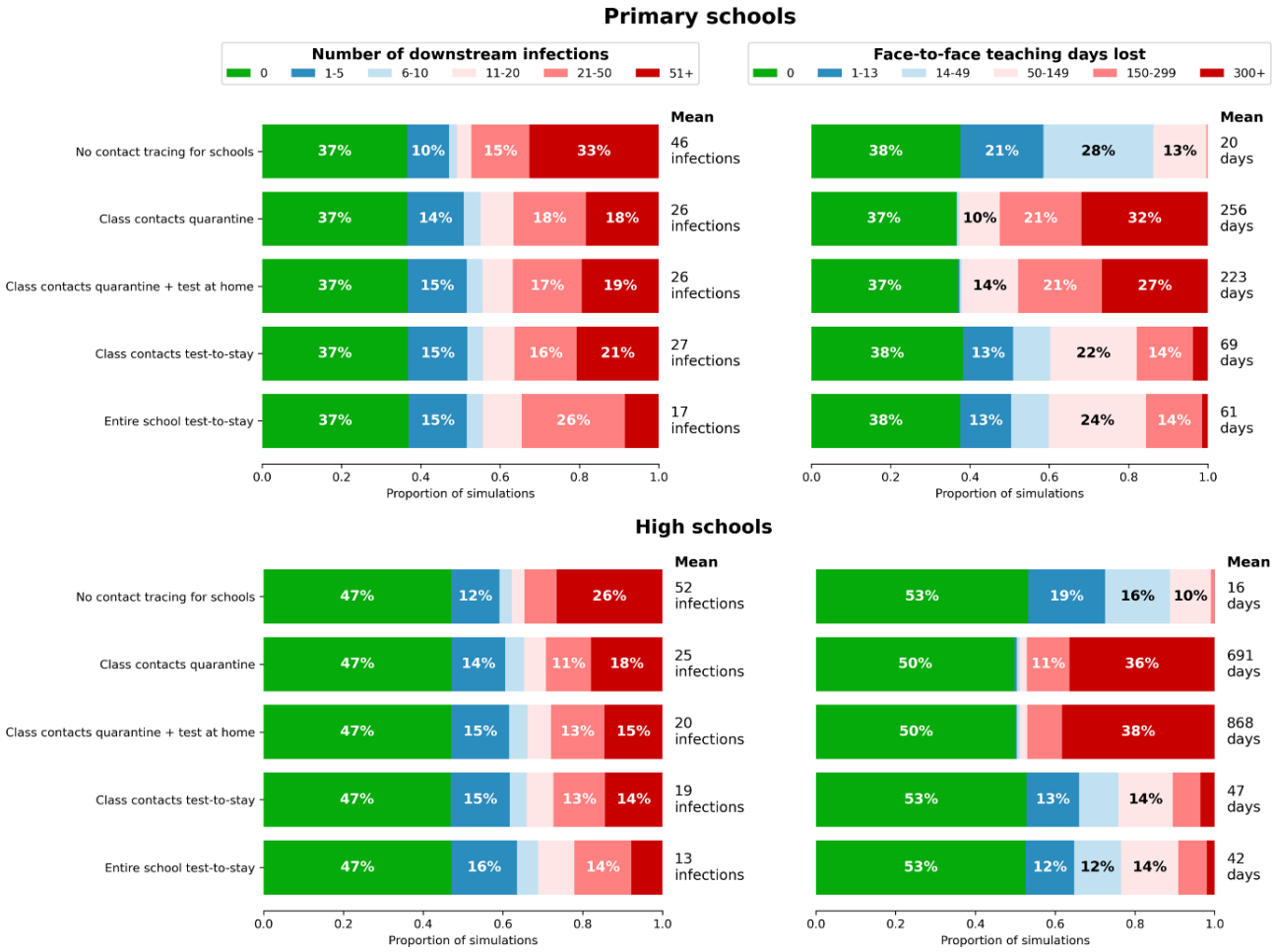


Figure 2.3.2 compares different contact management approaches in the *absence* of surveillance testing. Any form of contact management reduces the chance that outbreaks will grow to 50 or more – whether class contacts are sent home for 7 days or require daily RAT testing 'to stay'. But the number of days of school lost by the quarantine approach is dramatically different. The quarantine option including daily testing at home is to ensure that the likelihood of identifying an infection is equivalent to the 'test to stay' approach. The findings shown are for 70% RAT sensitivity, and 100% compliance. A sensitivity analysis finds that benefits of the test to stay approach are still seen, even if compliance is as low as 50%, because repeated testing increases the likelihood of detection.

Figure 2.3.2 Impact of alternative contact management approaches on size of outbreaks following incursion and days of face to face learning lost. No surveillance is assumed. All outputs are the results of 1,000 simulations.



These model findings reproduce the outcomes observed in a real world study comparing quarantine and test to stay in England. They strongly endorse test to stay as a policy to maintain face to face education and keep schools open. It should be noted that the reduction in outbreaks achieved by this measure is less than surveillance screening.

Additional analyses have demonstrated synergistic benefits of combining twice weekly surveillance screening with test to stay contact management (Attachment D). The greatest number of face to face teaching days gained through this approach occurs when community incidence is highest, resulting in multiple importations.

Evaluation of the ability to implement school based surveillance and testing strategies is recommended as a priority, to support a safe return to face to face learning. Such approaches will have maximum utility in small areas identified as at risk of higher than average community transmission.

Work Package 3: Review border measures & arrivals pathways in context of revised risk tolerance

Key question: How can arrivals caps and pathways be safely modified in the context of the changing risk environment as population vaccine coverage increases?

As Australia opens its borders to international arrivals, it is inevitable that infection importations will occur. We compare the effectiveness of different quarantine and testing requirements to reduce the risk of vaccinated adults and partially vaccinated family groups seeding infections in the community. Vaccination reduces the risk of infected people being released from quarantine into the community, mitigating against shorter duration of quarantine. We then compare scenarios for different numbers of arrivals, quarantine pathways and vaccine coverage for endemic and 'COVID-zero' scenarios, based on pre-COVID-19 traveller volumes. Vaccine uptake in the local population is the dominant determinant of the consequences of importation on local infection numbers in the arrival jurisdiction. Breach importations do not materially impact on established epidemics or lead to large outbreaks at the defined Phase C coverage threshold of 80%, combined with 'low' PHSMs.

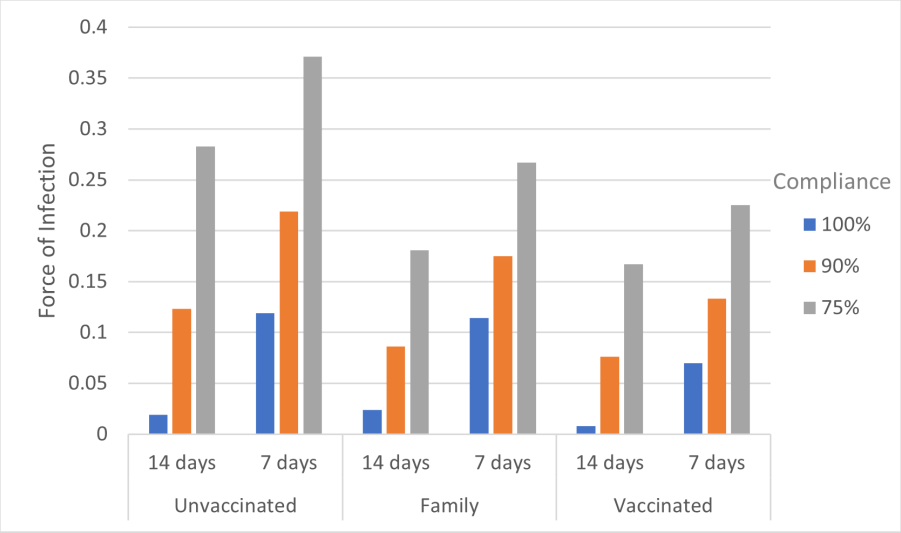
Effectiveness of alternative quarantine pathways

We have modelled a range of home quarantine pathways to compare the exposure days anticipated from an infected arrival passing through that system. Our updated calculations include assessment of the risks posed by family groups composed of adults and children, understanding that children less than 12 years are currently ineligible for vaccination. Vaccination reduces infectiousness and hence the risk posed by quarantine breach events from immunized travelers. In this way it mitigates against the observed increase in community exposure days resulting from shorter duration stays. A full table comparing the force of infection resulting from an infected arrival transiting through various pathways is provided in Attachment E.

Exposure days resulting from infected people being released into the community occur either because the initially infected traveler goes undetected, or they transmit infection to another traveler who goes undetected. We derive a measure called the 'force of infection' that relates those exposure days to their infectiousness, which peaks in the early stages of infection. This measure equates to the expected number of secondary infections produced by one infected arrival in a fully susceptible (ie unvaccinated) population.

Figure 3.1 compares three types of traveler groups– unvaccinated adults, family groups (comprising 2 vaccinated adults and 2 unvaccinated children <12 years) and fully vaccinated adults. Key differences for family groups are: children are not protected by vaccination but if they do contribute a quarantine breach are assumed intrinsically less infectious in the community than adults. If a child is identified as infected in quarantine, they will be isolated with a parent and not alone, so there is an ongoing risk of infection transmission within the isolation facility/medi-hotel that would not apply to adult travelers.

Figure 3.1: Force of infection per infected arrival in home quarantine, for unvaccinated arrivals, family units containing vaccinated parents and unvaccinated children, and unvaccinated arrivals. Results are shown by duration of stay (14 or 7 days) and compliance with quarantine (100%, 90% or 75%)



Different drivers of community exposures are assessed as before. Longer quarantine stays reduce incursion risk. Lower compliance with quarantine requirements is more influential at increasing risk than shortening the length of stay. And vaccination reduces risks across the board. Families contribute an overall risk that is intermediate between fully vaccinated and unvaccinated arrivals.

The estimated force of infection (FOI) for the quarantine pathways in Figure 3.1 has been benchmarked against the previous policy requirement of 14 days hotel quarantine for unvaccinated arrivals (FOI=0.042). Perfect compliance with 14 days home quarantine for a vaccinated adult is associated with an 80% lower FOI than that baseline (FOI=0.008). The scenarios below consider 7 days home quarantine with 90% compliance for vaccinated adults and family groups, for which the relevant FOIs are 3 and 4 fold higher than the previous policy but remain well below one (0.133 and 0.175, respectively). *Note that these values are for a traveler who enters the system infected. Vaccination and pre departure testing reduces the risk that a traveler who is exposed in their country of origin arrives in Australia infected.*

Definition of arrivals scenarios for endemic and 'COVID-zero' settings

We have devised arrivals scenarios in consultation with PM&C, Home Affairs and Treasury that allow us to calculate the aggregate weekly force of infection for different numbers of vaccinated adult and family group arrivals into endemic and 'COVID-zero' jurisdictions 'filtered' through alternative quarantine pathways. We have compared risks associated with 14 or 7 day stays in hotel or home quarantine (the latter assuming 90% compliance), 'no quarantine' (with PCR testing on days 1 and 5) and the previous 14 day hotel quarantine requirement for unvaccinated travelers.

All pathways other than 'no quarantine' are associated with a lower aggregate force of infection than 14 day hotel quarantine for unvaccinated arrivals. This reduction is because of the actions of vaccination prior to departure (preventing infection), as well as within and following release from quarantine (reducing infectiousness). It should be noted that incursion risks are mitigated by testing on days 1 and 5 and are higher if no tests are performed (see Attachment E for full details of all pathways).

The total number of arrivals is calculated as a proportion of 2019 traveler volumes into a large and medium jurisdiction for Australian citizens and permanent residents. We use numbers of travelers up to the age of 12 years from these data to allocate 'family groups' incorporating a corresponding proportion of adults in units of size four (two vaccinated parents, two unvaccinated children). Doubling the number of arrivals from 40% to 80% doubles the force of infection per unit time, *noting that this measure estimates the number of secondary infections anticipated in an unvaccinated population.*

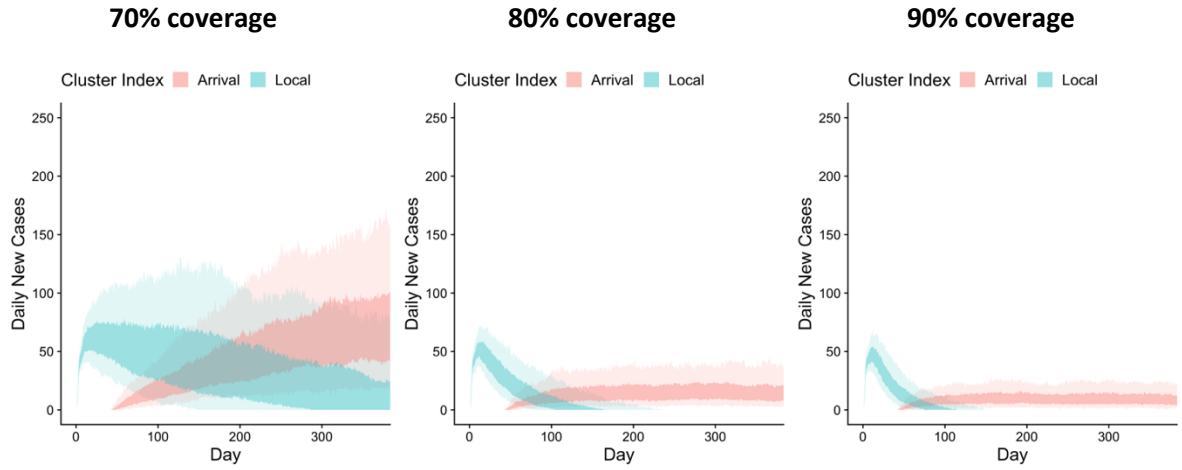
Consequences of importations for local epidemiology

<u>Scenario 1 – Endemic cases</u>

Epidemiological consequences of the arrivals scenarios above are demonstrated in Figures 3.2.1 and 3.2.2. The 'vaccine coverage' in these simulations is fixed at the beginning of the simulations, with no ongoing vaccine rollout assumed. We seed 200 'local' infections on day 0 to establish a local epidemic, with travellers beginning to arrive on simulation day 40. At 70% vaccine coverage, ongoing transmission of local strains occurs and is gradually superseded by new infections resulting from imported strains. For 80 and 90% coverage, locally transmitted strains become extinct at around 100 days.

Ongoing importation of strains is a continuous source of newly seeded infections, but transmission is sufficiently constrained by vaccination that large outbreaks do not occur.

Figure 3.2.1: Impact of incursions on endemic cases given differing vaccine coverage in the arrivals environment. Partial TTIQ and ongoing 'low' PHSMs are additional constraints on transmission. Travellers (vaccinated adults and families) are managed through a 7 day home quarantine pathway, with 90% compliance and PCR testing on days 1 and 5. Traveler volumes are 40% of 2019 citizen/Permanent Residents values from a large jurisdiction*.



Shaded areas denote uncertainty across multiple simulations. Teal shading reflects new cases resulting from local strains present at the beginning of the simulation. Salmon/pink shading denotes cases resulting from transmission chains seeded by importations.

**Estimates of traveller volumes used in the model for 40% are 32,767 per week based on 2019 arrivals into NSW*

Figure 3.2.2: As for Figure 3.2.1, but comparing 40% (left) and 80% (right) of 2019 arrivals, 80% coverage

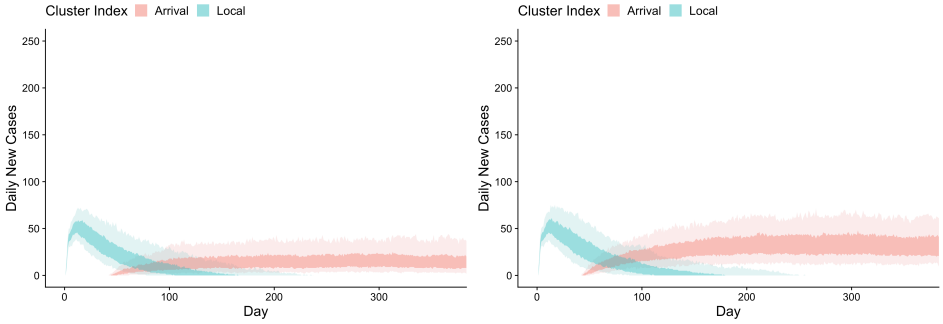
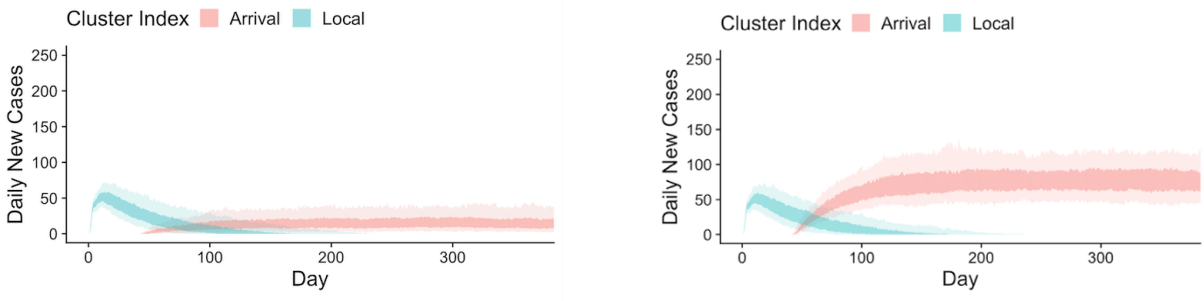


Figure 3.2.2 demonstrates that doubling the number of arrivals results in an approximate two-fold increase in daily incident infections resulting from importations. Further increases in traveller volumes would lead to similar linear impacts on importations, assuming the same mix of arrivals by vaccination status (an increase in the proportion of vaccinated adults compared with families would lead to a slight proportionate reduction in the scaling of this overall risk). The corresponding set point for the 'no quarantine' pathway is approximately three to four-fold higher (Figure 3.2.3) than for 7-day home quarantine.

Figure 3.2.3: As for Figure 3.2.1, but comparing 7 days home quarantine (90% compliance) (left) with the 'no quarantine' pathway with PCR testing on days 1 and 5 (right) and 80% coverage



These differences are explained by the total force of infection calculated for numbers of arrivals, traveller types including vaccine status and the quarantine pathways through which they are processed. Essentially, the level of infection in the arrivals destination relates directly and linearly to this value. However, in terms

of consequences, as in Figure 3.2.1 high vaccine coverage, partial TTIQ and low PHSMs strongly constrain transmission, preventing rapid outbreak growth. Note that these outputs assume homogenous vaccine coverage and transmission potential.

The importance of controls in place in the arrivals environment is demonstrated by an additional scenario for endemic cases considering the impact of partial TTIQ with only *baseline PHSMs* in place, for all the same arrivals considerations as above (Figures 3.3.1, 3.3.2 and 3.3.3). Note the marked difference in axes between these two sets of figures. **At 80% coverage, thousands of incident cases are expected daily with only baseline PHSMs in place, compared with fewer than 100 when ongoing low PHSMs are maintained.**

Such rapidly escalating infections are driven by 'local' cases which far exceed the rate of importation. Incursions do not materially impact on the established local epidemic. This scenario is demonstrative only, as an outbreak of the size shown for the 70 and 80% coverage examples would require imposition of additional measures to reduce disease burden and impacts on the health system and society.

Figure 3.3.1: As for Figure 3.2.1 but assuming Partial TTIQ and 'baseline' PHSMs in place

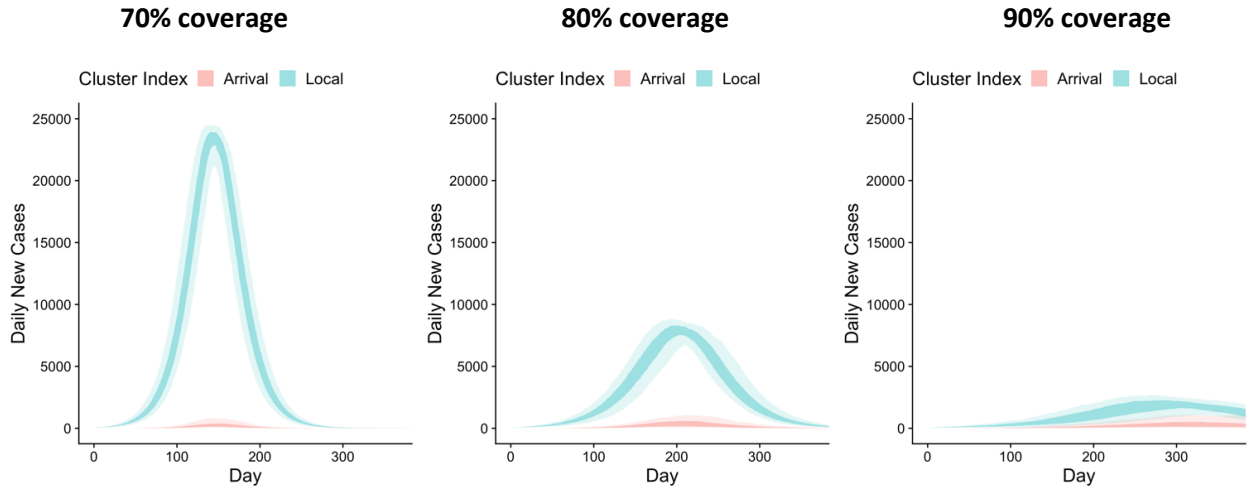


Figure 3.3.2: As for Figure 3.3.1 but comparing 40% (left) and 80% (right) of 2019 arrivals, 80% coverage

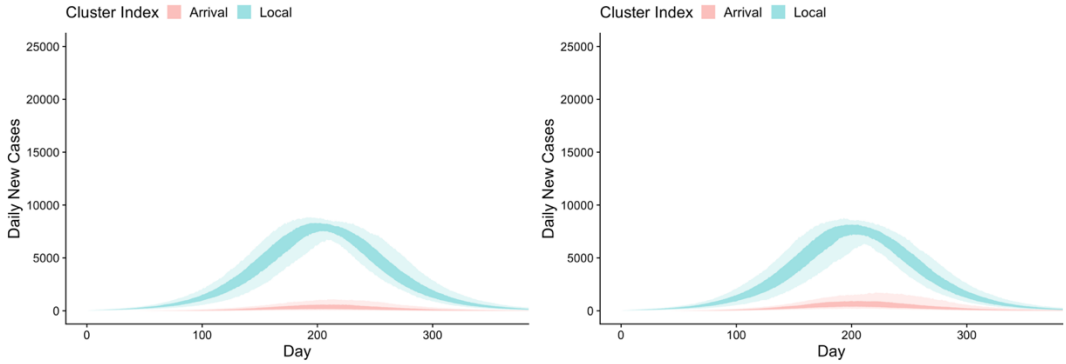
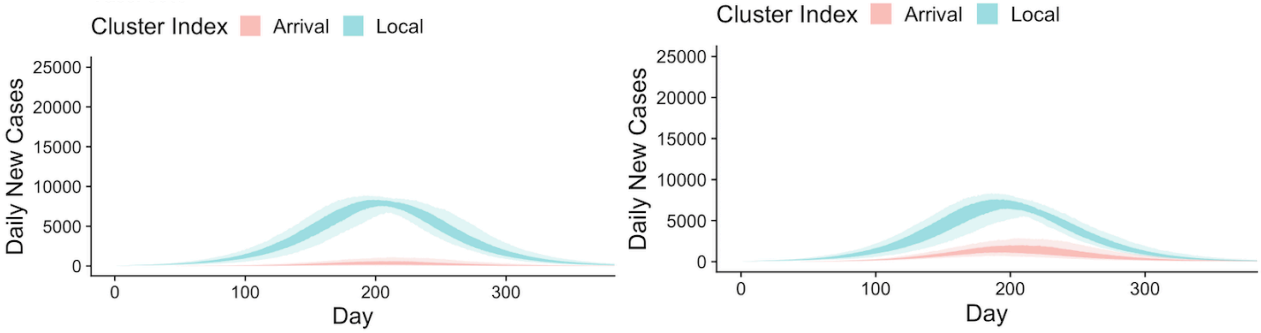


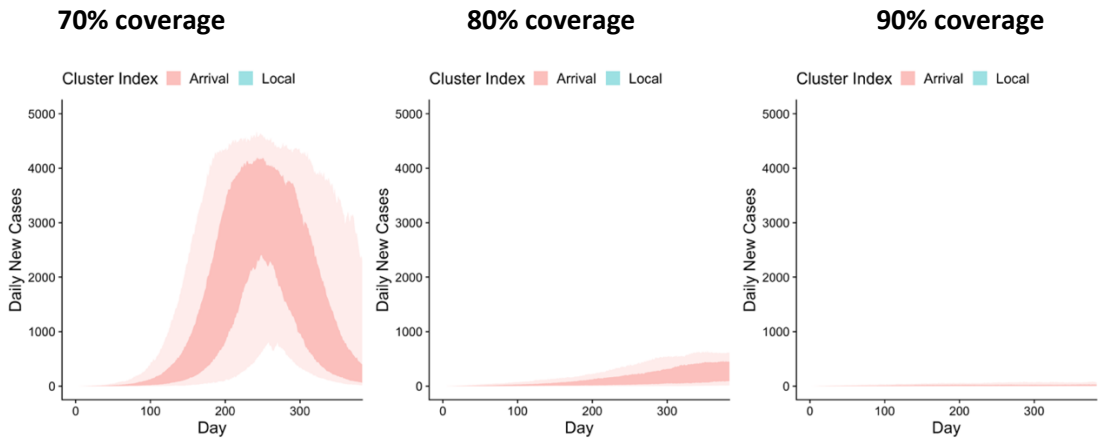
Figure 3.3.3: As for Figure 3.3.1, but comparing 7 days home quarantine (90% compliance) (left) with the 'no quarantine' pathway with PCR testing on days 1 and 5 (right) and 80% coverage



Scenario 2 – 'COVID-zero'

The simulations in Figure 3.3.1 and 3.3.2 share most of the same assumptions as previously but with *optimal TTIQ and baseline PHSMs* in place in a 'COVID-zero' jurisdiction. This difference accounts for the enhanced epidemic growth most apparent in the 70% coverage case, noting that the y axes in these figures are in the 1,000s compared with Scenario 1 (maximum 125). The seeded epidemics grow slowly initially because the transmission potential is just above one but escalate within a few months at 70% coverage. At 80% or higher coverage epidemic growth is slower as further constrained. Because all infections are seeded by 'arrival' strains only one colour is shown on the plots, but in reality it is implausible that only internationally seeded infections would circulate over the one year time frame of the simulations.

Figure 3.4.1: As for Figure 3.2.1 but for 'COVID-zero', and assuming optimal TTIQ and 'baseline' PHSMs. Traveler volumes are 40% of 2019 citizen/Permanent Residents values from a 'medium' jurisdiction*.



**Estimates of traveller volumes used in the model for 40% are 10,363 per week based on 2019 arrivals into WA*

Figure 3.4.2: As for Figure 3.4.1, but comparing 40% (left) and 80% (right) of 2019 arrivals, 80% coverage

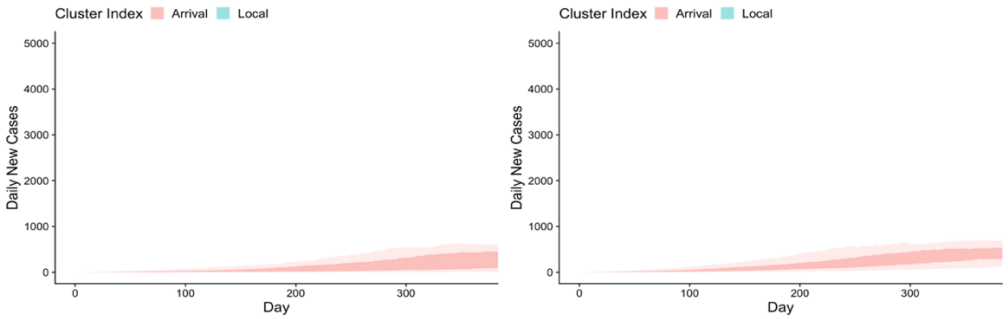
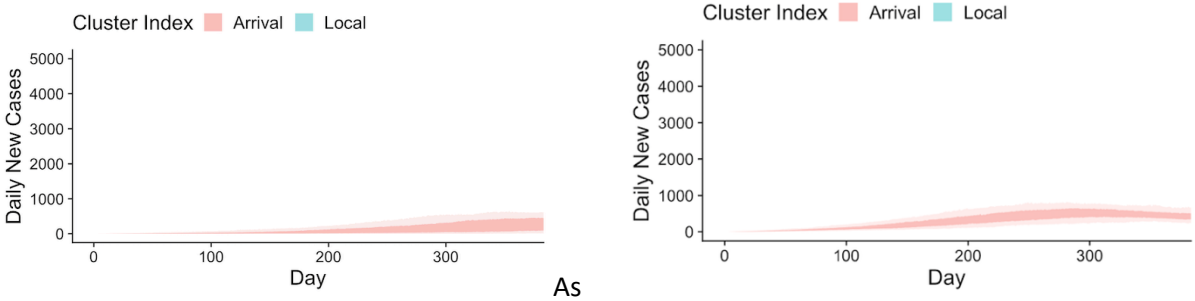


Figure 3.4.3: As for Figure 3.4.1, but comparing 7 days home quarantine (90% compliance) (left) with the 'no quarantine' pathway with PCR testing on days 1 and 5 (right) and 80% coverage



As previously, the set point of daily case numbers scales approximately linearly with the calculated FOI resulting from total arrivals. Other arrivals pathway scenarios are shown in full in Attachment E.

Note that all of these simulations assume consistent vaccine protection over time (ie immunity does not wane) and that the characteristics of imported strains are identical to those initially present in the population (ie they are not more transmissible and are equally preventable by vaccination).

Influential revisions to parameter assumptions

Between the previous and current phases of our modelling work we have extensively reviewed available evidence regarding age-dependent mixing and susceptibility to the Delta variant, vaccine uptake, and vaccine effectiveness assumptions against acquisition, infectiousness and disease outcomes. While values of individual parameters vary between phases of our work, we have assessed the consequences of these changes in aggregate and confirm that our previous recommendations of vaccine coverage thresholds for national plan transition phases remain robust.

Social mixing assumptions

In the first phase of our National Plan modelling, we developed an age-structured transmission matrix characterising infection spread within and between age groups based on population mixing assumptions using widely accepted social contact matrices and age-specific susceptibility and transmissibility estimates published by the London School of Hygiene and Tropical Medicine.

For this phase of work we have updated our mixing assumptions to align more closely with reported observations in the Australian context. We have re-estimated transmission parameters to fit infection age distributions from the UK post-reopening and with full school attendance, which have demonstrated few infections in primary schools in the absence of non-pharmaceutical interventions and vaccination. Our reanalysis finds a reduction in the proportional contribution of children aged 5-11 years to transmission, and some increase for those aged 16-24 years with the following consequences:

(i) A more optimistic expectation of overall vaccine impact on transmission potential (TP) in populations with a high proportion of children than previously anticipated (countered in some populations by large household size);
(ii) A boost in TP reduction associated with vaccination of the 16-24 years group.

Vaccine coverage assumptions

Our initial coverage scenarios considered optimal age-based vaccine distribution strategies to minimise transmission and disease. The Quantium team in Health advise that the actual rollout in the Australian population has most closely approximated the 'all ages' strategy, which resulted in high uptake in the peak transmitting age groups identified above, maximising population wide benefits of the program. Extension of vaccine eligibility to the 12+ years group has further increased whole of population coverage and can be considered as a 'bonus' to the target thresholds.

In addition, the pace of rollout has exceeded expectations, particularly in states with community transmission, enabling threshold targets of 70 and 80% to be reached in a timely manner. Of note, it is anticipated that 'final' vaccine coverage in the order of 90% will be achieved within weeks of the 80% target, which is much faster than in the original simulations provided by Quantium. Should these expectations be realised, we anticipate greater constraint of transmission in the initial weeks following the transition to Phase C than was estimated by our model, in which it took months to achieve this final coverage.

Vaccine effectiveness assumptions

We have updated our assumptions of vaccine effectiveness (VE) against infection and onwards transmission, based on new evidence from the UK specific to the Delta variant. On balance, these changes have resulted in some reduction in overall effectiveness of two doses of the Astra Zeneca vaccine (from 86% to 79%), but none for Pfizer (remains 93%) which has been the predominant vaccine delivered through the Australian program.

Since completion of the first phase of the National Plan modelling, further evidence has emerged regarding vaccine effectiveness (VE) against clinical outcomes for the Delta variant. On balance, these changes have resulted in some reduction in overall effectiveness against symptomatic infection of two doses of the Astra Zeneca vaccine (from 90% to 79%), but minimal change for Pfizer (from 92% to 90%) which has been the predominant vaccine delivered through the Australian program.

Clinical severity assumptions

In our National Plan modelling we reviewed all available evidence on clinical severity of SARS-CoV-2 infections. The bulk of this evidence related to the Wuhan strain, given that it circulated globally over an extended period. From this evidence we derived age-based estimates of the likelihood of hospitalisation and severe disease outcomes following detection of symptomatic infection.

Based on our review of available evidence about Alpha variant infections at that time, we applied an odds ratio (OR) of 1.42 to hospitalisation outcomes across all age groups. At that time, there was uncertainty in the literature about the relative clinical severity of the Delta variant compared with the Alpha variant. Published reports variously described it as milder, about the same, or more severe. On balance we assumed the same severity as for the Alpha strain.

Following completion of that phase of National Plan modelling it has become clear from published studies that the Delta variant is more likely to be associated with severe clinical outcomes than Alpha. The most informative study in the peer reviewed literature reports the odds ratio for hospitalisation given symptoms as 2.08 compared with the Wuhan strain. Given the same 'benchmark' (Wuhan) strain for both viruses, an OR of 2.08 for Delta represents an increase but not a doubling in severity compared to Alpha, for which the assumed OR was 1.42.

An OR is not the same as a percentage increase or decrease. If hospitalisation is rare as is the case for children, then it is approximately true that the OR of 2.08 means hospitalisation is twice as likely. Compared with Alpha, Delta may therefore result in an increase in admissions in this age group by as much as 40-50%. However, for older adults, in whom hospitalisation is a common outcome, the additional increased chance for hospitalisation due to the virus per se will be relatively lower, meaning that absolute numbers of hospitalisations may increase by as little as 10-15%.

More details regarding these parameter choices and tables summarising final assignments are contained in Attachment F.