COVID-19 in Colorado: The Fifth Wave

09/15/2021

Prepared by the Colorado COVID-19 Modeling Group

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Key Findings and Implications

This report coincides with a fifth surge of Colorado's epidemic curve that now reaches beyond the peak of hospitalizations in April 2020. Presently, the most critical questions are: for how long will hospital demand continue to rise and what level will it reach? how many excess deaths will the state experience? and what interventions might make a difference in the short run?

How long will hospitalization demand continue to rise and how high? The epidemic curve in Colorado, which we track with the number of Coloradans hospitalized with COVID-19, has been steadily rising since July 2021, driven by the Delta variant, unvaccinated populations, and increased population mixing. The most recent estimated value of the effective reproductive number, 1.1, means that infections and severe disease are still increasing, albeit more slowly than over the month of August. The figure below shows the projected course of COVID-19 hospitalizations if Colorado remains on the most recent, estimated trajectory and vaccinations follow recent trends (light green line): if that trajectory is sustained, hospital demand will continue to rise over the month of September but will remain well below the December 2020 peak. Hospital demand could approach the December 2020 peak, this time in November 2021 if we see a reduction in transmission control and no increase in vaccinations (pink line). Conversely, if transmission control increases (e.g., due to increased mask-wearing or other infection control behaviors), peak demand will be lower and hospital demand will decline in the next few weeks (purple line). An acceleration of vaccine uptake will lower peak hospital demand – with the most pronounced impact if transmission control drops (dark green line). Based on the projections below, we expect hospital demand to remain below the December 2020 peak. The timing and magnitude of the peak depend primarily on transmission control measures in the weeks ahead.
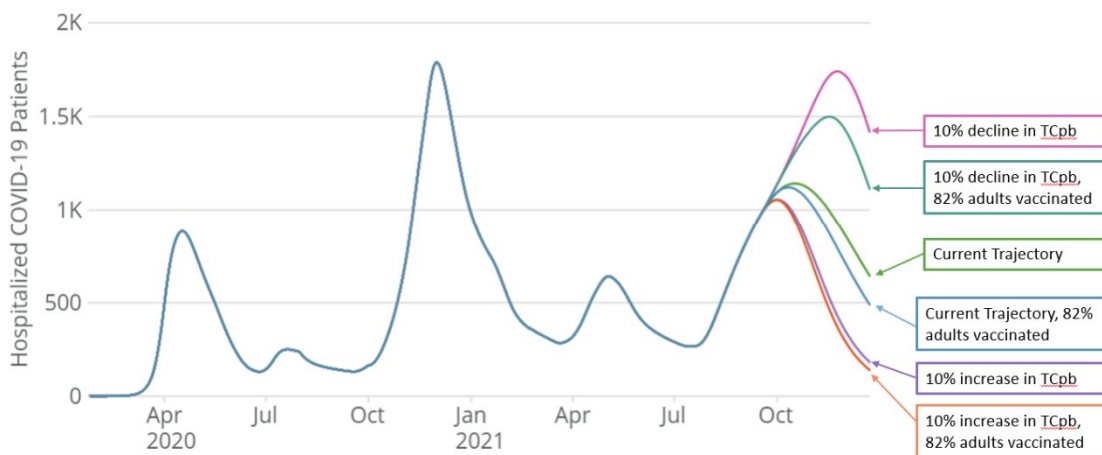

Figure. Projected number of hospitalized patients with COVID-19 per day through January 2022 assuming vaccine uptake follows current trends and no changes in transmission control (light green line), as well as for scenarios including a 10% increase in transmission control, a 10% decrease in transmission control, and increases in vaccine uptake such that 82% of adults are vaccinated with at least one dose by late October.

What is the future burden of hospitalizations and deaths? The table below provides the estimated cumulative numbers of deaths and of hospitalizations between now and December 1, 2021, if the Colorado epidemic remains on the most recent, estimated trajectory or if transmission control were to increase or decrease by 10%. For reference, Colorado has experienced 37,000 hospitalizations and 7,700 deaths due to COVID-19 to date. Given the virulence of the Delta variant, a continued or worsening surge could result in substantial additions to these figures over the next three months. Depending on the scenario, the range of COVID-19 deaths through December 1 extends from about 1,000 to 2,000.

Table. Projected COVID-19 hospital admissions and deaths from September 14, 2021, through December 1, 2021, under a range of transmission control and vaccine uptake scenarios.

	Vaccinations follow recent trends	Increased vaccine uptake (82% of adults vaccinated)
COVID-19 Hospital Admissions		
Transmission control increases 10%	7,946	7,555
No change in transmission control	11,012	10,266
Transmission control decreases 10%	15,512	14,236
Deaths		
Transmission control increases 10%	1,174	1,129
No change in transmission control	1,561	1,477
Transmission control decreases 10%	2,118	1,978

What interventions will slow and reverse the current surge? The Delta variant has had a substantial impact on Colorado. For the short-term, increases in infection control behaviors, such as mask wearing, will help slow the spread of infections, reduce peak hospital demand and prevent deaths. If transmission control increases by 10%, the burden of COVID-19 will be reduced substantially, such that ~3100 hospitalizations and ~390 deaths could be prevented compared to remaining on the current trajectory. In prior reports, we have shown that increasing use of masks both in schools and generally will be of benefit. Coloradans may choose to decrease their contacts with others as a consequence of the surge itself. In the long-term, a surge in vaccinations due to recent mandates and federal actions will be critical and allow further relaxation of transmission control.

The estimated effective reproductive number is 1.1. indicating growth of infections.

Approximately 1 in every 99 people in Colorado are estimated to be infectious.

Approximately 70% of the Colorado population is estimated to be immune to SARS-CoV-2.

Introduction

The purpose of this report is to answer two questions

1. What is the current state of the SARS-CoV-2 pandemic in Colorado?

2. What might future hospital demand for SARS-CoV-2 look like in Colorado under different scenarios of transmission control and vaccination?

To answer these questions, we use COVID-19 hospital census, vaccination, and case data and a mathematical model of the virus tailored to Colorado. We first characterize the current status of the COVID-19 epidemic in Colorado: how rapidly infections are increasing or decreasing, the proportion of the population estimated to be immune, and the proportion of the population estimated to be currently infectious.

We then generate projections of the potential future course of COVID-19 in Colorado. These are not predictions of what will happen but, rather, projections of what may happen in coming months under different scenarios. For example, we consider two vaccine scenarios: 1) vaccinations continue at current levels or 2) an increase in vaccinations such that 82% of Colorado adults are vaccinated by late October. We also consider three scenarios of "transmission control" - the impact of measures such as mask wearing, physical distancing, contact tracing, and moving activities outside on slowing the spread of infections. We generate projections assuming transmission control remains on the current trajectory, increases by 10% or decreases by 10%. The modeled range of transmission control is based on recent trends and the changes of transmission control observed over the pandemic in Colorado. Our primary focus is projecting hospital needs for COVID-19 patients in the months ahead, an indicator that reflects burden on the medical care system. We additionally estimate future COVID-19 mortality, a critical measure of overall impact.

About the model. The model is an age-structured SEIRV (susceptible-exposed-infected-recovered-vaccinated) infectious disease transmission model that has been calibrated to Colorado-specific data whenever possible. For example, the length of time that a COVID-19 patient is assumed to spend in the hospital varies by age and over time and is based on data provided by Colorado hospitals. Model details and a listing of recent model updates are provided in the Appendix at the end of this report. Key changes include the inclusion of new data from the Colorado Department of Health and Environment (CDPHE) on vaccination counts; these data include previously omitted vaccinations, and their inclusion raises the rate of vaccination. The estimation of mortality has been altered to better capture recent patterns in Colorado. The model also now reflects greater virulence for the Delta variant.

Question 1. What is the current state of the SARS-CoV-2 epidemic in Colorado?

Colorado is now in the fifth wave of the pandemic (Figure 1). SARS-CoV-2 infections and COVID-19 hospitalizations are increasing again in Colorado. The growth of infections and of hospitalizations has increased markedly since late July. Colorado experienced a first

peak in hospital demand in April of 2020 and that peak has just been passed (peak demand: 888 hospitalized COVID-19 patients). In December 2020 Colorado experienced the highest COVID-19 hospital demand to date (peak demand:1,847 COVID-19 hospitalized patients). The projections that follow show that the current wave could result in another peak in this range.
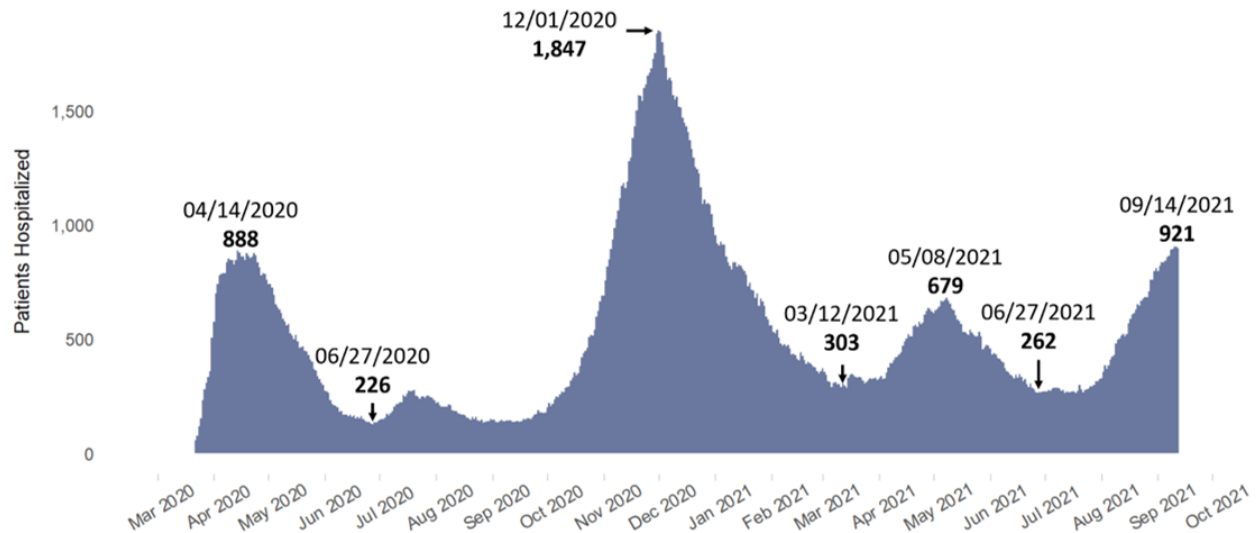

Figure 1. The number of people hospitalized with COVID-19 in Colorado, March 2020 to September 14, 2021.

Infections are increasing rapidly. COVID-19 hospitalizations have increased markedly since late July (Figure 2). Currently, the estimated effective reproductive number is currently 1.1 (Figure 3).

Figure 2 shows the current estimated trajectory of hospitalizations, based on the most recent model-fit compared to the daily reported number of people hospitalized with COVID-19 (Figure 2). For reference, the estimated trajectory one- and seven-weeks prior is also shown. The change in the trajectory is evident with the two most recent trajectories being far steeper than the estimated trajectory from 7/26. The projected increase in hospitalizations is slower this week compared to last week.

Our current estimate of the effective reproductive number (Re) is 1.1 (Figure 3). The effective reproduction number (Re) is a measure of how rapidly infections are spreading. When the effective reproduction number is below 1, the number of infections is decreasing. When the effective reproduction number is above 1, the number of infections is increasing. Due to the lag between infections and hospitalizations, this estimate reflects the spread of infections occurring on approximately 09/13.
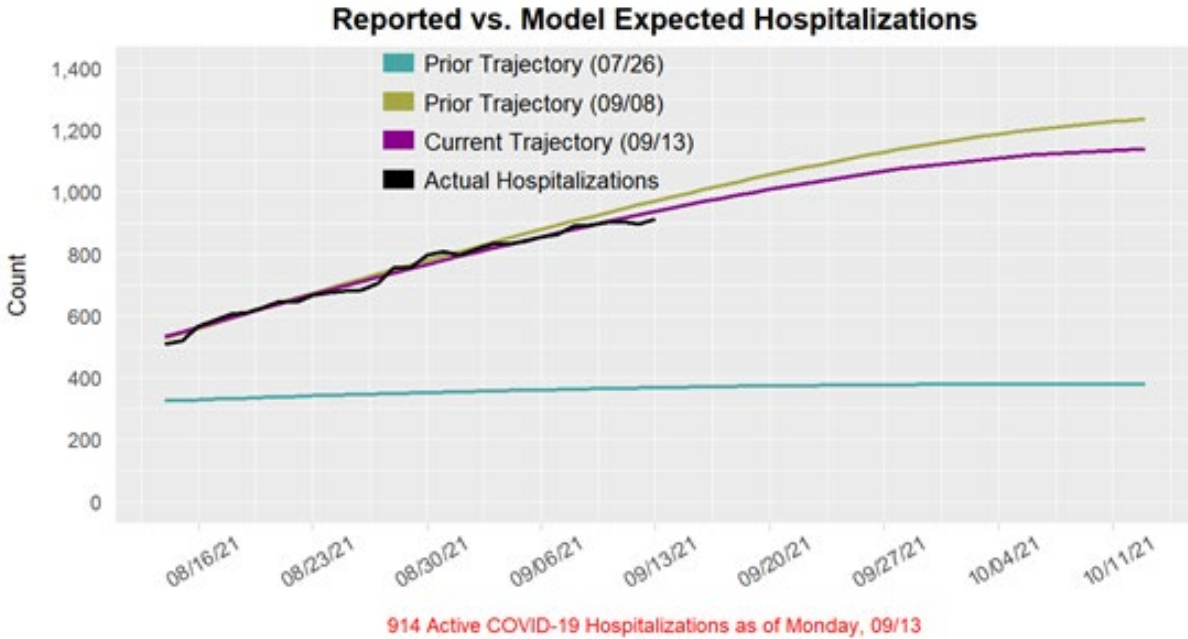
Reported vs. Model Expected Hospitalizations

914 Active COVID-19 Hospitalizations as of Monday, 09/13

Figure 2. The projected course of COVID-19 hospitalizations if Colorado were to remain on the current estimated trajectory (purple line), the trajectory estimated one week prior (gold line) or on the trajectory estimated seven-weeks prior (turquoise line). Actual daily number of people hospitalized with COVID-19 in Colorado is shown in black. Trajectories are generated assuming Colorado continues vaccinations consistent with current trends.

Effective Reproduction Number Over Time
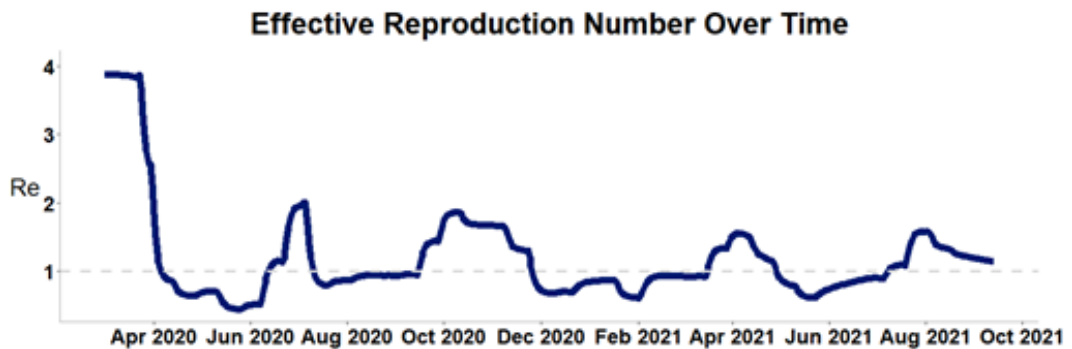
Figure 3. Estimates of the effective reproduction number over time based on data through 09/13/2021.

Infection prevalence is increasing (Figure 4). We estimate that approximately 1,005 of every 100,000 Coloradans or 1 in every 99 people are infectious in Colorado as of 09/13. We estimate SARS-CoV-2 infection prevalence is the highest it has been in 2021.

At higher levels of infection prevalence, susceptible individuals are more likely to encounter infectious individuals among their contacts. Because many people experience no

symptoms or mild symptoms of COVID-19, many infections are not identified by surveillance systems. The estimates we present here are intended to provide an approximation of all infections, including those not detected by the Colorado Electronic Disease Reporting System (CEDRS). These estimates are generated using the model by assuming the most recent transmission control parameter (estimated for the period 08/21 to 08/31) remains at the estimated value through 09/13. These estimates are sensitive to the model assumptions, including assumptions about the probability an infected individual will be symptomatic and require hospital care, which vary by age, and assumptions about the virulence of variants.
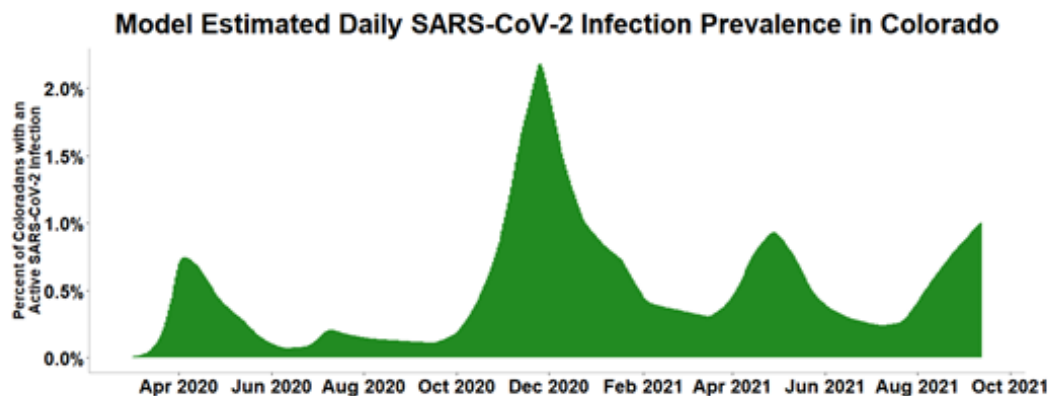

Figure 4. Estimated daily number of people who are infectious and infected with SARS-CoV-2 (point prevalence). Estimate is shown per 100,000 population. The number of infectious individuals is inferred using the model and based on hospitalizations.

The current growth of infections is fueled by the Delta variant and changes in population mixing (Figure 5). Using our model and recent hospital trends, we estimate the level of transmission control due to policies and behaviors (TC_{pb}) is 68%. This estimate is for the period 08/21 to 08/31, given the lag between infection and hospitalization. Because of this lag, this estimate of TC_{pb} does not account for recent changes in population mixing or in infection control measures (e.g., mask-wearing). Over the past 12 weeks, estimates of TC_{pb} have ranged from 61% to 79%.

When we account for variants in addition to policies and behaviors, our estimate of overall transmission control (TC) drops to 29%. Thus, the Delta variant is responsible for a 39 percentage point drop in transmission, the difference between the overall level of transmission control and that from policy and behavior. The Delta variant now accounts for nearly all of the SARS-CoV-2 infections in Colorado.
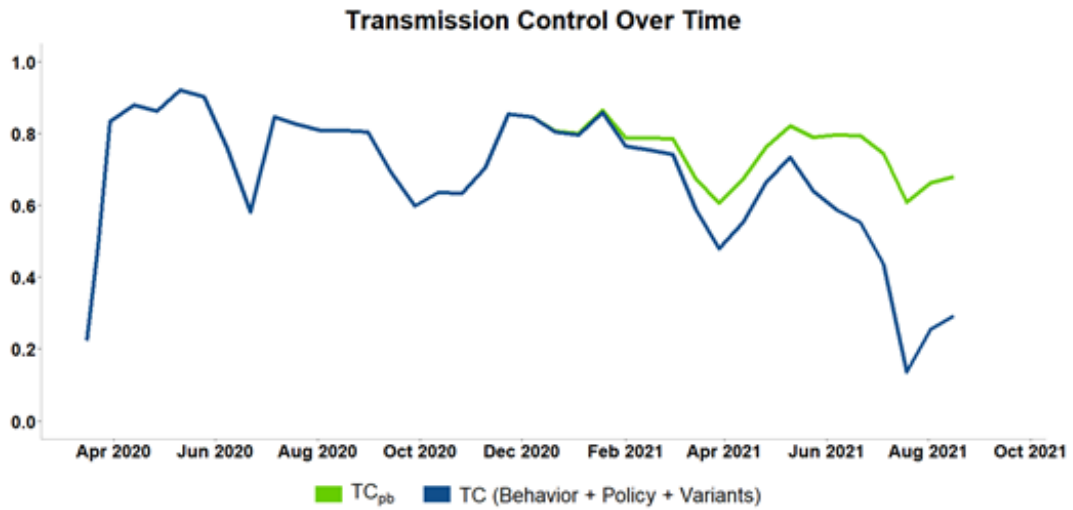
Figure 5. The estimated transmission control value for each two-week period since the beginning of the epidemic due to behavior and policy only (TCpb, green line) and the estimated transmission control accounting for behavior, policy, and variants (TC, blue line). On the graph, the value is shown for the mid-point of each two-week period. Transmission control is estimated using model fitting approaches to align model output with COVID-19 hospitalizations.

Population immunity is increasing. We estimate that approximately 4,055,000 people in Colorado, or 70% of the Colorado population, are currently immune to SARS-CoV-2 as of 09/13 (Figure 6). Immunity is highest in those 65+ and lowest in children (Figure 7).

People can develop immunity to SARS-CoV-2 by vaccination or by prior infection. The proportion of the population immune is an important measure because as more people develop immunity, the spread of infections slows. As the proportion immune increases, infectious individuals are less likely to encounter people who are still susceptible to infection (not immune). We estimate the proportion of the population immune using our age-structured SEIRV model and data on vaccinations in Colorado provided by CDPHE. We assume that not everyone who was previously infected or vaccinated is immune, and that immunity wanes over time based on recent scientific evidence (Details are provided in the model documentation).
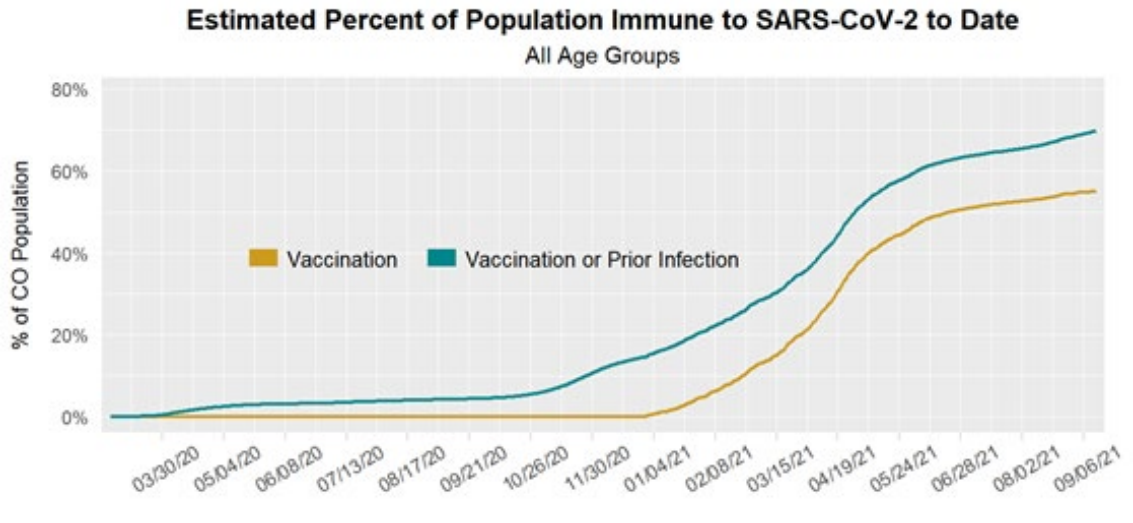
Estimated Percent of Population Immune to SARS-CoV-2 to Date
All Age Groups

Figure 6. Estimated percent of the population in Colorado assumed to be immune to SARS-CoV-2 due to infection and/or vaccination through 09/13.

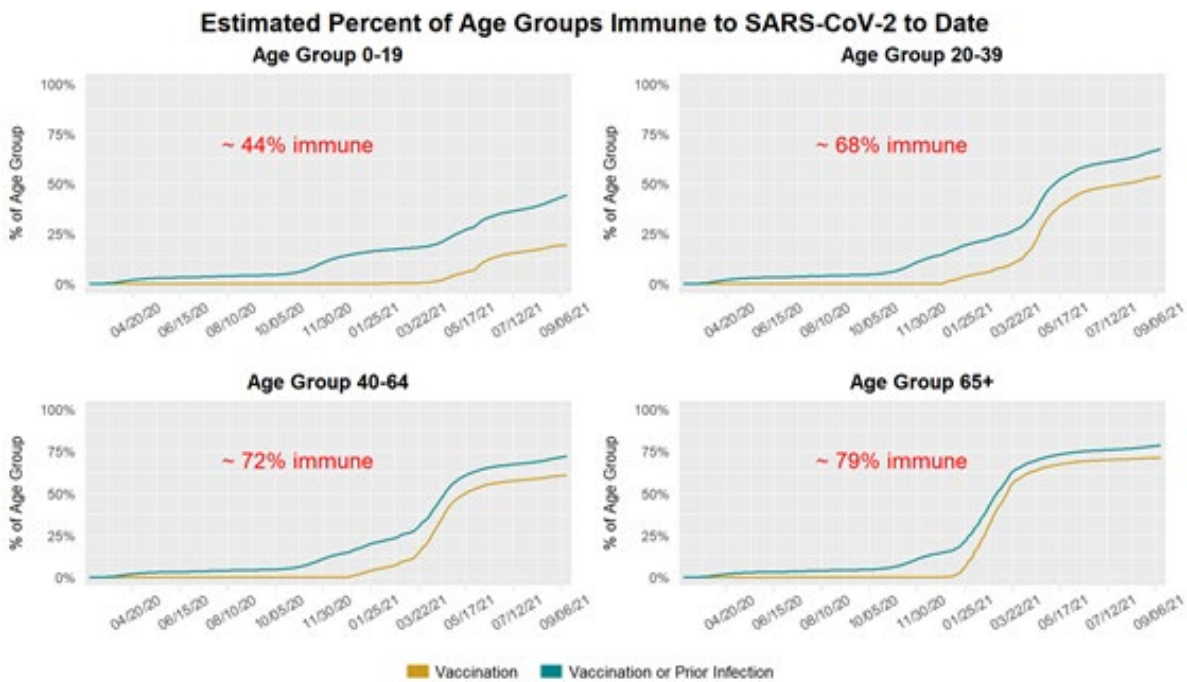**Estimated Percent of Age Groups Immune to SARS-CoV-2 to Date**

Figure 7. Estimated percent of each age group in Colorado assumed to be immune to SARS-CoV-2 due to infection and/or vaccination through 09/13/21.

The status of the pandemic varies across Colorado. SARS-CoV-2 infections are estimated to be increasing in four regions based on COVID-19 hospital data through 9/05/2021. The estimated prevalence of infections is particularly high in the East Central LPHA region. The Southeast and East Central LPHA regions have the lowest percentage of

the population that is fully vaccinated (Southeast: 34%; East Central: 36%). Further details can be found at: https://www.colorado-data.org/regional-epidemic-models.

Question 2. What might future hospital demand for SARS-CoV-2 look like in Colorado?

We generated projections of future COVID-19 hospital demand and mortality in Colorado using our age-structured SEIRV model. These are not predictions of what will happen but, rather, projections of what may happen in coming months under different scenarios. We considered two key factors that may change in the weeks ahead: vaccinations and transmission control.

Transmission control. Throughout the pandemic, there has been uncertainty about future levels of transmission control as it reflects a complex and still incompletely understood combination of behavior, policy, and, perhaps, weather. Recent mobility data suggest people are moving at near pre-pandemic levels, although there is room for further growth in interactions. In addition, our estimate of transmission control is inherently lagged, such that it reflects infections occurring approximately two weeks ago. To capture both potential increases in population mixing (e.g., due to school or business openings) and increases in the adoption of infection control measures (e.g., increased masking) we consider three scenarios: 1) transmission control holds at 68%, 2) transmission control falls by 10%, and 3) transmission control increases by 10%. In scenarios 2 and 3, the change is assumed to occur gradually over the next eight weeks. We have chosen to model 10% changes in transmission control as we have observed 10% changes in transmission control during past surges during the pandemic.

Vaccinations. We consider two vaccine uptake scenarios. First, we assume that vaccinations follow current trends such that 77% of adults and 63% of 12-17 year olds are vaccinated by late October with at least a first dose. We note that vaccinations increased this summer in all age groups but have since declined (Figure 8). This scenario assumes vaccine uptake continues to decline in the weeks ahead. We label this the current vaccination trajectory assumption.

We also considered an accelerated vaccine uptake scenario whereby 82% of adults are vaccinated by late October with at least a first dose (in this scenario, vaccinations in 12-17 are unchanged, reaching 63% by late October).
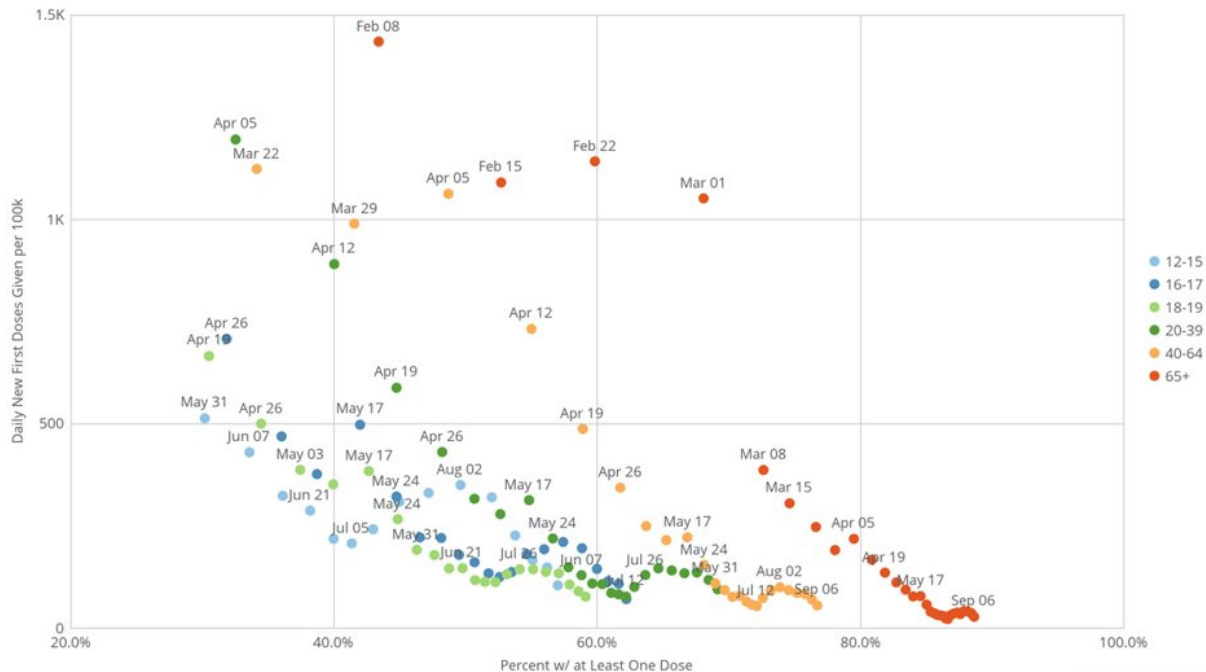
Figure 8. New vaccinations vs. percent vaccinated by age group, 2/01/2021 - 9/06/2021. Each point shows the average daily number of first dose vaccinations administered each week by age group

In these projections, we assume the Delta variant continues to account for over 90% of SARS-Cov-2 infections in Colorado through the fall.

Key Takeaways from the Projections. Under all scenarios modeled, including staying on the current trajectory, hospitalizations and deaths are projected to increase over the month of September. If transmission control drops by 10%, the number of hospitalized patients could approach to the December 2020 peak in late November 2021 (Figure 9), however, projected deaths are far below the December 2020 peak (Figure 10). Under this scenario, there could be ~16,000 COVID-19 hospital admissions and ~2,100 COVID-19 deaths between now and December 1, 2021 (Table 1). Under that scenario, hospital demand continues to increase through late November.

If transmission control improves by 10%, the peak will be lower and hospital demand is project to begin to decline in the next few weeks, leading to fewer COVID-19 hospital admissions (~8,000 by December 1, 2021) and fewer deaths (~1,200).

If transmission control does not change, hospital demand is projected to increase through mid-October. Hospital demand could reach 1,100 COVID-19 patients statewide.

Increased vaccine uptake will prevent COVID-19 hospitalizations and deaths, with the greatest impacts seen in scenarios where transmission control declines. In these scenarios, the impact of increasing vaccine uptake to 82% of adults by late October is relatively modest. This is largely due to time it takes to build immunity to the virus following vaccination, the short time horizon of our projections (<3 months), and the relatively small

increase in vaccinations between the current trends vs. the high uptake scenario. In the long-term, the gains of increased vaccination will be greater than show here.
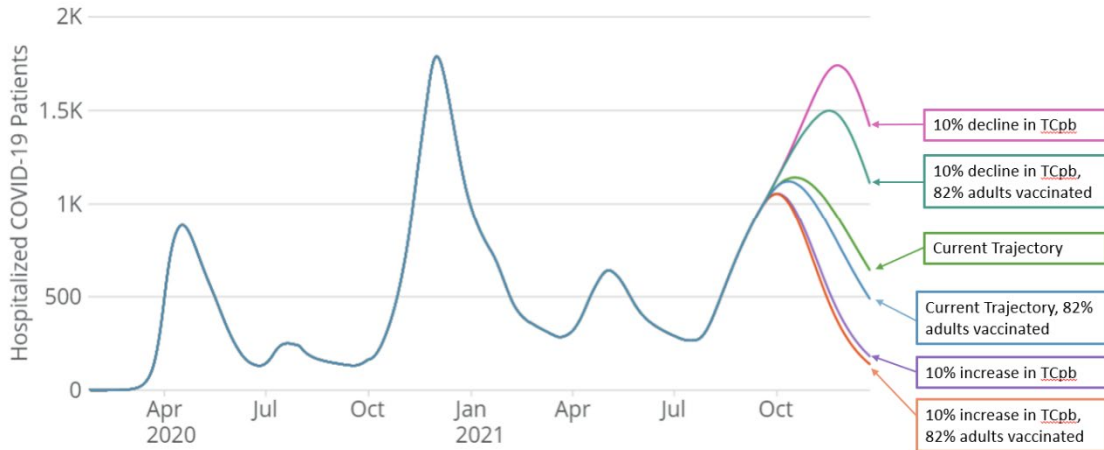

Figure 9. Projected number of hospitalized patients with COVID-19 per day through January 2022 assuming vaccine uptake follows current trends and no changes in transmission control (light green line), as well as for five additional scenarios including a 10% increase in transmission control, a 10% decrease in transmission control, and increases in vaccine uptake such that 82% of adults are vaccinated with at least one dose by late October.
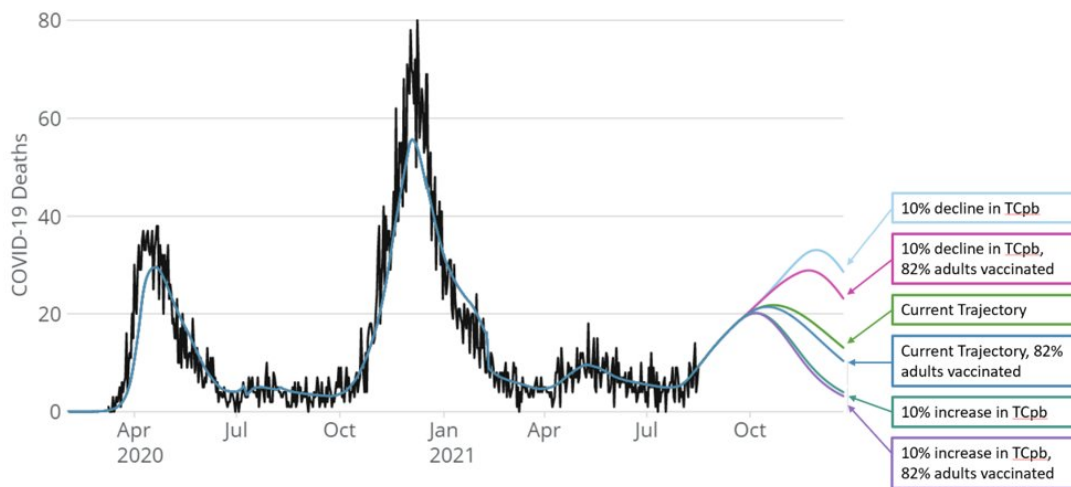

Figure 10. Projected number of COVID-19 deaths per day through January 2022 assuming vaccine uptake follows current trends and no changes in transmission control (light green line), as well as for five additional scenarios including a 10% increase in transmission control, a 10% decrease in transmission control, and increases in vaccine uptake such that 82% of adults are vaccinated with at least one dose by late October. Actual deaths among COVID-19 cases are shown in black.

Table 1. Projected COVID-19 hospital admissions and deaths from September 14, 2021, through December 1, 2021, under a range of transmission control and vaccine uptake scenarios.

		Vaccinations follow recent trends	Increased vaccine uptake (82% of adults vaccinated)
COVID-19 Hospital Admissions			
Transmission control increases 10%		7,946	7,555
No change in transmission control		11,012	10,266
Transmission control decreases 10%		15,512	14,236
Deaths			
Transmission control increases 10%		1,174	1,129
No change in transmission control		1,561	1,477
Transmission control decreases 10%		2,118	1,978

Caveats. We caution that our model projections have limitations that lead to uncertainty. First, there is considerable uncertainty regarding the future course of the epidemic under each of our scenarios. To provide some understanding of the uncertainty in model estimates, we have carried out analyses that describe the inherent variability of the projections due to chance. In the figure below (Figure 11), each color represents a projection scenario (-10% TC in red; current trajectory in grey; +10% TC in blue; all assuming vaccines follow current trends). Each line represents a projection that accounts for transmission control parameter uncertainty: the different values are drawn from a normal distribution defined by estimated mean and variance from historical data. This approach underscores the uncertainty in the exact height and timing of the peak for each scenario. However, it is also clear that, even accounting for this uncertainty, there are clear differences in future demand if transmission control increases vs. decreases by 10%. Note that these projections do not capture uncertainty in how transmission control may vary over time.
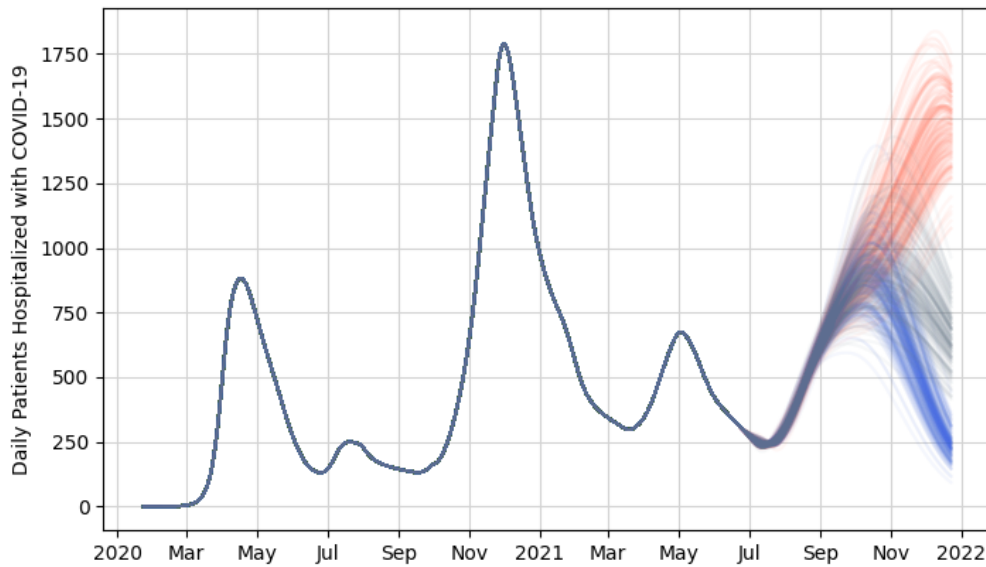
Figure 11. Range of projected COVID-19 hospital demand if transmission control decreases by 10% (red lines), remains on the current trajectory (grey lines) and increases by 10% (blue lines). Each line represents a projection that accounts for transmission control parameter uncertainty.

Second, COVID-19 deaths were higher than expected based on our model during the April 2020 and December 2020 peaks (Figure 12). This is consistent with recent literature suggesting hospital mortality increases as hospitals admit high numbers of COVID-19 patients, even below capacity limits. If Colorado does approach patient loads similar to December 2020 (e.g., >1500 patients), a similar increase in mortality could occur that is not captured in our projections.
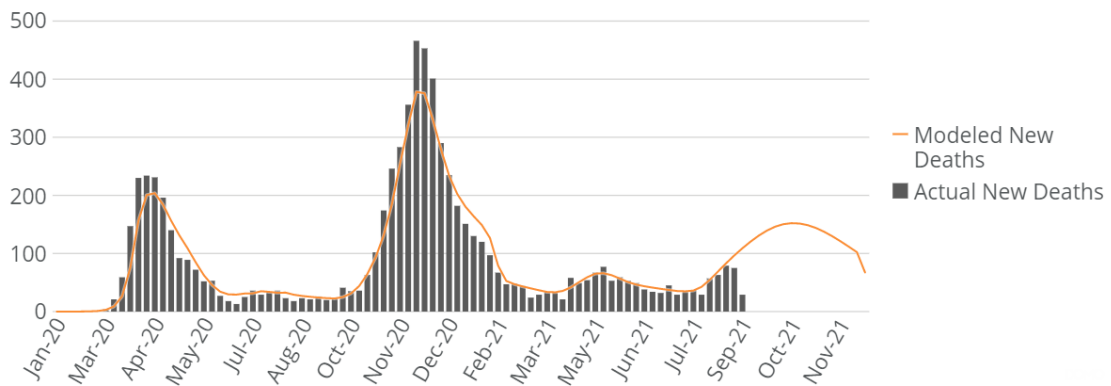

Figure 12. Actual (black line) vs. model-estimated (orange line) COVID-19 deaths per week from March 2020.

Appendix

Model Updates.

- The statewide model now incorporates vaccination data for which the county of residence is unknown.

- We updated several hospitalization and mortality parameters to align our model outputs to actual COVID-19 mortality and hospitalizations in Colorado to date. Specifically for ages 65+, we increased hospital mortality prior to February 2021, decreased non-hospital mortality, and decreased the hospitalization rate for those with symptomatic infections. For younger age groups, we decreased hospital mortality and increased non-hospital mortality.

- Based on growing evidence that the Delta variant is more virulent than Alpha variant, we now assume that symptomatic infection with the Delta variant is 1.7 times more likely to lead to hospitalization than the Alpha variant. This is based on two large peer-reviewed studies from the United Kingdom (Sheik et al, Twohig et al) and a pre-preprint from Canada that found increased rates of hospitalization among reported SARS-CoV-2 cases with Delta vs. Alpha variant, as well as evidence from Colorado and elsewhere that the Delta variant leads to more severe disease. We note that the science is evolving rapidly and there remains uncertainty in the magnitude of the effect (mean estimates from the aforementioned studies range from 1.5 to 2.3). Because we fit our model to hospitalizations, this update leads to lower estimates of infection prevalence and infection-acquired immunity.

Model fit. We assess model fit by comparing the model-estimated number of hospitalizations to actual hospitalizations. Figure A1 showing model-estimated and actual hospitalizations since the beginning of the pandemic.
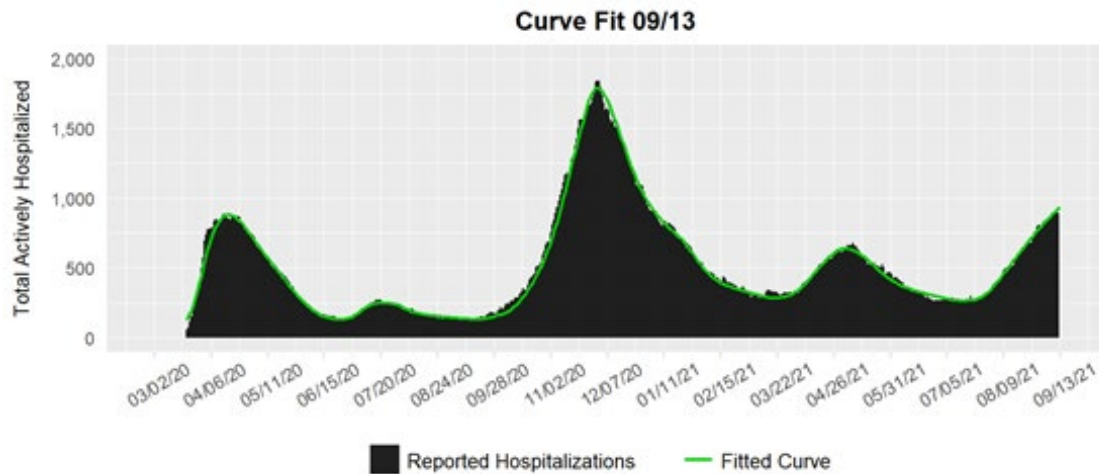

Figure A1. Current model fit (green line) to the count of hospitalized COVID-19 cases (black lines) through 09/13 using the age-structured SEIR model. Hospitalized COVID-19 cases are from CDPHE reported COVID-19 hospitalizations and EMResource (EMR) hospital census data provided by CDPHE.

Variants of Concern. We estimate variant prevalence using data from CDPHE and incorporate variant prevalence in our model.
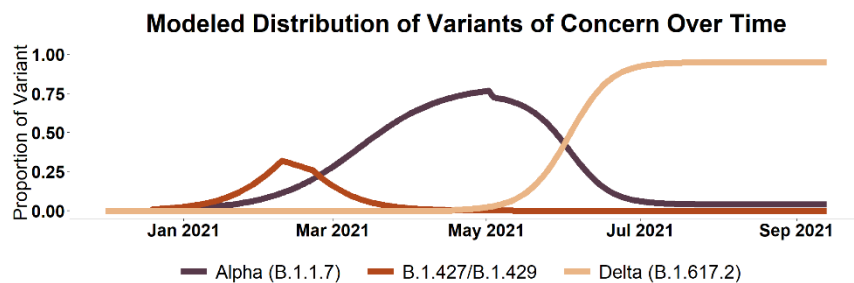

Figure A2. Estimated prevalence of variants of concern: Alpha (purple), B.1.427/B.1.429 (dark orange), Delta (light orange) in Colorado over time used in the SEIR model.

Case detection. We compare model-estimated infections to the number of cases reported in order to estimate the proportion of cases detected over time.
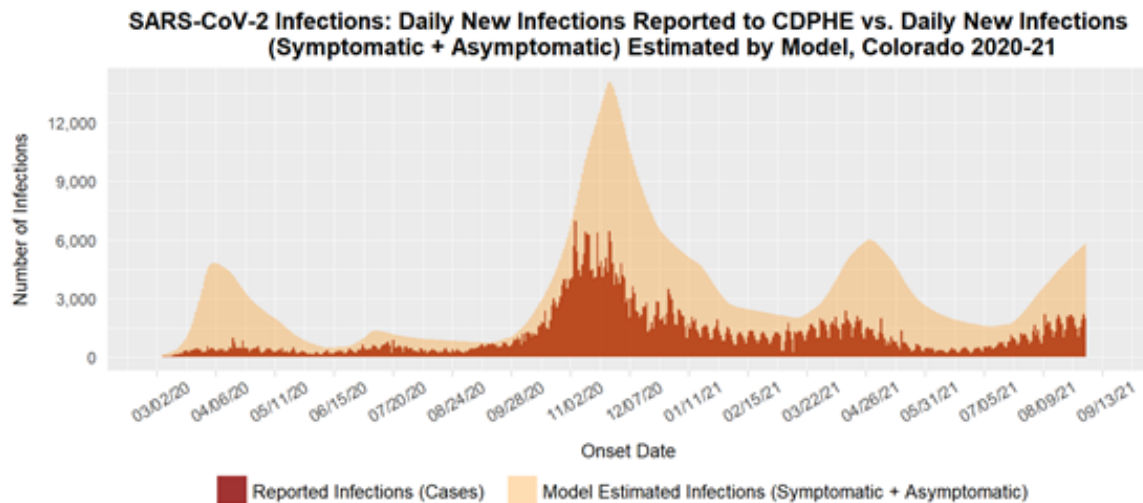

Figure A3. Estimated daily number of new (incident) SARS-CoV-2 infections based on the total estimated by the SEIR model (light orange graph) and reported cases (dark orange graph) over time shown.

Code, Documentation, and Prior Reports

Code for our model is available on GitHub: https://github.com/vanadata/covid-models

Documentation for the model: https://agb85.github.io/covid-19/SEIR%20Documentation.pdf

Prior modeling reports and documentation: https://agb85.github.io/covid-19/

Regional modeling results: https://www.colorado-data.org/regional-epidemic-models