# The current state of COVID-19 in Colorado

# 9/30/2020

**Prepared by the Colorado COVID-19 Modeling Group**
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## Summary

**Snapshot of current SARS-CoV-2 transmission in Colorado**

- Hospitalizations are increasing.
- Trajectories of hospitalization vary by region throughout Colorado. Focal points of increasing hospitalizations include the East Central LPHA region and the Metro LPHA region. Other regions continue to see declining or stable hospitalizations.
- The estimated effective reproductive number is between 1.21 and 1.27 and it has risen over the last month. Due to the lag between infection and hospitalization, the latest estimates reflect transmission through approximately 09/15.
- We estimate that approximately 118 of every 100,000 Coloradans are currently infectious. This has increased compared to last week.
- We estimate approximately 5.2% of Coloradans have been infected with SARS-CoV-2 to date.
- The estimated current level of transmission reduction is 74% for the period of 09/01 to 09/15. This estimate indicates an approximate 74% reduction in total transmission-relevant contacts, inclusive of reductions due to contact tracing, self-isolation, mask wearing, and all other policy and behavioral changes compared to a situation where transmission was uncontrolled.
- The estimated current level of social distancing is 59% for the period of 09/01 to 09/15. There is an approximate 59% reduction in social distancing, assuming 90% mask wearing and self-isolation by people with SARS-CoV-2. In the model, social distancing refers to all reductions in contacts that could spread infections, not accounted for by our assumptions about mask wearing and self-isolation. This term is being phased out as we begin to use transmission reduction.
- Using an extended modeling approach that includes case data, we estimate transmission reduction varies significantly by age group, with individuals aged 20-39 having the lowest transmission reduction (58%), and individuals over 65 remaining at high transmission reduction (89%).

**Snapshot of the potential future trajectory of SARS-CoV-2 in Colorado**

- If we remain on our current trajectory, we expect to continue to see growth in cases and hospital demand. We do not expect to exceed hospital or ICU capacity in the next month.

- The impact of increased contacts over the winter holidays depends on the trajectory of infections between now and Thanksgiving. Further growth in transmission between now and then will make the consequences of a possible holiday "bump" more severe.

**Contact tracing**

- Using data on contact tracing levels from 33 LPHAs, there is evidence that contact tracing has had a substantial impact on transmission in the state to date, contributing to reduced transmission and hospitalizations over the month of August.

# Introduction

We used our age-structured SEIR model and COVID-19 hospital census data to characterize the current status of the COVID-19 epidemic in Colorado and the collective impact of efforts to date to reduce the spread of the SARS-CoV-2 virus. These estimates are based on hospitalization data through 09/28/2020. We use these estimates to generate projections of the potential future course of SARS-CoV-2 in Colorado. These include near-term projections based on the current estimated trajectory, projections that consider the impact of further relaxation of social distancing, as well as projections that examine the potential impact of increased social contacts over the Thanksgiving to New Year holidays.

The report this week introduces a new “transmission reduction” parameter that provides an estimate of the collective impact of all policies and behaviors on the spread of SARS-CoV-2. This parameter is a measure of the percent reduction in transmission-relevant contacts and has the advantage of requiring fewer assumptions in our model.

We use the transmission reduction model to generate two new sets of estimates. First, we estimate variability in transmission reduction by age group, using a new modeling approach that uses both hospitalization and case data for parameter estimation. Second, we estimate the impact of contact tracing efforts on transmission, using survey data from 33 LPHAs.

# Transitioning from social distancing to transmission reduction

Our model to date has included a social distancing parameter, in addition to separate parameters describing mask wearing and self-isolation of infected individuals. Social distancing as a parameter in the model is different from what social distancing means colloquially. In our model, “social distancing” includes behavior, policy, contact tracing and all reductions in transmission not accounted for based on our assumptions about case isolation and mask wearing. The estimate of social distancing is sensitive to the assumptions made about mask wearing and isolation. Moreover, impacts of contact tracing not captured by the self-isolation parameter may be folded into the social distancing estimates.

We have developed a new model parameterization that replaces social distancing, mask wearing and self-isolation with an overall transmission reduction parameter. This transmission reduction parameter is the percent decrease in effective contacts between infected and susceptible individuals compared to pre-pandemic behavior. This parameter captures ALL behavioral and policy changes in response to the SARS-CoV-2 pandemic including mask wearing, physical distancing, improved ventilation, working from home, contact tracing (including both isolation and quarantine), moving activities outside, seasonal impacts on transmission. This approach has the advantage of requiring fewer assumptions. For example, in the current model we assume mask wearing jumps from 70 to 90% on July 16, the date of the statewide mask order – an assumption that becomes unnecessary with the new model. For clarity, we refer to this new model parameterization at the TR model. We refer to the model with social distancing, mask wearing and self-isolation as the SD model.

In the Figure 1, below, we show a side-by side comparison of the two approaches (parameterization of the two models is described in Appendix Table A1). In both models, we fit the model output to hospitalizations. The transmission reduction metric is closely aligned with the social distancing metric. Transmission reduction values are higher than social distancing values at most time points, as the model terms for the effects of mask wearing and case-isolation have been removed.

Currently, given the proportion of susceptibles remaining in the population, transmission reduction levels under 78.5% will lead to increasing infections and Re > 1, whereas if contact rates are reduced such that transmission reduction is over 78.5%, infections will flatten or decrease.

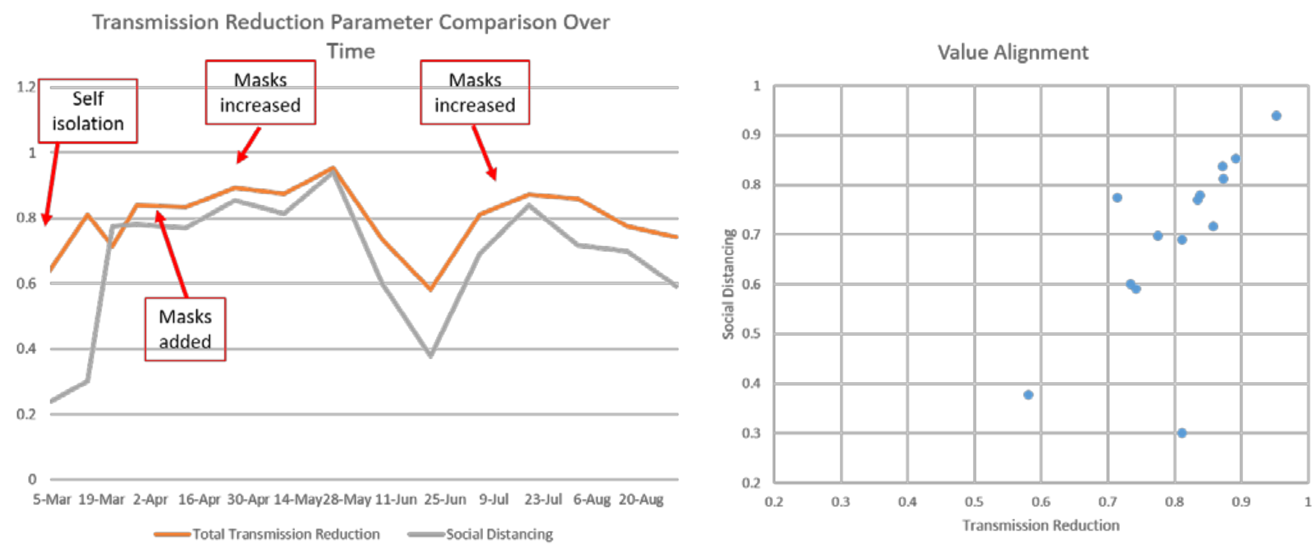



**Figure 1.** Comparison of estimated transmission reduction vs. social distancing parameters over time. The transmission reduction model removes explicit assumptions about mask wearing, self-isolation and social distancing and, instead includes a since "transmission reduction" parameter. The model used to generate the social distancing estimate is the model with assumptions regarding self-isolation (starting 03/05) and mask wearing (starting 04/04 and increasing 04/27 and 07/16).

## Current COVID-19 hospitalizations and model fit

We are currently fitting the model to hospitalizations using two separate methods, described above. The social distancing ("SD") approach includes assumptions about mask wearing and self-isolation behavior of cases. The transmission reduction ("TR") approach removes those assumptions and estimates a single parameter, transmission reduction, which encompasses all policies or behaviors that decrease transmission of SARS-CoV-2.

Figure 2 shows COVID-19 hospitalizations (black bars) and the green line shows the current model fit to the data using the SD method (the TR model fit is similar). Table A1 provides values for model parameters for the SD and TR approach. Our most recent estimate of social distancing, for the period 9/01 to 9/15, is 59%. This describes reductions in the contact rate assuming mask wearing and self-isolation of cases. The estimate for transmission reduction for the same time frame is 74%. We note that due to the approximately 13-day lag between infection and hospitalization, we are currently only able to estimate social distancing and transmission reduction through 9/15.

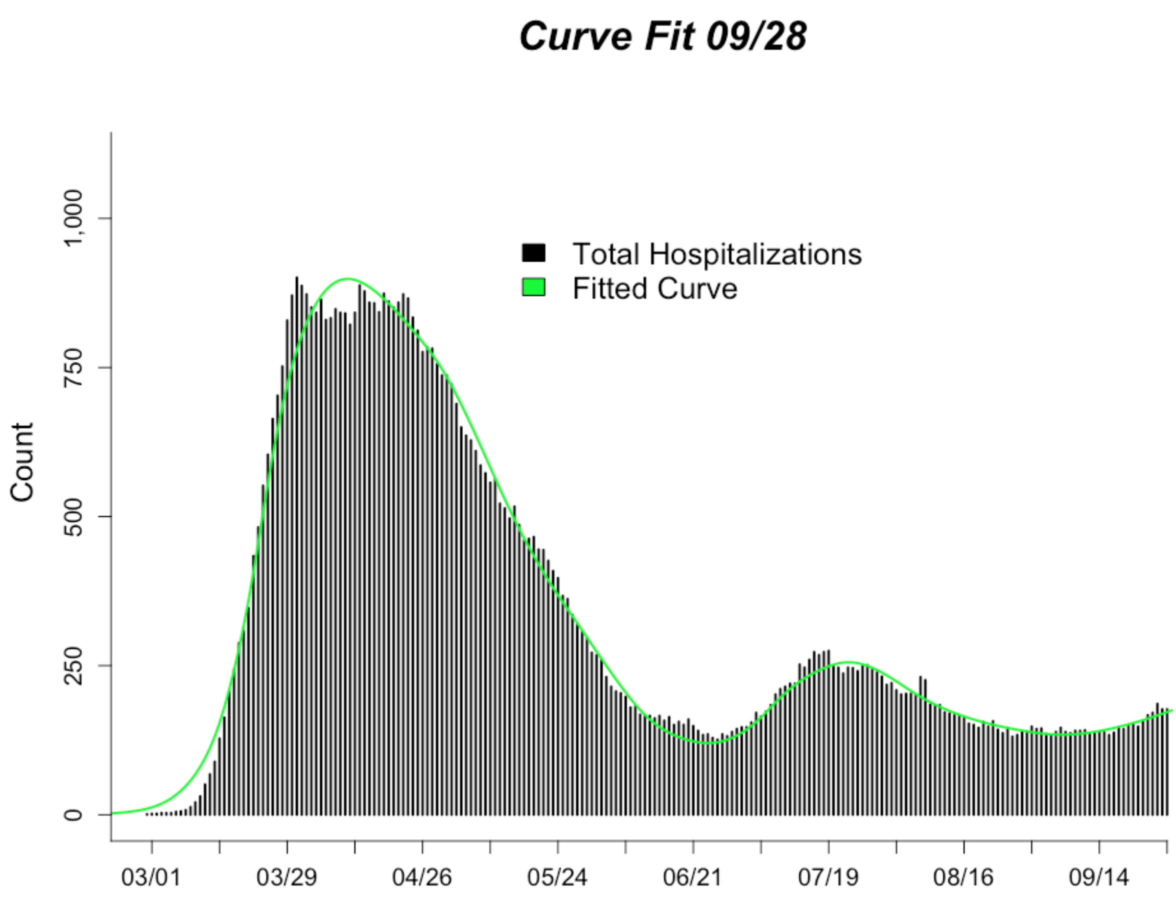



**Figure 2.** Current model fit (green line) to count of hospitalized COVID-19 cases (black lines) using the age-structured SEIR model – the SD model. Hospitalized COVID-19 cases are from CDPHE reported COVID-19 hospitalizations and EMResource (EMR) hospital census data provided by CDPHE.

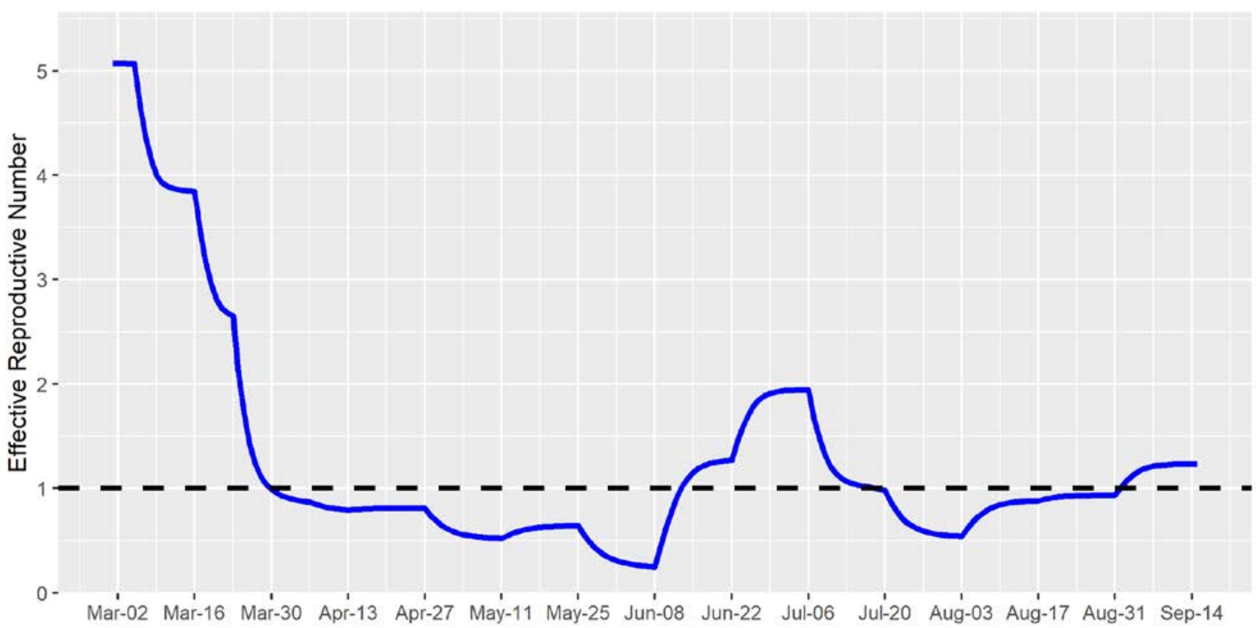
## The effective reproductive number

The estimated effective reproductive number is shown in Table 1 and Figure 3. Table 1 provides estimates we generated using two different methods for the SD model, and the estimate from the TR model, all of which are similar. We also provide values from two external groups that use different data and methods (RT-Live uses SARS-Cov-2 case data and covid-19-projections.com uses mortality data). Trends in these external estimates reflect our estimates.

**Table 1.** Current and prior estimates of the effective reproductive number (Re) in Colorado.

| | Current Estimate (09/28) | Estimate one week ago (09/21) | Estimate two weeks ago (09/14) |
|---|---|---|---|
| Estimate of Re, approach 1, SD model* | 1.24 | 1.08 | 1.10 |
| Estimate of Re, approach 2, SD model* | 1.27 | 1.05 | 1.10 |
| Estimate of Re, from TR model * | 1.21 | - | - |
| Estimate from RT-Live | 1.10 | 1.16 | 1.05 |
| covid-19-projections.com | 1.03 | 1.04 | 0.94 |

*Our estimates are based on hospitalization data through the date listed. Estimates from the external sites are extracted on the day listed. Because of the 13-day lag between infection and hospitalization, on average, our current estimate reflects transmission up to approximately September 15. Approach 1 uses SD model output to estimate the average number of new cases generated by existing cases, accounting for the latent period and duration of infectiousness. The second method uses the SD model structure to estimate the dominant eigenvalue for a matrix describing population flows across the model compartments. The Re from the TR model uses Approach 1 for calculation.



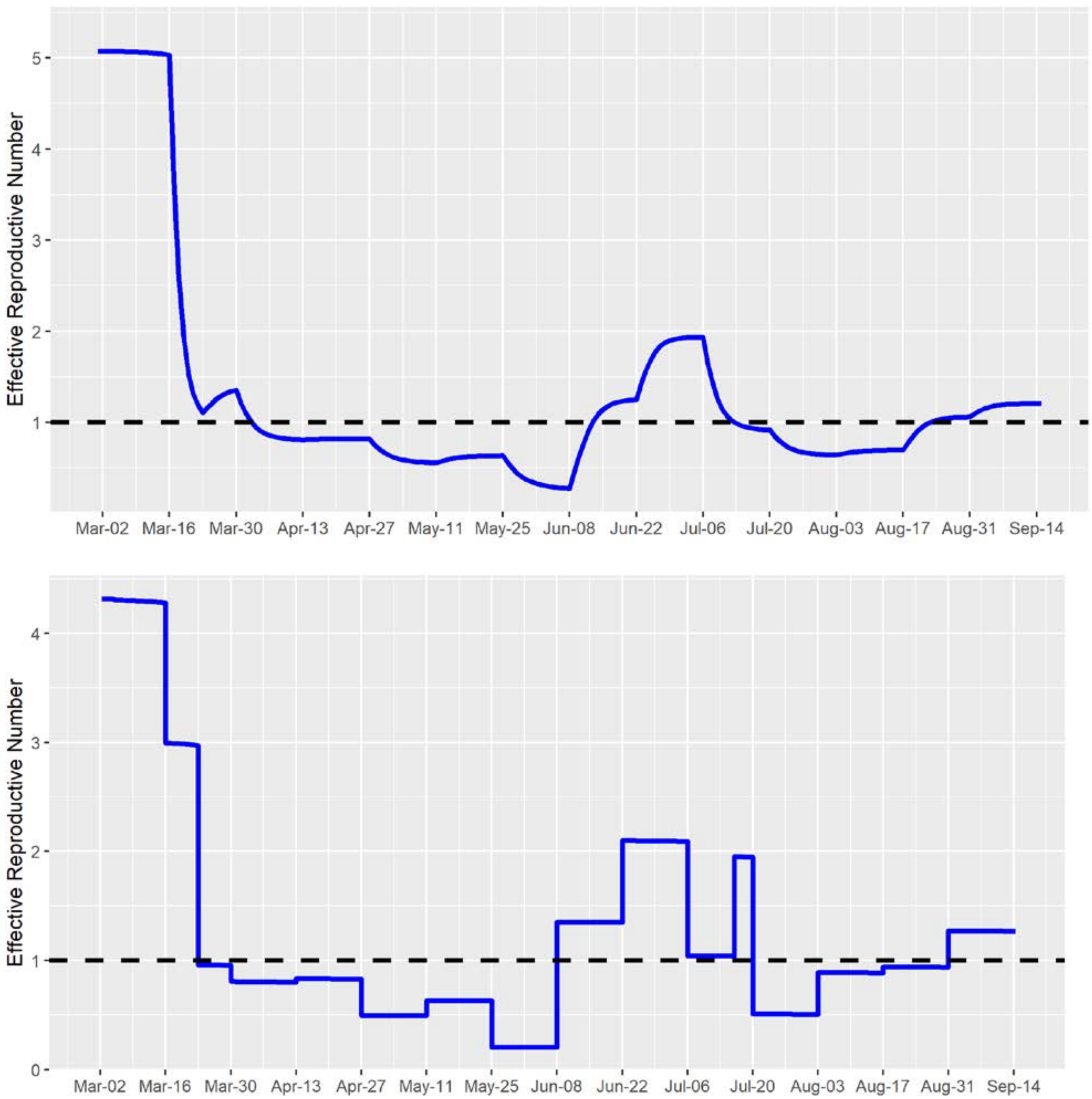



**Figure 3.** The effective reproductive number using approach 1 (top) and approach 2 (bottom) based on the old version of the SEIR model. The effective reproductive number using approach 1 from the new model-fitting method estimating transmission reduction instead of social distancing is shown in the middle.

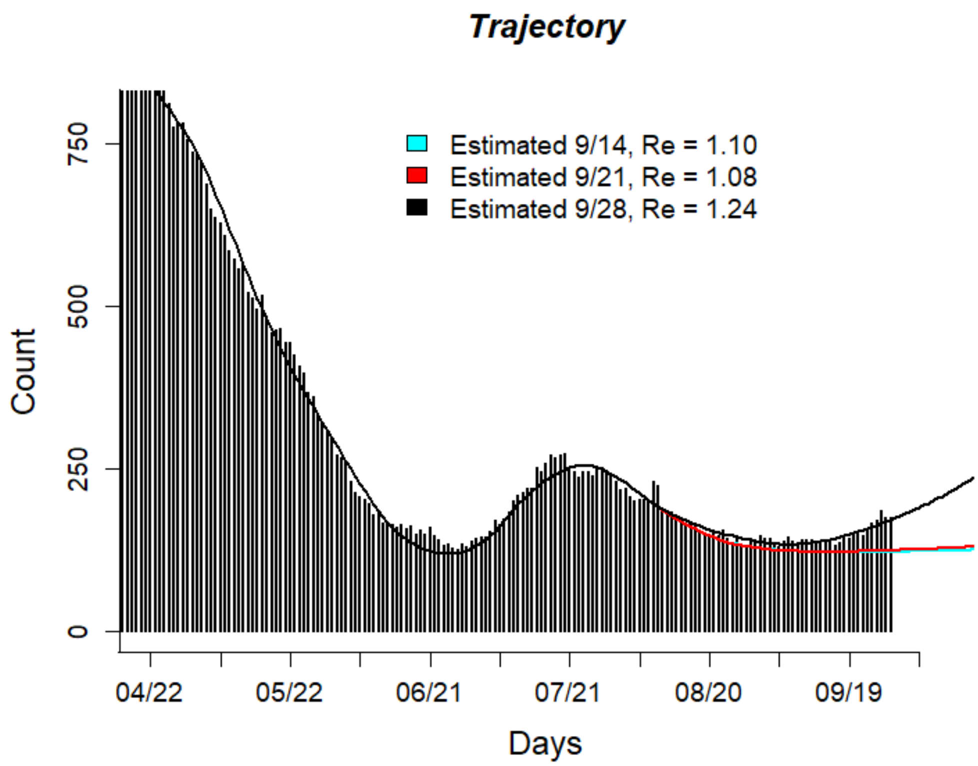
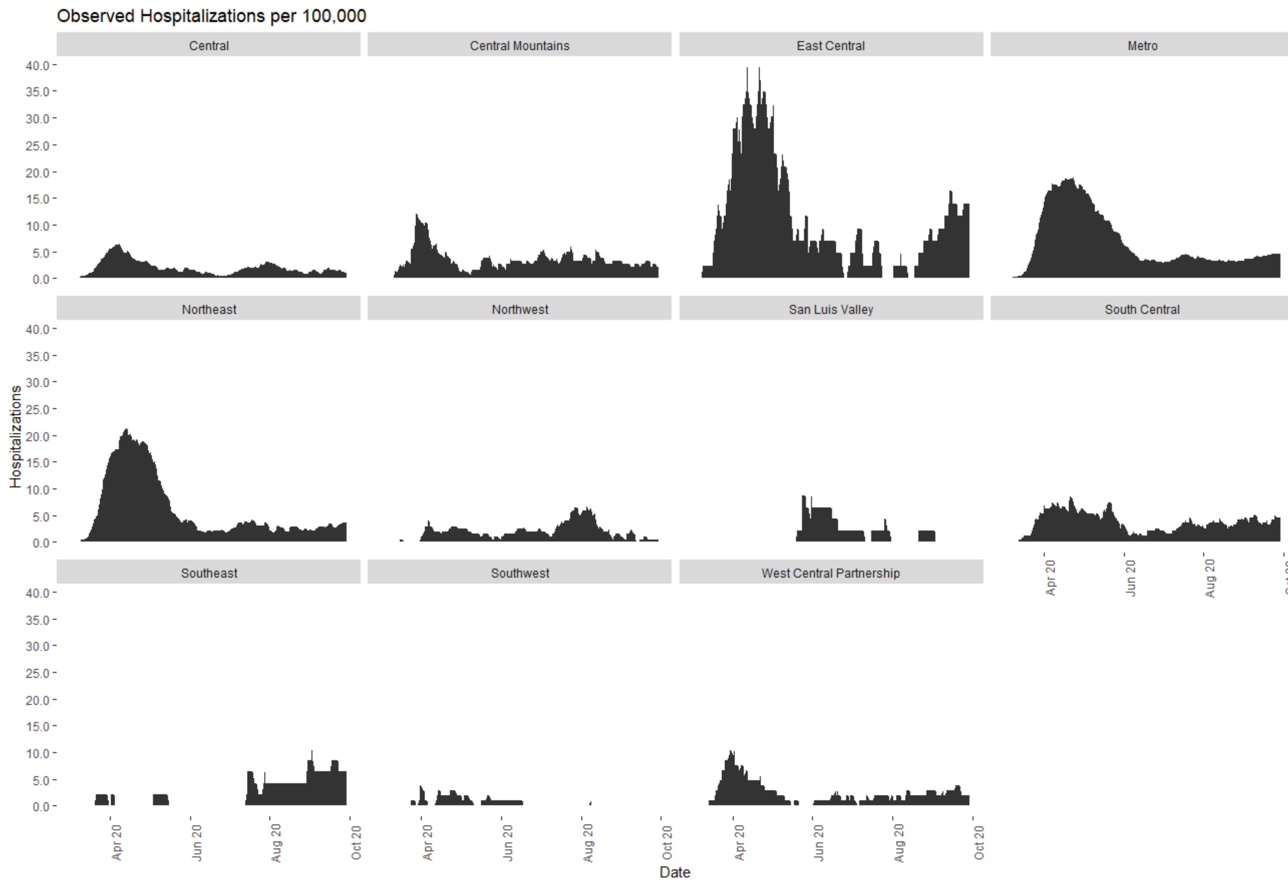



**Figure 4.** The projected trajectory of COVID-19 hospitalizations if Colorado remains on the current estimated trajectory (black line), the trajectory estimated one week prior (red line), and the trajectory estimated two weeks prior (teal line). Each trajectory is generated assuming social distancing levels remain at the estimated levels: current estimate 59% based on the period 9/01 to 9/15 (black line), one week prior estimate 66% based on the period 8/31 - 9/08 (red line), two-week prior estimate 67% based on the period 8/17 to 9/01 (teal line). Note that the estimation periods overlap as we re-estimate parameters each week and use the past approximately 10 days to estimate the most recent social distancing parameter.

## Patterns of hospitalizations vary by region throughout Colorado

The magnitude and trajectory of the pandemic vary by region and county in Colorado. Some regions (notably East Central LPHA regions and Metro LPHA region) are experiencing marked increases in hospitalizations while other regions are experiencing flattening or decreasing hospitalizations. Within the Metro region, most counties are experiencing increases in hospitalizations.


Observed Hospitalizations per 100,000
Central
Central Mountains
East Central
Metro
Northeast
Northwest
San Luis Valley
South Central
Southeast
Southwest
West Central Partnership
Hospitalizations
40.0
35.0
30.0
25.0
20.0
15.0
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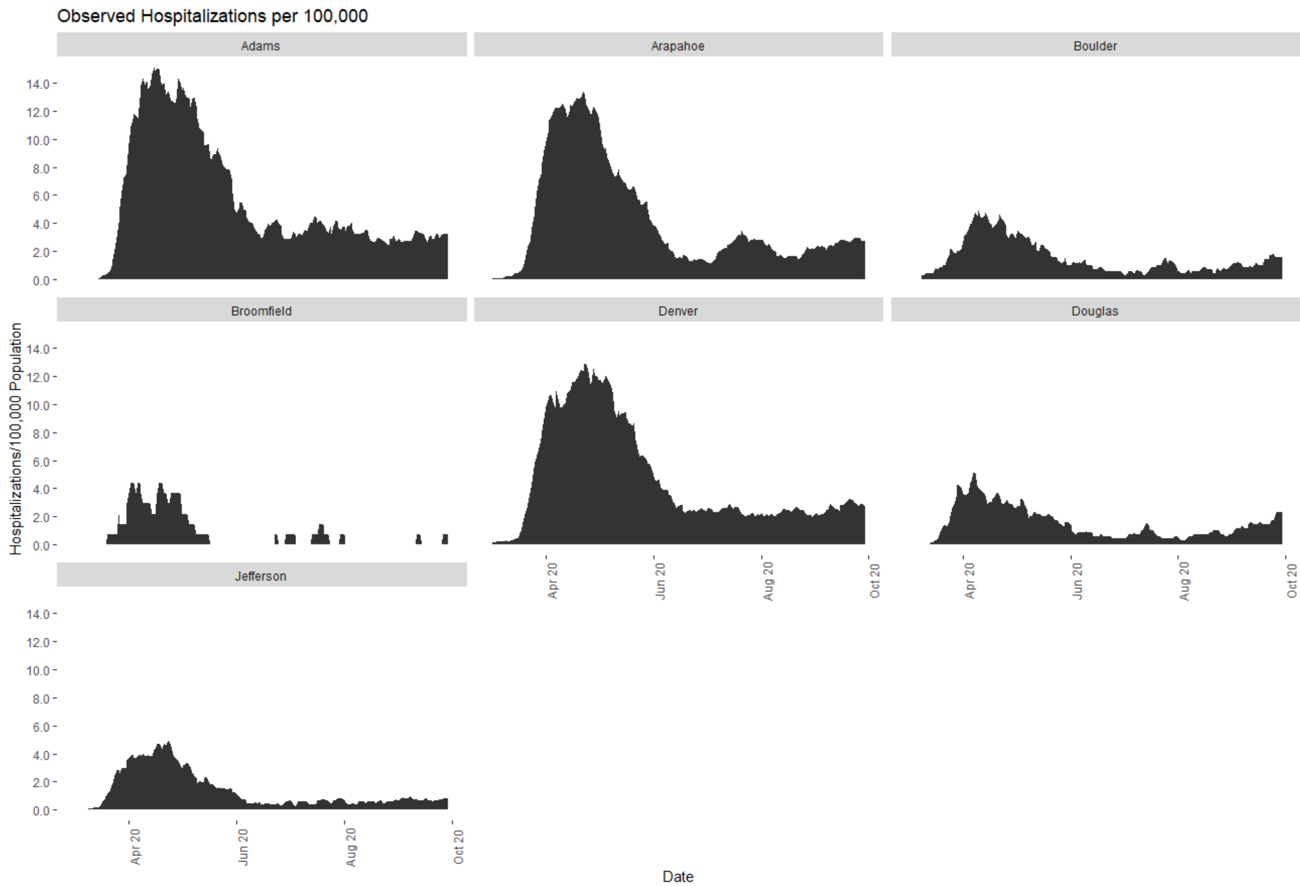
5.0
0.0
Apr 20
Jun 20
Aug 20
Oct 20
Date



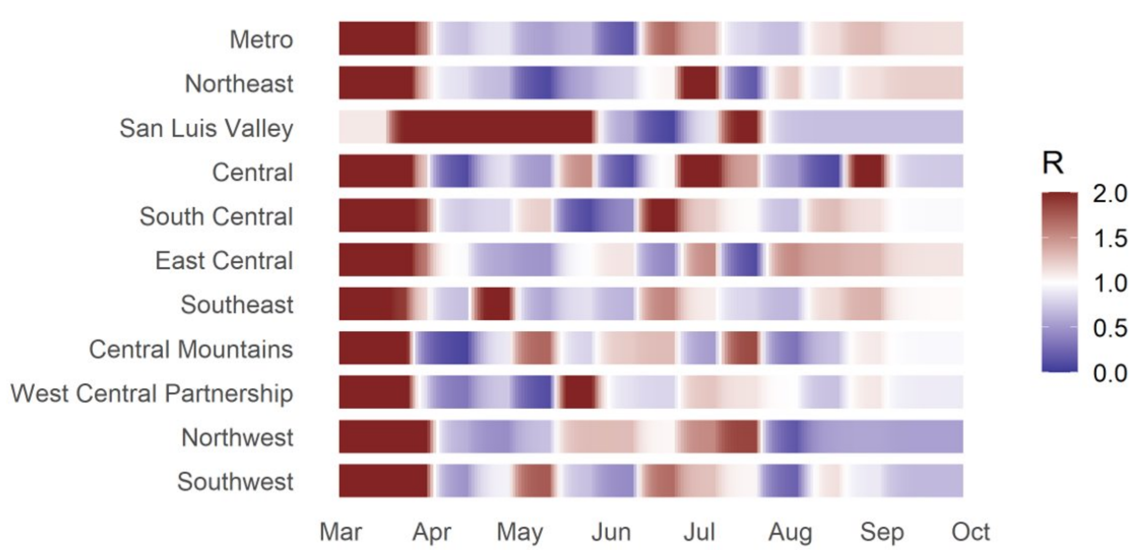




**Figure 5.** Hospitalizations per 100,000 population by Colorado LPHA region (top) and within the 7 Metro Denver counties (middle). The effective reproductive number over time in the 11 LPHA regions, calculated from COPHS data on September 28.

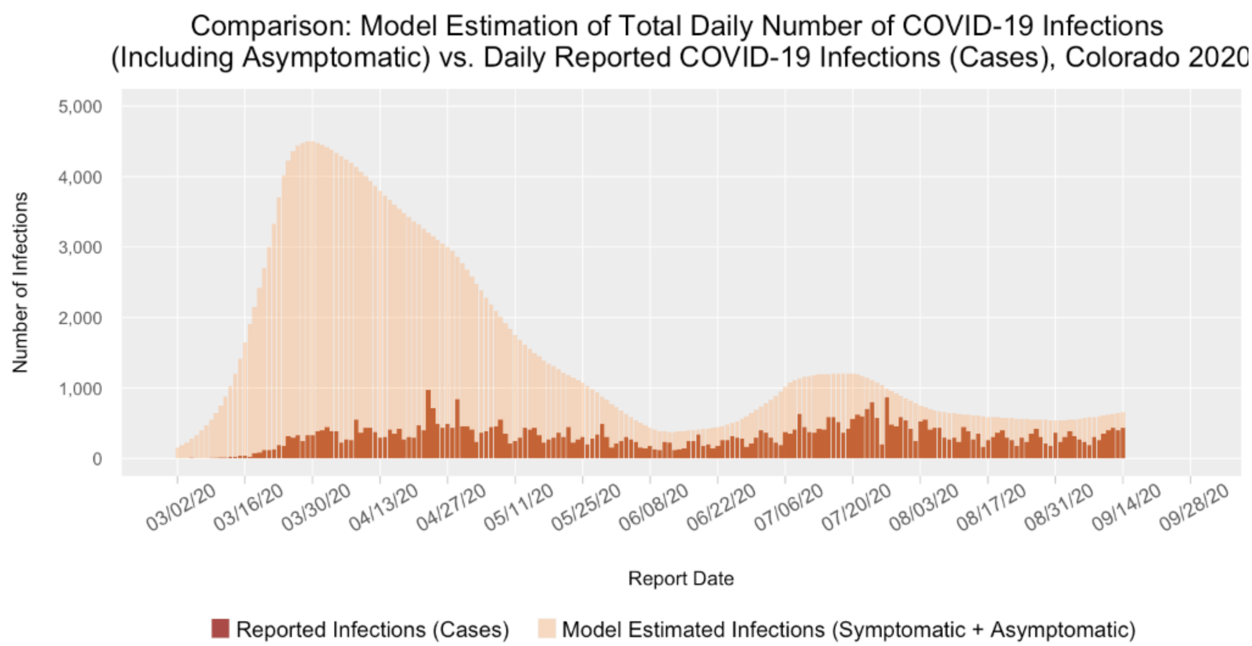
## The cumulative and current number of infections in the population

We use the SD model output to estimate the cumulative number of infections to date and the approximate number of infectious individuals in the population. Given the characteristics of SARS-CoV-2 and of COVID-19, many infections are not detected by surveillance systems – the estimates provided here are intended to provide an approximation of the total number of infections, as well as the proportion detected by the Colorado surveillance system. These estimates are sensitive to model assumptions, including assumptions about the probability an infected individual will be symptomatic and require hospital care, which we assume varies by age. These estimates are generated from the SD model, noting that the TR model produces similar estimates.

We estimate that approximately 303,000 people in Colorado, or 5.2% of the population have been infected to date.

We estimate that there are approximately 6,900 infectious individuals in Colorado at present: approximately 1 in every 850 Coloradoans.

We estimate that approximately 54% of infections in the past two weeks were detected, including both asymptomatic and symptomatic infections. This estimate is generated by comparing daily reported SARS-CoV-2 cases in Colorado to model-estimates of the number of incident infections.



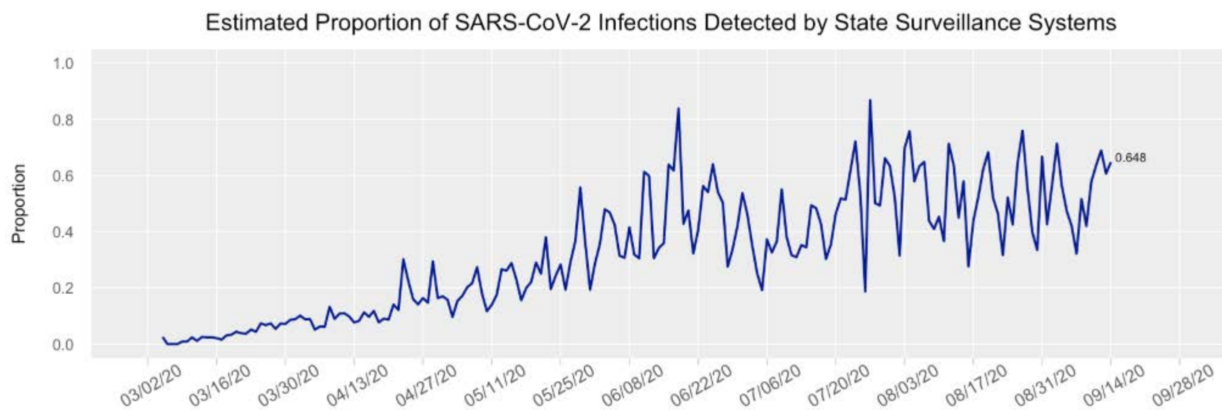



**Figure 6.** Estimated daily number of new (incident) SARS-CoV-2 infections based on the SEIR model (dotted line) and reported cases (solid line) over time shown in the top panel. Lower panel shows the estimated proportion of SARS-COV2 infections that are being captured by Colorado state surveillance systems, over time. The proportion detected is estimated by dividing the total number of new cases captured by state surveillance systems by the model-estimated number of new infections each day. The number of cases captured by state surveillance systems is the number of cases reported by CDPHE, using the onset date of symptoms (if onset date is not available, onset date is imputed by CDPHE using a proxy distribution of recent onset dates). Data are shown through 9/15, to account for typical lags between symptom onset and case report.

## The distribution of reported infections and hospitalizations by age, race and ethnicity

**Reported SARS-CoV-2 Cases by age group.** Figure 7 shows the weekly number of reported new SARS-CoV-2 infections by age group. Recent reports of new cases are highest for those aged 20 - 39. The average proportion of COVID-19 cases in people under age 40 over the last two weeks is approximately 67%.

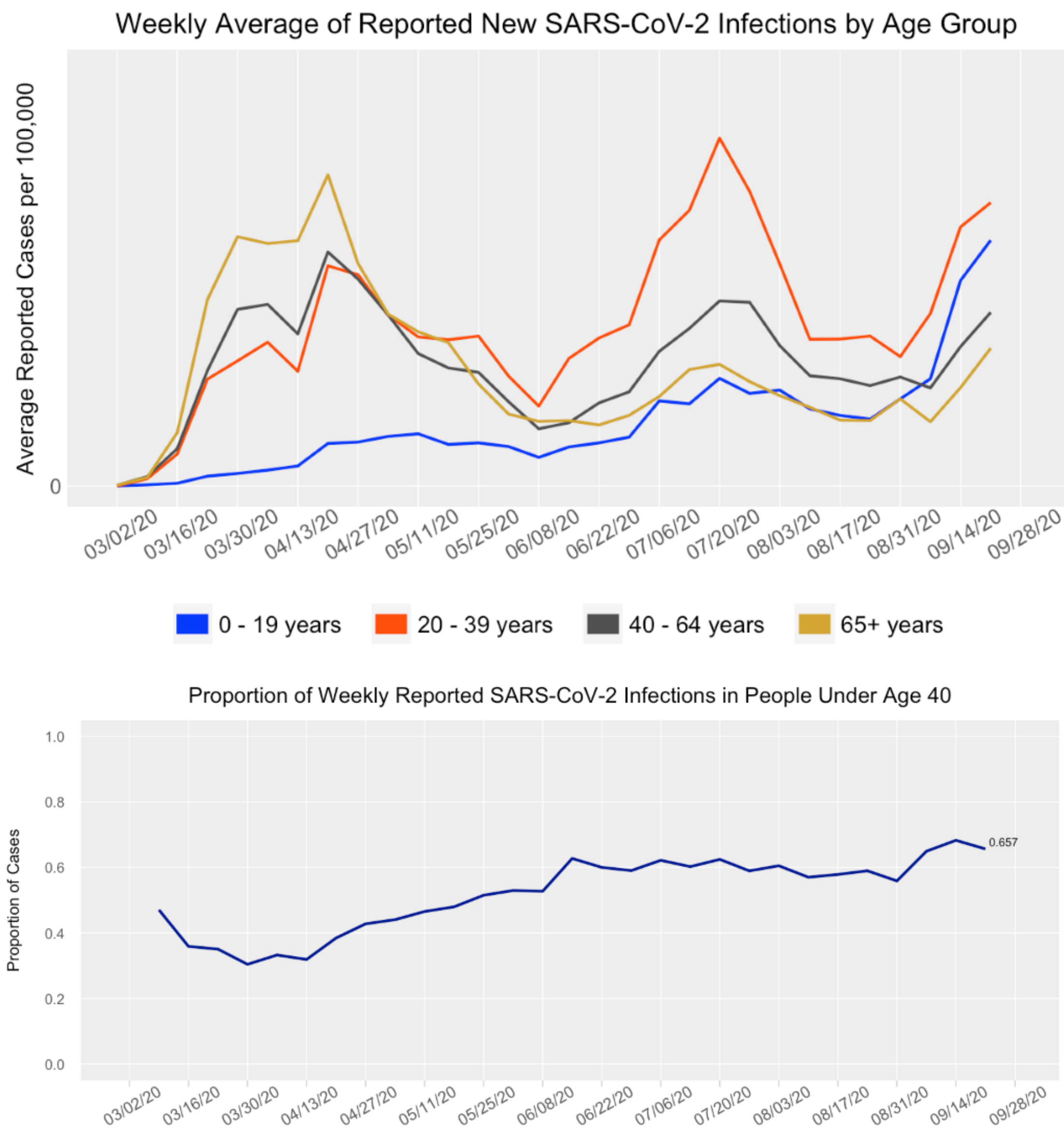



**Figure 7.** Distribution of weekly new (incident) reported SARS-CoV-2 cases by age group (top) and the proportion of all cases among individuals under 40 (bottom). Reported cases are based on CDPHE data and shown by onset date (if onset date is not available, onset date is imputed by CDPHE using a proxy distribution of recent onset dates). Incident cases per 100,000 were obtained by standardizing weekly reported age-specific case and hospitalization counts to the Colorado population distribution by age, gathered from the Colorado Census 2020 estimates. Data are shown through 9/15/2020, to account for typical lags between symptom onset and case report.

**COVID-19 hospitalizations by age group.** Figure 8 shows the number of individuals hospitalized with COVID-19 by age group from March through the present. This is based on hospital census records. Currently, individuals age 40-64 account for the greatest COVID-19 hospital use. People under 40 account for approximately 18% of COVID-19 hospital use.

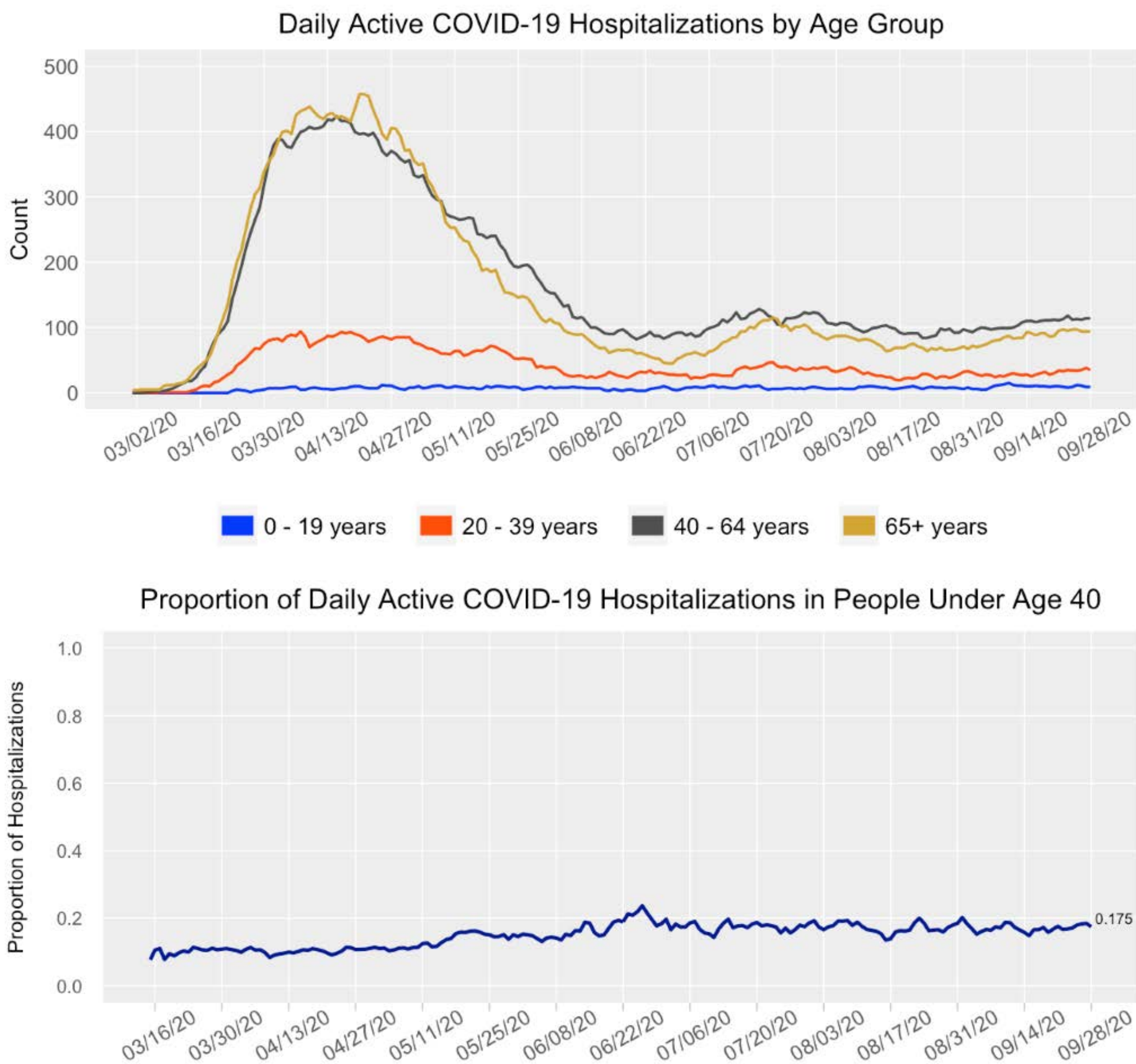



**Figure 8.** The number of individuals hospitalized with COVID-19 by age group from March through the present (top) and the proportion of COVID-19 hospital beds occupied by individuals under age 40. Data based on Colorado hospital census data.

**COVID-19 reported cases by race/ethnicity.** Figure 9 shows the number of reported cases by race/ethnicity from March through the present. Hispanic populations continue to be disproportionately impacted.

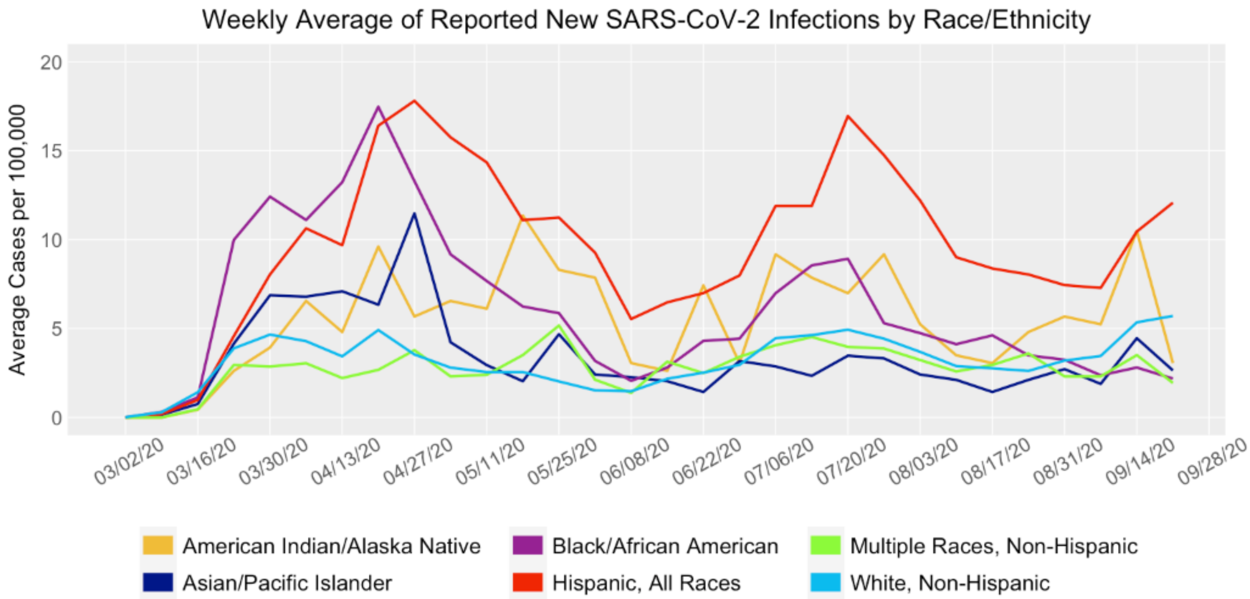



**Figure 9.** Distribution of weekly new (incident) reported SARS-CoV-2 infections by race and ethnicity in Colorado. Reported cases are based on CDPHE data and shown by onset date (if onset date is not available, onset date is imputed by CDPHE using a proxy distribution of recent onset dates). Cases and hospitalizations per 100,000 were obtained by standardizing weekly reported race-specific case and hospitalization counts to the race/ethnicity distribution of the state of Colorado gathered from the CDPHE COVID-19 Case Summary Dashboard. These standardized estimates combine Asian and Native Hawaiian/Pacific Islander races and exclude Other/Unknown races (which account for 33% of observations over the last two weeks).

## Using age-specific case data to estimate transmission reducing behaviors by age

Due to the variation in behavior by age and the increase in cases seen among younger age groups, we wanted to evaluate how transmission reduction varied by age group. In order to do this, we used the transmission reduction model and the CEDRS case data presented in Figure 7 to fit age-group specific levels of transmission reduction. To accomplish this it is necessary to make assumptions about the detection rates over time: We took the probability of detection from the overall model (calculated by comparing daily model estimated infections to reported infections (Figure 6)) as a time series (daily time-step) and fit observed CEDRS case data to age-specific estimated infections over time. The model fits the data well (Figure 10) although the height of the black dotted line from February to April indicates a much higher proportion of undetected infections among individuals under 20 in the initial phase of the epidemic than we assumed. Individuals aged 20-39 have relatively high contact rates currently (TR = 58%) and are driving an increase in infections, likewise individuals under 20 have high contact rates (TR = 69%). Despite an increasing trend in infections, individuals over 40 have relatively low transmission reduction.

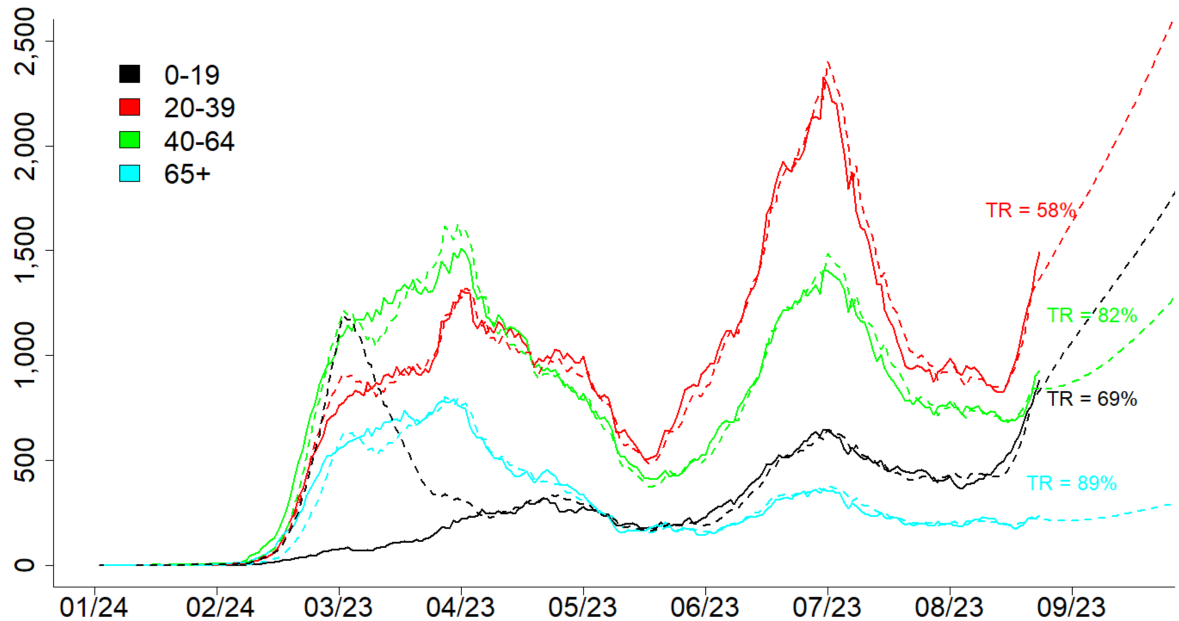


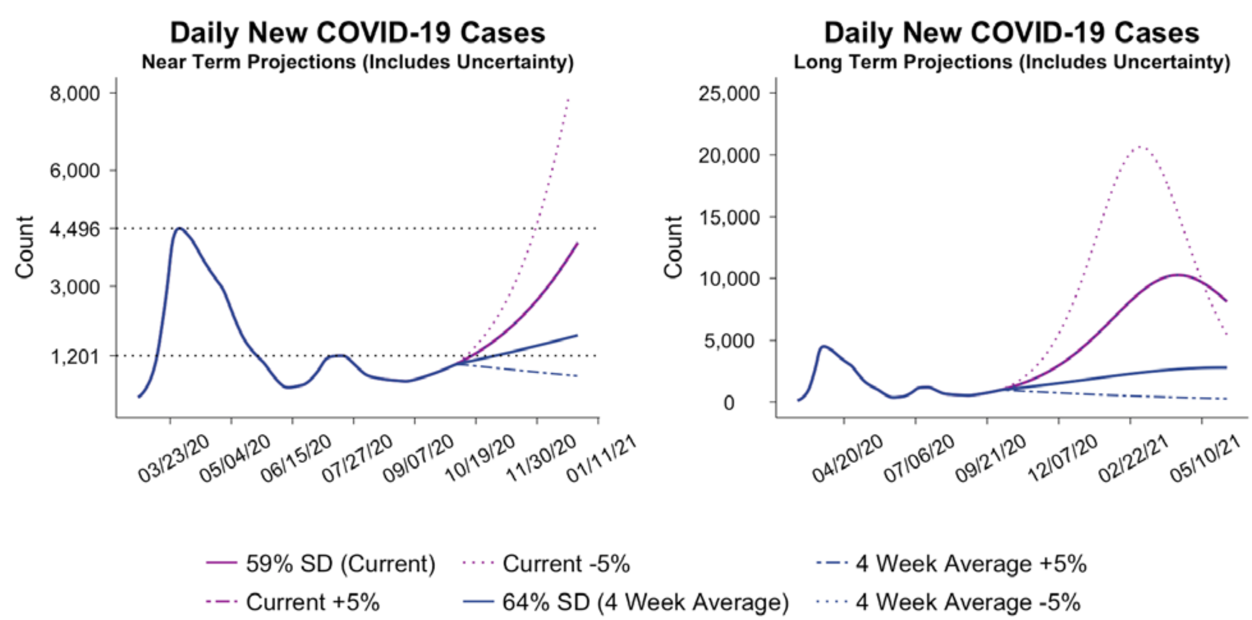

**Figure 10.** Observed cases over time by age group (solid lines), and model estimated cases (dotted lines) from a model fit to case data and allowing for age-group specific differences in levels of contact rates over time. Current age-group specific levels of transmission reduction are indicated next to model estimated trend lines.

# What do we project for the coming months?

We used the social distancing model fit to the parameters described in Table A1 to project the expected number of total hospitalizations and need for critical care beds in the coming months for three sets of scenarios: 1) current and recent trajectories; 2) relaxation of social distancing; 3) potential decreases in social distancing around the winter holidays

## Projections: Current and recent trajectories

Projections were generated assuming we remain on the current trajectory and accounting for uncertainty in our current estimated trajectory (Figure 11). As hospitalization numbers have fluctuated in recent weeks, leading to variation in estimates of social distancing, we estimate current trajectory two ways: first examining the trajectory based on the most recent social distancing parameter estimated for the most recent period, 08/31 – 9/15, and second by using the average social distancing parameter estimated for the last four weeks (the period 08/17 to 09/15). We additionally show projections in two different ways, showing near term projections (over the next 12 weeks) to allow easy visualization of the short-term possible projections, and show long-term projections to indicate the potential peaks under different long-term trajectories. Projections assuming we remain on our current trajectory or the four-week average trajectory, indicate that we may see a surge in infections but are unlikely to exceed hospital capacity in the next 8 weeks.



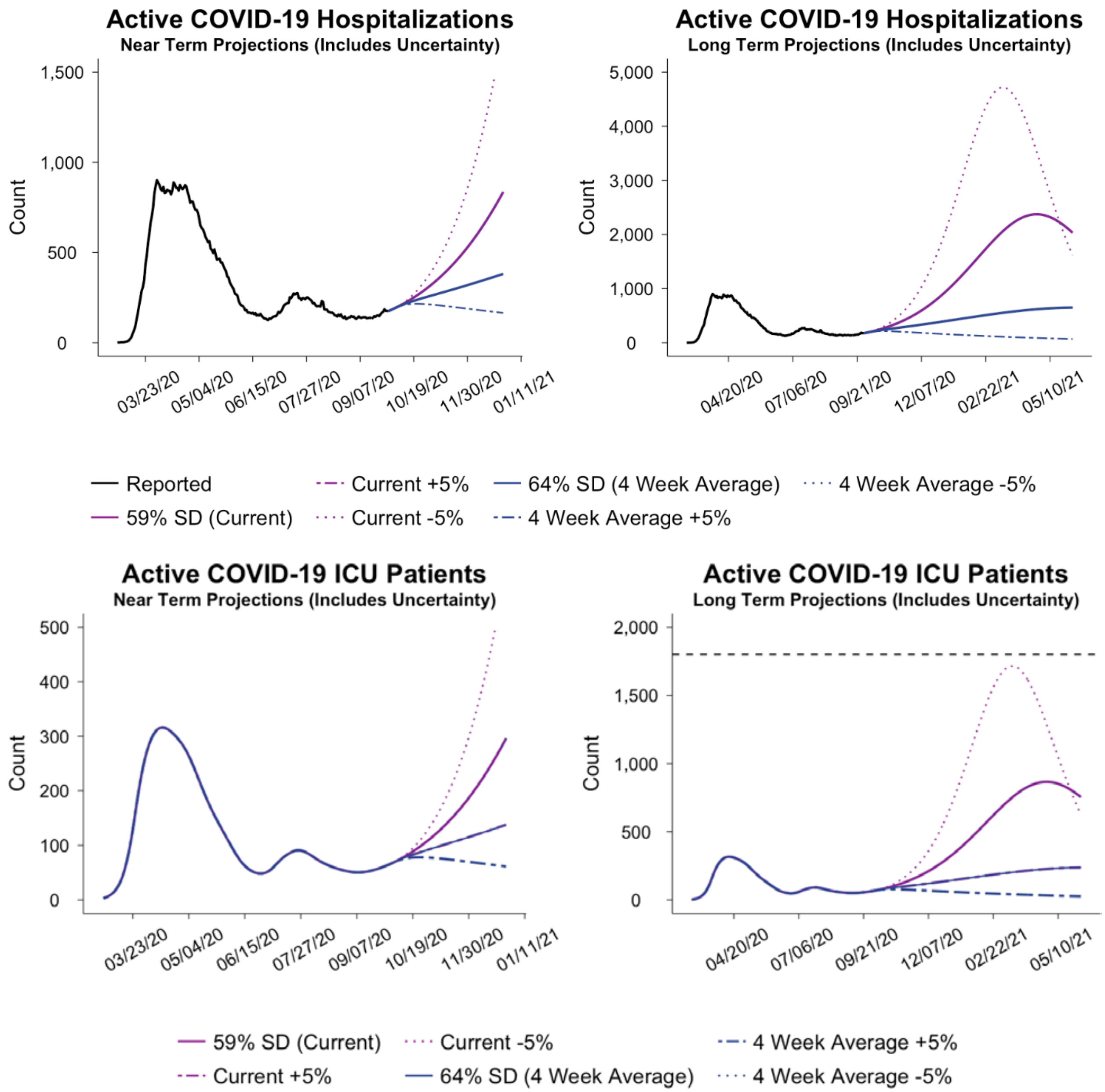



**Figure 11.** Projected daily count of new infections (top), hospital (center), and intensive care (ICU) demand (bottom) in the near-term (left) or long term (right) if we remain on the current trajectory estimated based on the most recent social distancing estimate (purple line, 59% for the period 8/31 – 9/15), and based on the three-week average (blue line, 64% for the period 08/17 – 9/15). Dashed and dotted lines represent a 5% overestimate / underestimate respectively in the social distancing parameter. These scenarios assume mask wearing increases to 90% on 7/16, the date of the state-wide mask order, and case isolation remains at current levels. These projections use model-fit parameters through 9/15 and then switch to the projected parameter values.

## Projections: Relaxation of social distancing

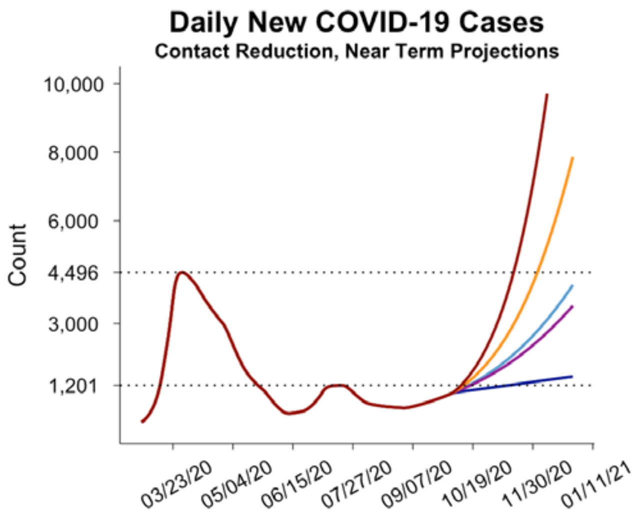
Projections were also generated to evaluate the potential impact of theoretical changes to the current trajectory – looking at the potential impact of reductions in social distancing (Figure 12 and Table 2). For the purpose of these projections, we assume social distancing is relaxed on 10/02. Projections are generated assuming mask wearing increased to 90% on 7/16, the date of the state-wide mask order.

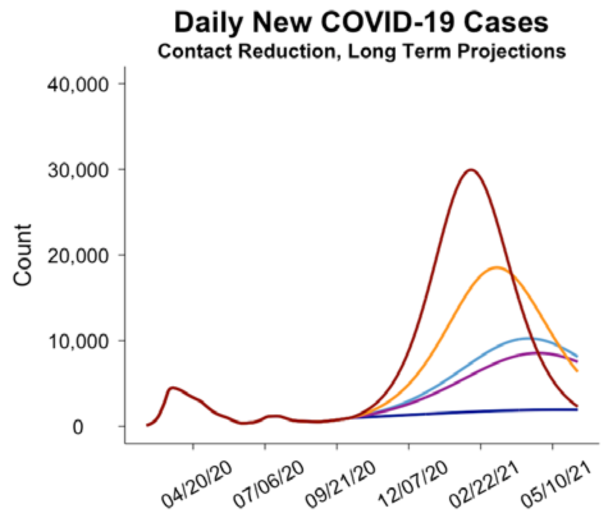
Projections show that if social distancing continues to relax to levels as low as 55 or 50%, we could see substantial growth in cases in the months ahead, with the sharpest growth at the lowest levels of social distancing. ICU capacity is expected to be exceeded this fall in the 50% scenario.

**Table 2.** Comparison of the projected date that ICU capacity is reached, the date ICU demand peaks, the estimated number of ICU beds needed at the peak, and the cumulative COVID-19 deaths at different levels of social distancing. Based on CDC recommendations, in the 50 – 65% scenarios, half of older adults (age 65+) are assumed to practice high levels of social distancing (80%). Projections assume mask wearing and case isolation remain at current levels.

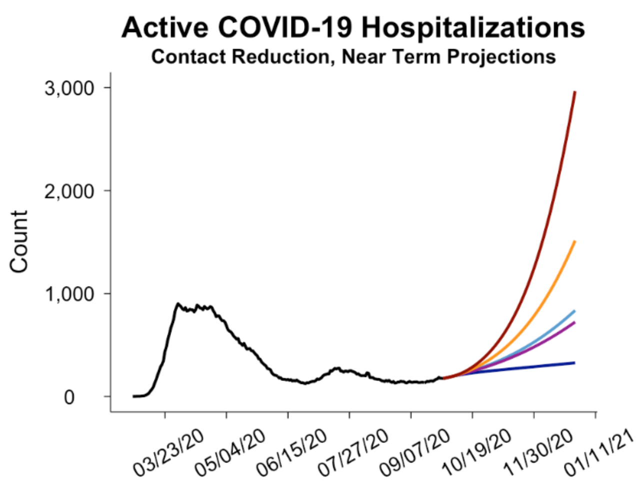
| | Date ICU Capacity Reached* | Date of ICU Peak | ICU Need at Peak** | Cumulative cases through 12/31/2020** | Cumulative deaths through 12/31/2020** |
|---|---|---|---|---|---|
| **Current trajectory** | | | | | |
| Current trajectory (8/31 – 9/15, 59%) | N/A | 04/26/2021 | 870 | 580,000 | 3,200 |
| Three-week average (08/17 – 9/15, 64%) | N/A | past | past | 460,000 | 2,700 |
| **Intervention scenarios** | | | | | |
| Social distancing at 50%¶ | 1/21/21 | 2/23/21 | 2,500 | 1,116,000 | 5,100 |
| Social distancing at 55%¶ | N/A | 3/23/21 | 1,550 | 754,000 | 3,800 |
| Social distancing at 60%¶ | N/A | 5/06/21 | 730 | 549,000 | 3,100 |
| Social distancing at 65%¶ | N/A | past | past | 442,000 | 2,600 |

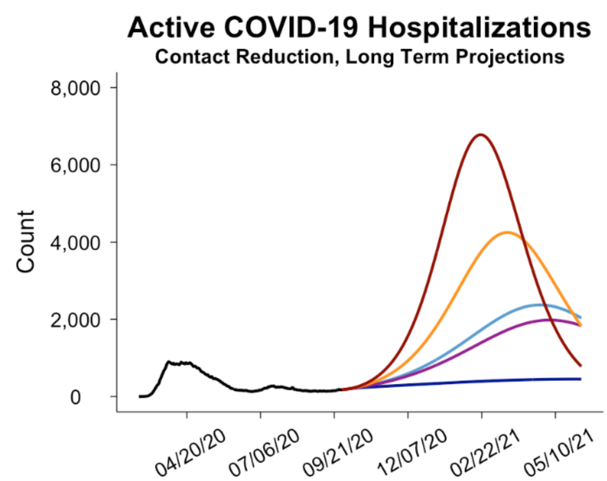
*ICU capacity for COVID-19 patients is estimated to be 1800 in Colorado, a figure provided by the Colorado Department of Public Health and the Environment.
**Estimates are rounded to two significant figures.
¶ Intervention are modeled assuming social distancing remains at the current estimated level until 10/02, at which point it changes to the indicated value. These intervention scenarios differ from current trajectory scenarios in that they assume half of individuals 65 and older maintain high levels of social distancing.




59% SD (Current) 65% SD 60% SD 55% SD 50% SD




Reported 65% SD 55% SD
59% SD (Current) 60% SD 50% SD

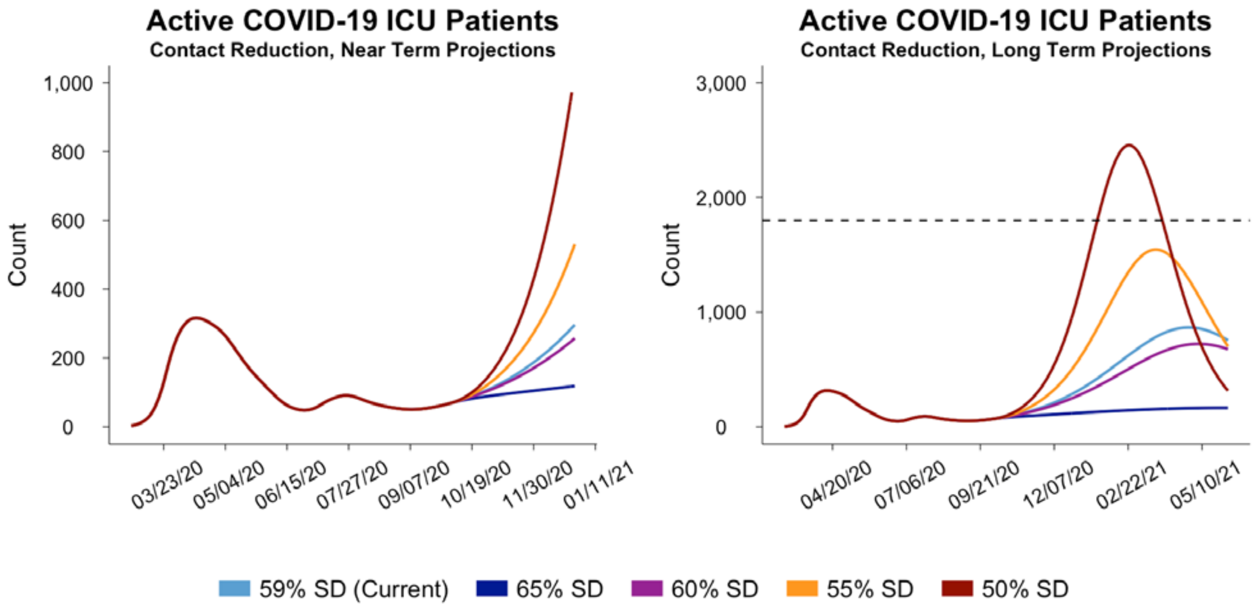



**Figure 12.** Projected daily count of new infections (top), hospital demand (middle), and intensive care (ICU) demand (bottom) in the near-term (left) and long-term (right), assuming social distancing remains at current levels (59%), or switches to 65, 60, 55 or 50% on 10/02. Projections are shown assuming mask wearing remains at 90% starting from 7/16, the date of the state-wide mask order. Based on CDC recommendations, in the scenarios half of older adults are assumed to practice high levels of social distancing (80%). Case isolation is assumed to remain at current levels. Dashed lines on the new infections plot indicate the number of new infections estimated during the April and July peaks. Dashed line on the ICU plot indicates estimated hospital capacity.

## Projections: decreases in social distancing during the holiday season.

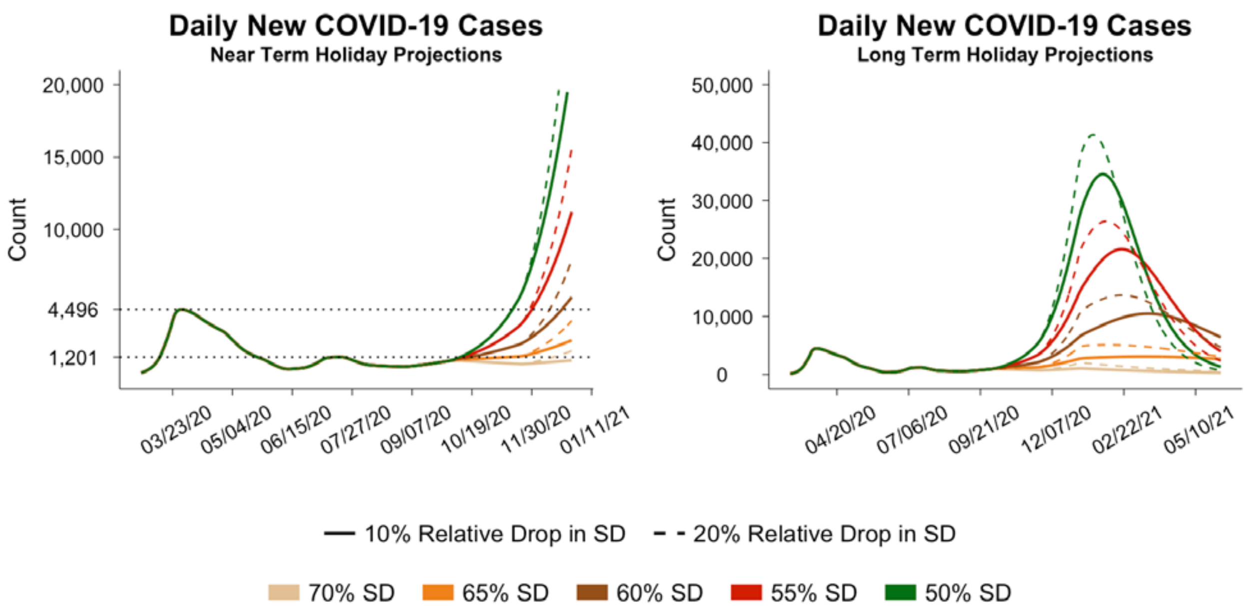
Given the recent rise in cases around the Independence Day and Labor Day holidays, we generated preliminary scenarios to evaluate the potential impact of theoretical increased social contacts over winter holidays. These scenarios assume social distancing decreases starting the Friday before Thanksgiving, 11/20/2020, and lasts until 1/03/2021. We do not know what the true increase in infectious contacts will be over the holiday season – we modeled 10% and 20% decreases as preliminary scenarios. We generated projections for five different social distancing scenarios in the weeks ahead. Scenarios in which social distancing is increased to 70% or 65%, or when social distancing is at 60% or decreased to 55%, or 50% on 10/02. This allows us to examine the extent to which the level of infections entering the holiday season impacts the severity of any increase in cases over the holidays.

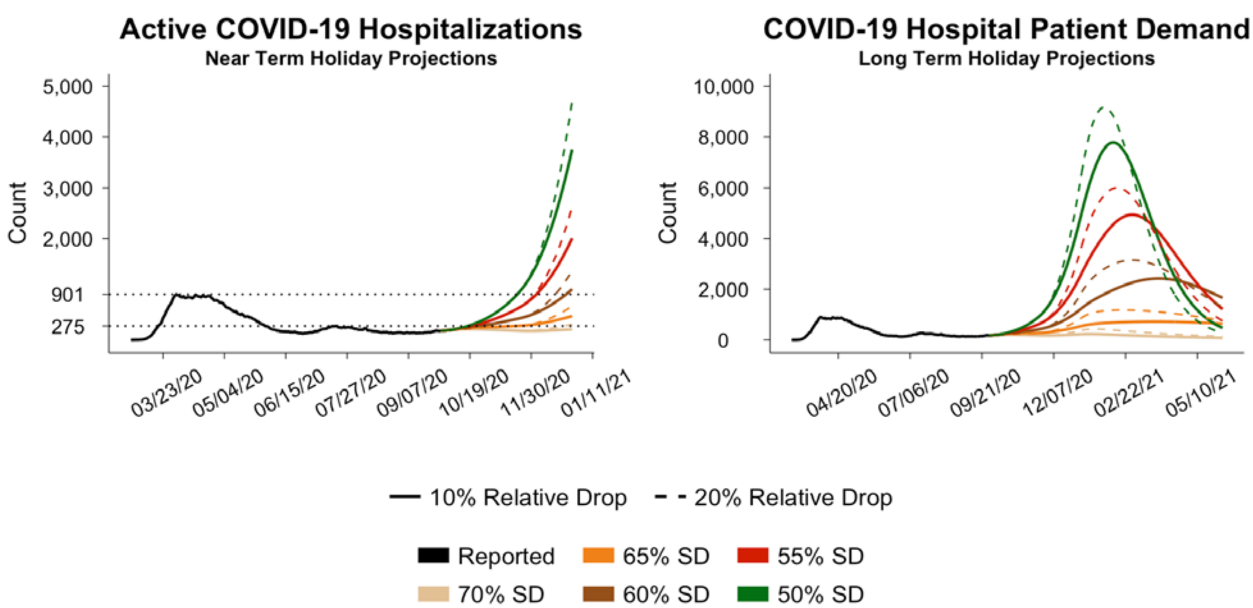
As shown in Figure 13 and Table 3, a holiday increase in contacts has the potential to lead to an increase in infections and hospital demand. This increase will happen more rapidly and the peak will be higher if we enter the holidays at a higher level of infection. Controlling infections in October and November can reduce the severity of a holiday "bump."

**Table 3. Peak ICU usage under different holiday season scenarios**

| Social Distancing levels from 9/25 until 11/19 | ICU Peak Usage |
|---|---|
| 10% Relative Decrease in SD Over Holidays (11/20 - 01/03) | |
| ~Current (60%) | 890 |

| | |
|---|---|
| 70% | Past |
| 65% | Past |
| 55% | 1,800 |
| 50% | 2,800 |
| 20% Relative Decrease in SD Over Holidays (11/20 - 01/03) | |
| ~Current (60%) | 1,200 |
| 70% | Past |
| 65% | 440 |
| 55% | 2,200 |
| 50% | 3,300 |



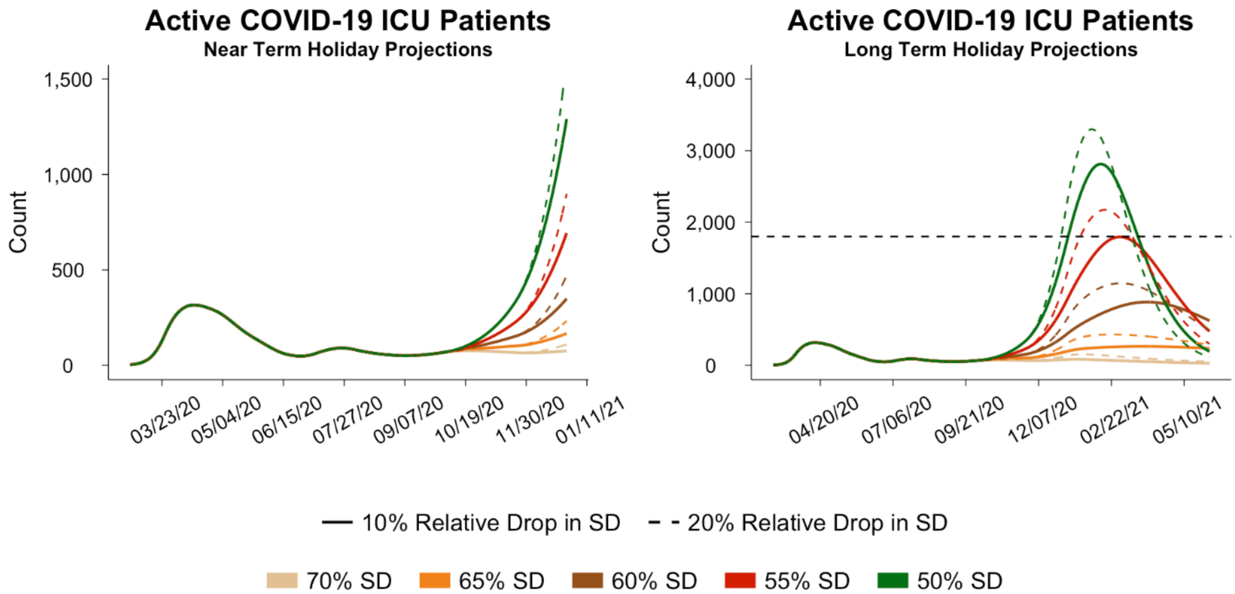



**Figure 13.** Projected daily count of new infections (top), hospital demand (middle), and intensive care (ICU) demand (bottom) in the near term (left) and long term (right), with a 10% relative decrease in social distancing over the winter holidays shown in solid lines and a 20% relative decrease in social distancing over the holidays shown in dotted lines. Model assumes social distancing remains at ~ current levels (60%), or switches to 70, 65, 55 or 50% on 10/02. Decreases in social distancing around the winter holidays is assumed to begin 11/20/2020 and last until 1/03/2021. Projections are shown assuming mask wearing remains at 90% starting from 7/16, the date of the state-wide mask order. Case isolation is assumed to remain at current levels.

## How has contact tracing impacted transmission?

For the purpose of this analysis, contact tracing was incorporated in the transmission reduction model through inclusion of an additional compartment in each age category, the Isolated Infectious compartment (II), as per [1]. Individuals who move to the isolated infectious compartment are exposed and infectious individuals who have been identified by public health officials, are told to quarantine, and comply. Infectious individuals are removed from both the I (symptomatic) and A (asymptomatic) compartments to the II compartment at the following rate: pID*pCT*κ*π*ω. These parameters are as follows:

- pID is the proportion of total infections, including asymptomatic and symptomatic, that are detected by public health authorities. For the purpose of this analysis, pID is calculated from the statewide model fit to hospitalizations.
- pCT is the proportion of detected cases traced. κ is the average number of contacts per identified infectious individual. Data collected by CDPHE on contact tracing from 33 LPHAs was used to estimate these values. It was not feasible to identify both variables from the data, however, it was possible to calculate the total number of contacts contacted per case in the LPHA which is equivalent to pCT* κ
- π is the probability that a traced infectious contact is isolated before infecting other susceptible individuals. This value is dependent on the lag between symptom onset and case report to health authorities, as well as the amount of time it takes for contact tracing to occur after a case is reported. In Colorado, we typically see a lag of approximately 7 days between symptom onset and case report – which translates to an average of 8 days between the onset of infectiousness and report. Assuming contacts are reached within the targeted 24 hours of case report, for any infectious contacts that occurred in the 9 days of case infectiousness, on average 5/9 of those days could have led to an infectious contact that could have infected another individual in those 5 days between onset of infectiousness and tracing. The time between case report and contact interview was estimated from LPHA reports on contact tracing.
- ω is the probability a contact-traced individual is infected and has been estimated from the literature [2-7]. Estimates for secondary attack rates among household contacts range from 4.6% to 19.3%, and among non-household contacts range from 0% to 0.55%. We use the approximate average 9% secondary attack rate among household contacts and 0.275% attack rate among non-household contacts. We assume the average individual has two household contacts, and, those are the most likely individuals to be successfully traced. Thus, if only 2 contacts are traced per case, both are likely to be household, and we use the household secondary attack rate of 9%. As data suggests on average fewer than two contacts were reached per case, the secondary attack rate of 9% was used for the purpose of this analysis.

Contact tracing data was collected by CDPHE weekly from 33 LPHAs for five weeks from 07/13 to 08/17. These data were used to estimate the average number of contacts per case for each participating LPHA region. LPHAs ranged from very large (i.e. Denver) to small (i.e. San Juan County) and so estimates from each LPHA were weighted based on the number of cases within the LPHA for the week of report in order to generate state-wide estimates of contact tracing. LPHAs which did not report were assumed to have similar contact tracing metrics to other LPHAs of similar size and case load.

To estimate the impact of contact tracing, the transmission reduction parameter was refit to the hospitalization data, under the assumption of contact tracing levels from the data which changed over time. Contact tracing was introduced on June 1, assuming a linear increase up to July 13 levels, and then changed weekly in accordance with estimates from the LPHA data.

**Table 4.** Metrics calculated from LPHA Contact Tracing Report Data provided by CDPHE

| Date | PCT*k = contacts /case | Total lag time from symptom onset to contact interview (days) | Pi = probability that contact was reached before infecting others | PID = Proportion of infections detected (from state model) |
|---|---|---|---|---|
| 7/13/2020 | 0.64 | 11.51 | 0.35 | 0.384 |
| 7/20/2020 | 0.74 | 9.12 | 0.44 | 0.441 |
| 7/27/2020 | 0.83 | 8.49 | 0.47 | 0.44 |
| 8/3/2020 | 1.34 | 9.22 | 0.43 | 0.447 |
| 8/10/2020 | 1.16 | 8.94 | 0.45 | 0.413 |

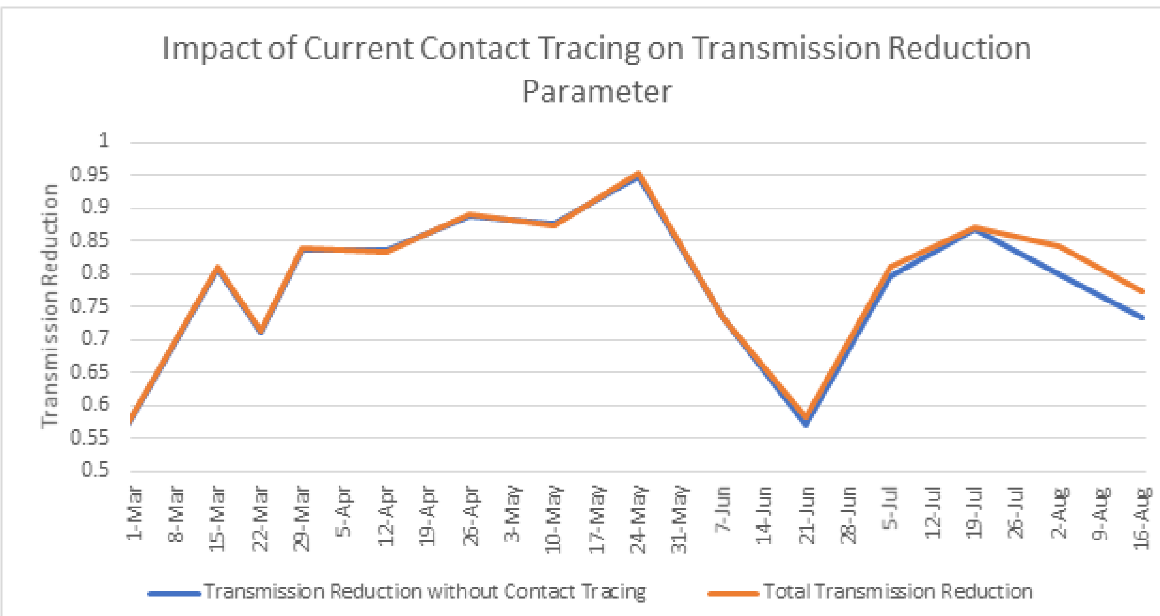



**Figure 14.** Transmission reduction parameter estimates over time, with and without contact tracing in the model. In the model fit to contact tracing data. The transmission reduction parameter can be interpreted as total transmission reduction minus the transmission reduction due to contact tracing. Vertical line indicates introduction of contact tracing into model.

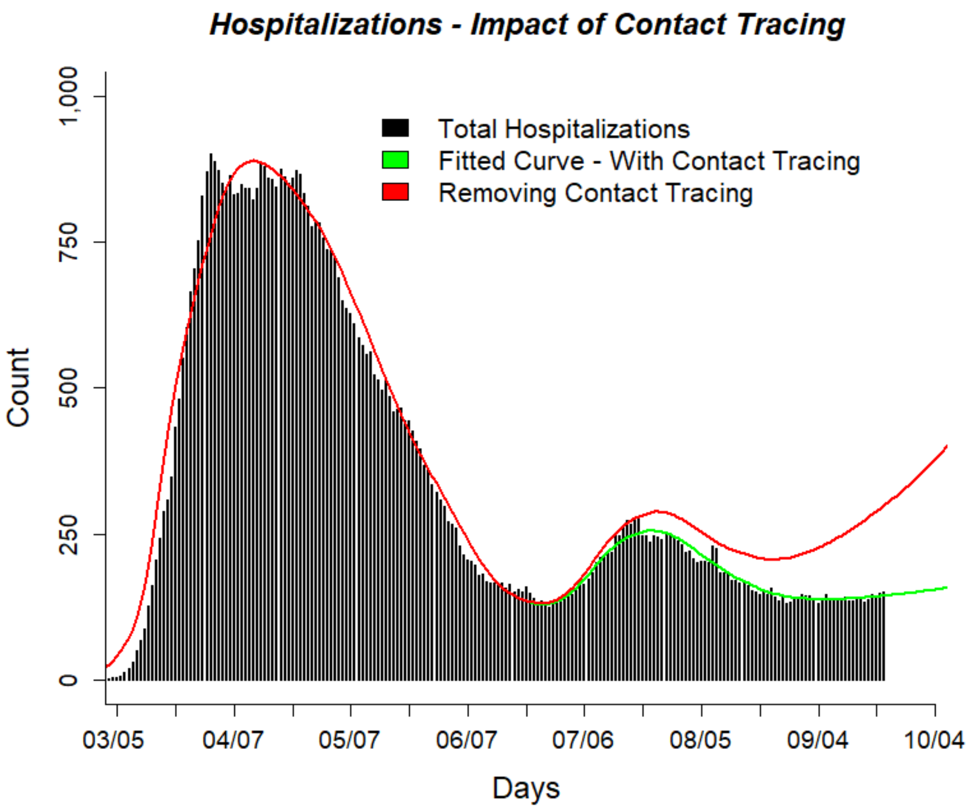



**Figure 15.** Model fitted to hospitalization data including contact tracing. The green line is the fitted line, under the assumptions of contact tracing (outlined above). The red line is the same model, when contact tracing is set to 0 and can be interpreted as the counterfactual level of hospitalizations, had contact tracing not occurred.

Interpretation: Addition of contact tracing at the current levels has increased the amount of transmission reduction in Colorado by ~5% at various time points. Contact tracing likely played a vital role in suppressing transmission and maintaining low levels of hospitalizations over the months of July and August. Previous research has found evidence that increasing the proportion of cases successfully traced can increase the effectiveness of contact tracing [8], and severe delays in contact tracing can limit its efficacy [9]. Reviewing the data from the 33 LPHAs, it appears LPHAs with greater case-loads are limited in their ability to contact sufficient cases in an efficient time-frame suggesting re-allocation of resources to LPHAs with more cases could improve the effectiveness of contact tracing state-wide.

# Appendix

Code for our model is available on GitHub: https://github.com/agb85/covid-19

Model simulations evaluating the potential impact of interventions can be generated using our app: https://cucovid19.shinyapps.io/colorado/. This site also includes detailed documentation of our model. The app is updated weekly to reflect our most recent parameter estimates.

**Appendix Table A1.** Estimated model parameters based on fitting our model output of total hospitalizations to reported hospitalizations in Colorado. The "SD" model includes a social distancing parameter with assumptions for mask wearing and self-isolation of symptomatic cases as described in the table. The new "TR" model includes a single transmission reduction parameter that accounts for all reduction in effective contacts as a result of all policy and behavior changes to reduce transmission.

| | Range of possible values | Fitted value, SD model | Fitted value, TR model | Fit using data through |
|---|---|---|---|---|
| **Social distancing*** | | | | |
| Estimated social distancing level over past four weeks, 08/17 – 09/15 | 0-99% | 59% | | 09/28 |
| Estimated current social distancing level, 08/31 – 09/15 | 0-99% | 64% | | 09/28 |
| **Transmission Reduction** | | | | |
| Estimated transmission reduction level over past four weeks, 08/17 – 09/15 | 0-99% | | 74% | 09/28 |
| Estimated current transmission reduction level, 08/31 – 09/15 | 0-99% | | 76% | 09/28 |
| **Mask wearing** | | | | |
| Percent of individuals wearing masks, 4/4 to 4/27 | | 50% | N/A | Assumed¶ |
| Percent of individuals wearing masks, 4/27 to 7/15 | | 70% | N/A | Assumed¶ |
| Percent of individuals wearing masks, 7/16 to present | | 90% | N/A | Assumed |
| **Case isolation** | | | | |
| Decrease in infectious - symptomatic contact rate due to self-isolation by symptomatic after March 5 (dividing by 0.57 gives proportion that self-isolate) ** | 0.1 - 0.8†† | 0.44 | N/A | 06/24 |
| **Case detection** | | | | |
| Proportion of cases detected over the last 14 days | 0.0 – 1.0 | 42% | N/A | 08/10 |
| **Transmission parameters** | | | | |
| The rate of infection (beta) | 0.2 - 0.6†† | 0.48 | 0.48 | 06/24 |
| Ratio of infectiousness for symptomatic vs. asymptomatic individuals (lambda) | 1.0 - 4.0†† | 1.39 | 1.39 | 06/24 |

*The social distancing parameter estimates the percent decrease in effective contacts between susceptible and infectious individuals. This parameter accounts for social distancing policies intended to avoid contact altogether (e.g., through workplace and school closures) as well as policies and individual behaviors to reduce potential contact with the virus (e.g., maintaining at least 6 feet of distance between people outside of one's household, and handwashing).

†Social distancing estimated weekly and averaged over time period of interest.

¶Given the difficulty in disentangling the effect of mask wearing from social distancing in decreasing transmission, we cannot fit this parameter at this time. Survey data suggests levels of mask wearing in June were are

approximately 70% [10]. Recent data from local public health agencies suggest mask wearing is above 90% in stores.
**Self-isolation by symptomatic cases is assumed to occur 1 day after the onset of infectiousness and decrease the 67% of contacts that typically occur outside of the home. This parameter jointly accounts for the percent of symptomatic individuals that self-isolate and the imperfect decline in contacts. Dividing the value in the table by 0.57 gives the proportion of symptomatic individuals that self-isolate.
††The range of potential parameter values for case isolation [11] and the rate of infectiousness for symptomatic vs. asymptomatic individuals [12, 13] are based on the literature, and for the rate of infection, were obtained from the MIDAS Online COVID-19 compilation of parameter estimates [14].

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