SAND2020-4300PE

Sandia COVID-19 Medical Resource Modeling

New Mexico – Updated Results

21 April 2020

SNL Pandemic Modeling Team

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.
SAND2020-3961 PE

Sandia's Modeling Effort

Building from epidemiological projections, develop quantitative guidance for:

Current Emphasis

RESOURCES

Number of resources needed over time

Optimal distribution of limited resources

Disease-control impacts of resource availability

TESTING

Optimal testing configuration and deployment

Impacts of testing strategies for EMS and Healthcare workers to limit contagion and secondary community disease spread

HEALTHCARE WORKFORCE

Optimal healthcare workforce policies to limit disease spread to community, patient and staff in resource constrained settings

Mathematical approach includes optimization, logistics, and resource modeling

Sandia's approach is agnostic to which epi model input is used; we are prepared to receive data from any epi model

Epidemiological Models Available for State of New Mexico

For the New Mexico analysis, three epidemiological models are used as inputs to Sandia's resource models to understand the range of resource needs across all different epidemiological model approaches

	LOCAL MODEL	IHME (UW)	LANL EPIGRID
Approach	Parameter-driven With data SIR	Data-driven Statistical	Parameter-driven SEIR+
Goal		Death Count Forecasting Health Service Utilization	To address contagion, disease progression, geographical heterogeneity, and the effect of human actions modulating epidemic dynamics.
Version Used	Worst case scenario provided 4/14 3:05pm; Best case scenario provided 4/20	4/12/20	4/21/20

Number of Resources Needed Over Time | Approach

Inputs

Local | IHME | EpiGrid

Hospital Arrivals Over Time

Model

Demographics

Treatment Stage

Fates

Parameters

Maximum time on ventilator
Maximum time in ICU if not ventilated
Probability of going to ICU
Probability of needing ventilator
Probability of death if ventilated
Probability of death if not ventilated
…

Outputs

Committed Resources Need Over Time	Consumable Resources Need Over Time	Personnel Need Over Time
Beds	Gown	Floor Nurse
ICU Beds	N95 Mask	ICU Nurse
Metered Dose Inhaler	Face Shield	Physician
Ventilator	Gloves	Respiratory Therapist
	Sedatives	

This approach can be applied to any geographic scale for which epi results are available

Caveats: Modeling

Model Framework

- Practitioners have fixed roles and are dedicated to specific stages – possible overestimation of personnel

Model Implementation

- The code is simple and provides correct answer to a set of test cases; unit tests, documentation, and review are forthcoming

Configuration/Parameters

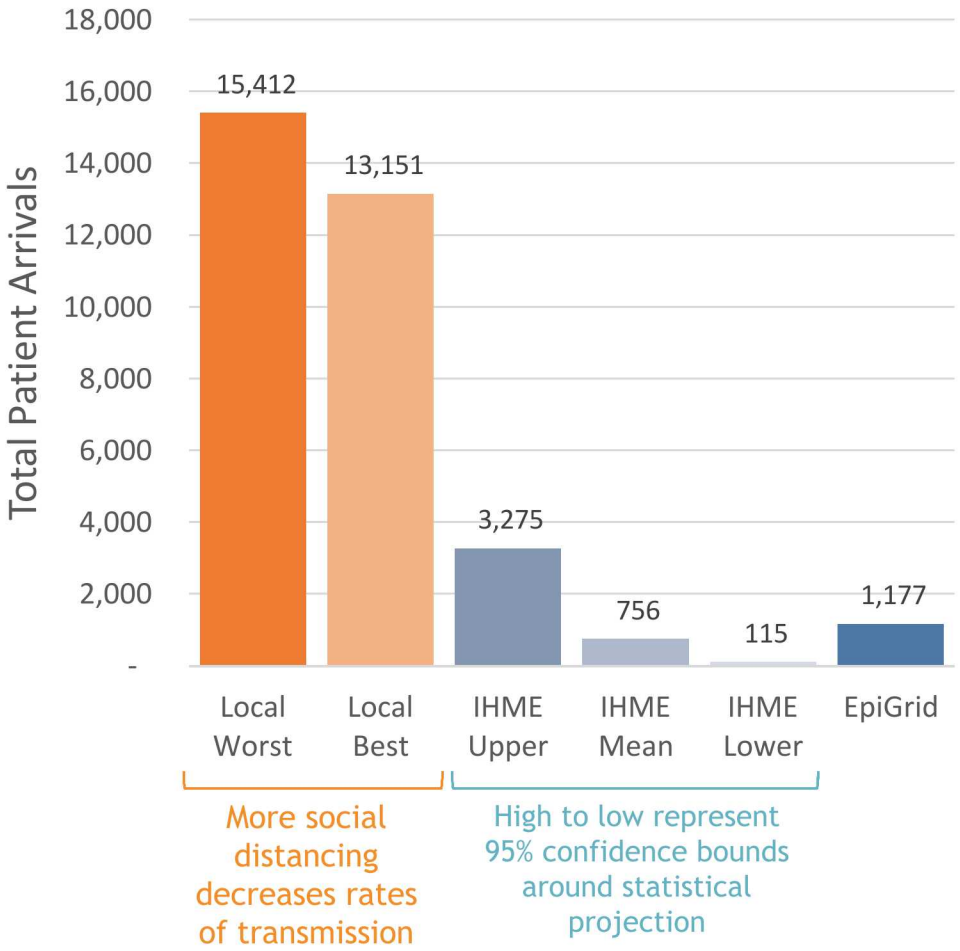
- Resource requirements from background medical services are not included
- Some categories of workers (e.g. Environmental Services) were not included
- PPE consumption rates in this context are not well characterized. Input reflects planning and recent practice
- Patient feeds from the epi models do not come with demographic characteristics; Treatment pathway probabilities are therefore not conditional on age, pre-existing conditions, etc.
- Relationship between inherent stochasticity (e.g. running model replications with the same parameters) vs. changing governing parameter (uncertainty) not yet characterized
- Initial results suggest output is dominated by scale of patient stream from epi model, but parameter uncertainty is also significant (e.g. the ratio of standard deviation to the mean is 0.3-0.4 for many response quantities, which results in wide uncertainty predictions). Properly accounting for epi scenario uncertainty vs. parameter uncertainty will be case-specific and is an important aspect of these studies.

New Mexico Inputs

New Mexico Epi Inputs (4/21)

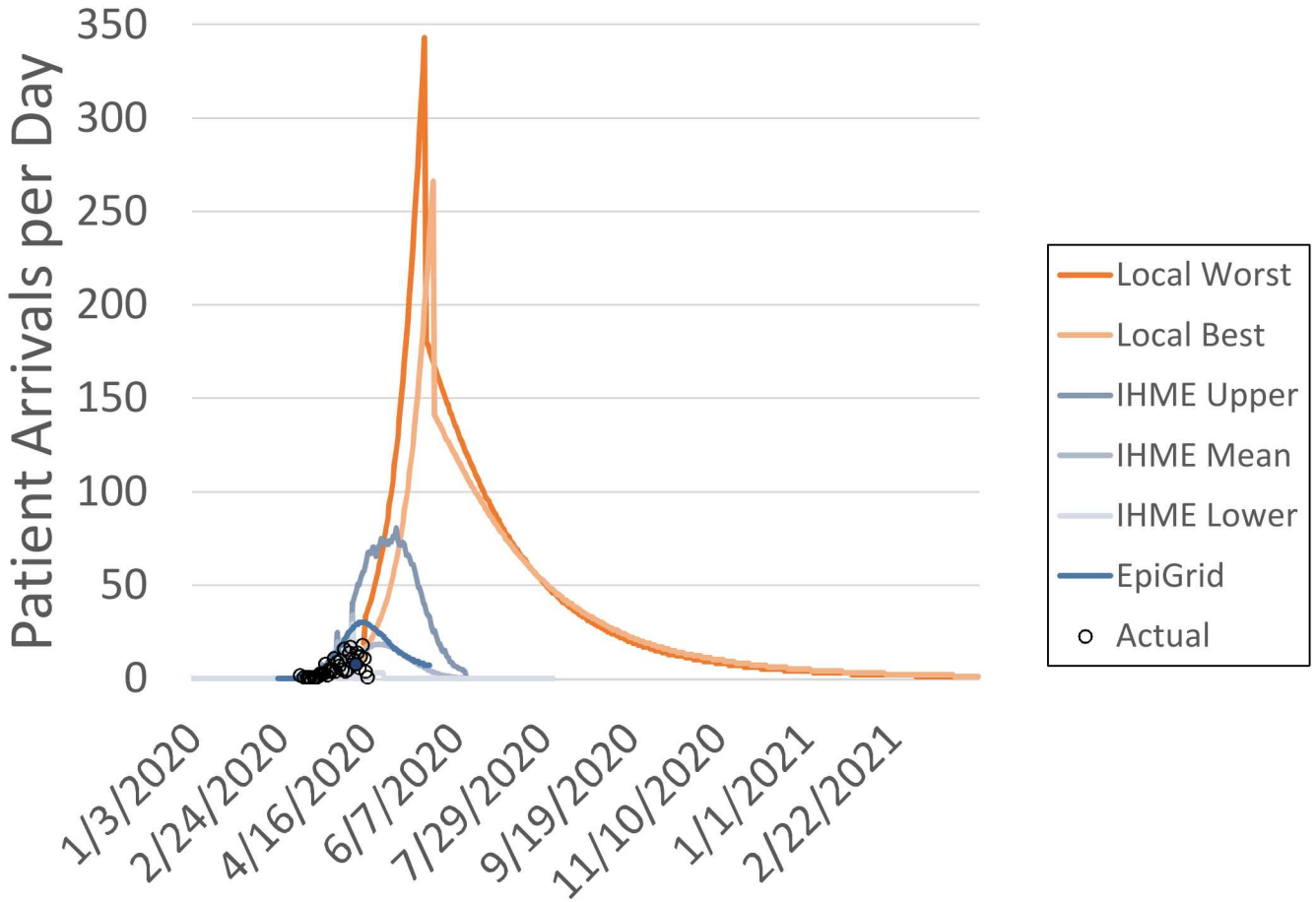
Inputs

Local | IHME | EpiGrid



Outputs

Committed Resources Need Over Time | Consumable Resources Need Over Time | Personnel Need Over Time



Data as of: Local: 4/14; IHME: 4/12; EpiGrid: 4/13; Actuals: "COVID19 linelist Exp 17APR20.xlsx" email from Hicks

New Mexico Results
Comparing All Epi Models

New Mexico Results – Comparing All Epi Models (4/21)

Inputs

Local | IHME | EpiGrid

Outputs

Committed Resources Need Over Time | **Consumable Resources Need Over Time** | **Personnel Need Over Time**

				Committed Resources (Max Needed)				Consumable Resources (Total Needed)				
Epi Model	Scenario	Patient Arrivals	Statistic	Bed (Cap: 2,403)	ICU Bed (Cap: 546)	Metered Dose Inhaler	Ventilator (Cap: 328)	Gown	N95	Face Shield	Gloves	Sedatives
EpiGrid	Baseline	1,184	Mean	137	55	46	46	23,602	19,310	16,138	71,803	4,587
			Std. Dev.	21	20	19	19	8,097	7,898	7,852	29,537	1,978
Local	Worst Social Response	15,412	Mean	1,269	476	384	384	296,943	242,047	203,749	892,310	59,361
			Std. Dev.	192	175	163	163	104,286	99,939	99,977	366,851	25,109
	Best Social Response	13,151	Mean	972	361	291	291	253,669	206,906	173,967	762,631	50,545
			Std. Dev.	140	127	117	117	88,414	85,101	85,070	312,491	21,249
IHME	Upper	3,275	Mean	350	137	113	113	64,702	52,168	44,522	191,402	12,670
			Std. Dev.	57	50	47	47	25,614	24,133	23,699	85,468	5,669
	Mean	756	Mean	87	35	30	30	15,745	12,787	10,784	47,260	2,920
			Std. Dev.	15	13	12	12	5,788	5,565	5,392	19,333	1,314
	Lower	115	Mean	40	15	11	11	2,792	2,303	1,863	8,797	435
			Std. Dev.	6	6	5	5	926	817	800	3,073	219

New Mexico Results – Comparing All Epi Models (4/21)

Inputs

Local | IHME | EpiGrid

Outputs

Committed Resources Need Over Time | Consumable Resources Need Over Time | Personnel Need Over Time

	Bed						ICU Bed						Metered Dose Inhaler						Ventilator					
	Local Worst	Local Best	IHME Upper	IHME Mean	IHME Lower	EpiGrid	Local Worst	Local Best	IHME Upper	IHME Mean	IHME Lower	EpiGrid	Local Worst	Local Best	IHME Upper	IHME Mean	IHME Lower	EpiGrid	Local Worst	Local Best	IHME Upper	IHME Mean	IHME Lower	EpiGrid
Min	891	699	252	57	25	91	177	151	50	12	3	17	117	101	38	8	2	14	117	101	38	8	2	14
Max	1,749	1,303	472	124	53	192	874	628	240	63	29	108	866	622	235	62	29	106	866	622	235	62	29	106
Mean	1,269	972	350	87	40	137	476	361	137	35	15	55	384	291	113	30	11	46	384	291	113	30	11	46

Ranges in demand are dictated by uncertainties in parameters (e.g., probability the patient goes into the ICU, needs a ventilator, length of stay)

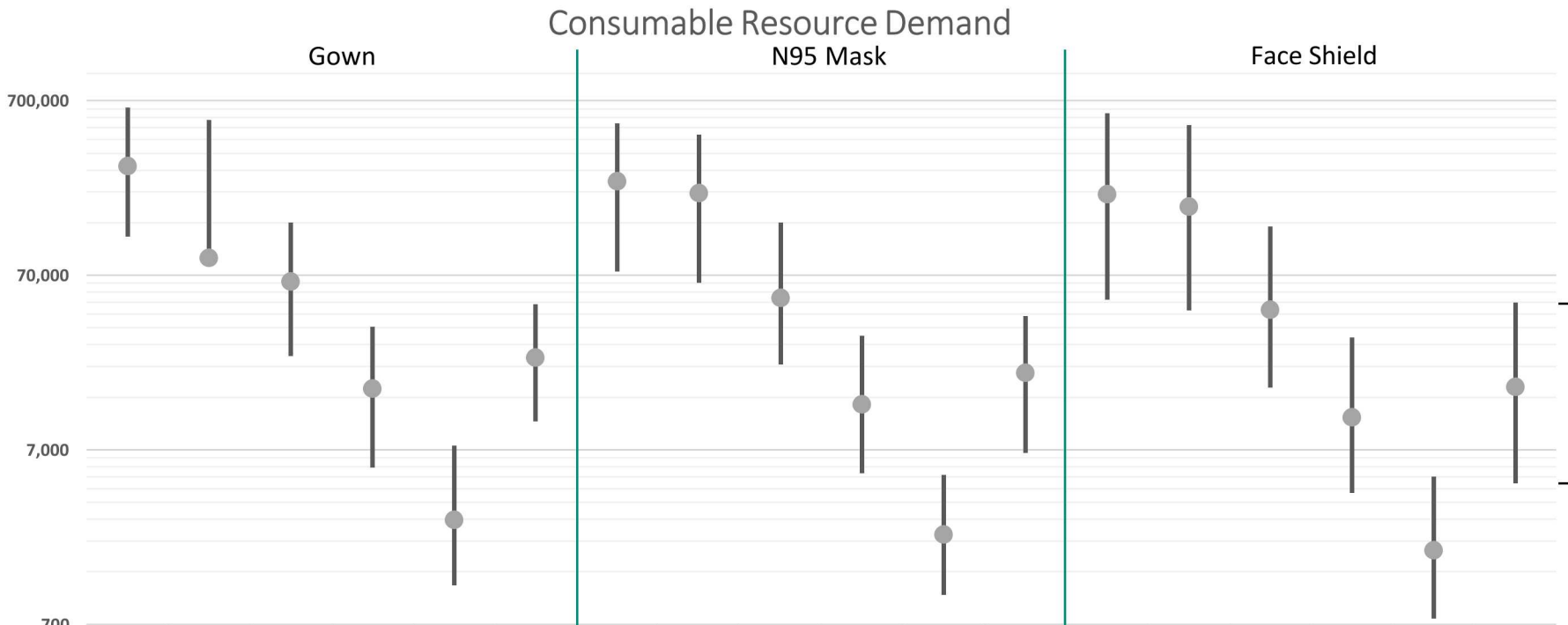
New Mexico Results – Comparing All Epi Models (4/21)

Inputs

Local | IHME | EpiGrid

Outputs

Committed Resources Need Over Time | **Consumable Resources Need Over Time** | Personnel Need Over Time



	Gown						N95						Face Shield					
	Local Worst	Local Best	IHME Upper	IHME Mean	IHME Lower	EpiGrid	Local Worst	Local Best	IHME Upper	IHME Mean	IHME Lower	EpiGrid	Local Worst	Local Best	IHME Upper	IHME Mean	IHME Lower	EpiGrid
Min	117,274	101,966	24,129	5,549	1,176	10,191	73,960	63,789	21,628	5,155	1,038	6,756	50,790	44,305	16,012	3,973	757	4,513
Max	640,272	546,589	141,483	35,717	7,427	48,161	522,722	450,646	141,037	31,597	5,037	41,159	595,227	509,094	133,855	30,856	4,927	48,950
Mean	296,943	88,414	64,702	15,745	2,792	23,602	242,047	206,906	52,168	12,787	2,303	19,310	203,749	173,967	44,522	10,784	1,863	16,138

Ranges in demand are dictated by uncertainties in parameters (e.g., probability the patient goes into the ICU, needs a ventilator, length of stay)

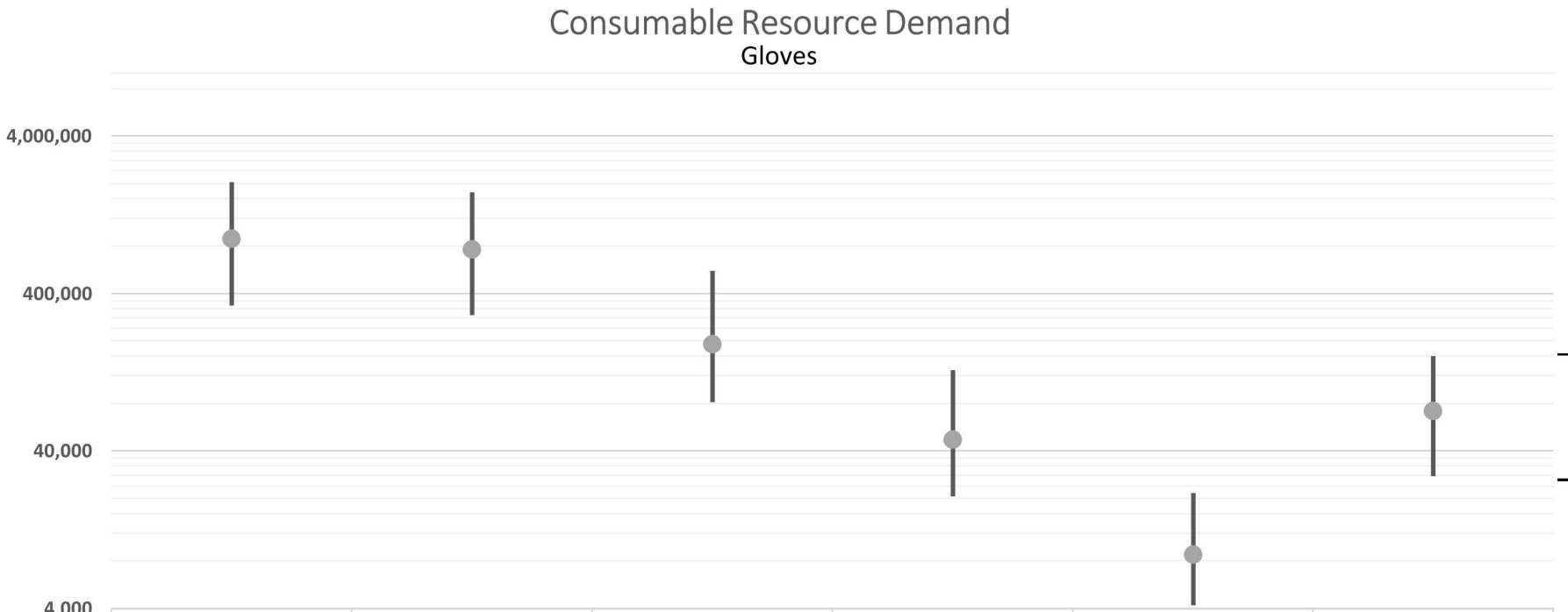
New Mexico Results – Comparing All Epi Models (4/21)

Inputs

Local | IHME | EpiGrid

Outputs

Committed Resources Need Over Time | **Consumable Resources Need Over Time** | Personnel Need Over Time



	Local Worst	Local Best	IHME Upper	IHME Mean	IHME Lower	EpiGrid
	Gloves					
Min	336,645	293,279	81,653	20,591	4,207	27,631
Max	2,049,025	1,760,964	556,672	130,862	21,687	160,348
Mean	892,310	762,631	191,402	47,260	8,797	71,803

Ranges in demand are dictated by uncertainties in parameters (e.g., probability the patient goes into the ICU, needs a ventilator, length of stay)

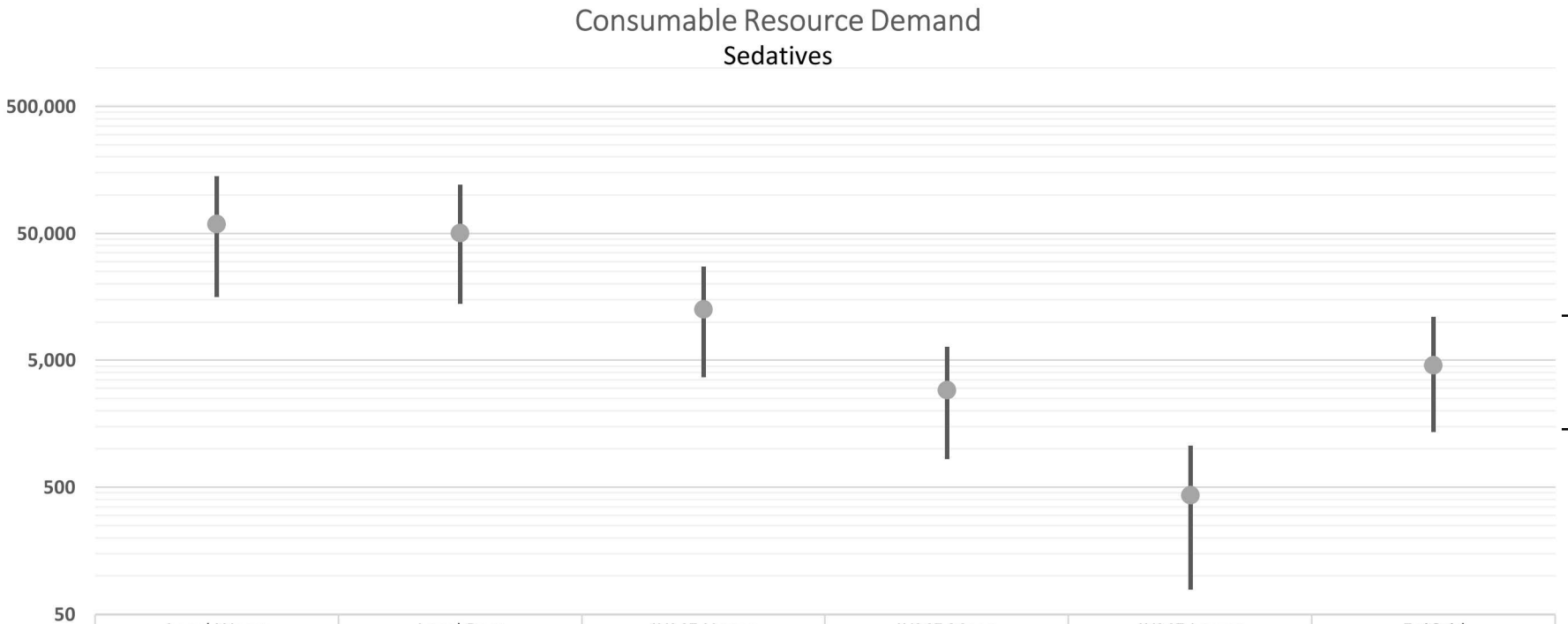
New Mexico Results – Comparing All Epi Models (4/21)

Inputs

Local | IHME | EpiGrid

Outputs

Committed Resources Need Over Time | **Consumable Resources Need Over Time** | Personnel Need Over Time



	Local Worst	Local Best	IHME Upper	IHME Mean	IHME Lower	EpiGrid
	Sedatives					
Min	15,744	14,040	3,684	836	78	1,373
Max	141,929	121,245	27,579	6,392	1,069	11,062
Mean	59,361	50,545	12,670	2,920	435	4,587

Ranges in demand are dictated by uncertainties in parameters (e.g., probability the patient goes into the ICU, needs a ventilator, length of stay)

New Mexico Results Using EpiGrid Input

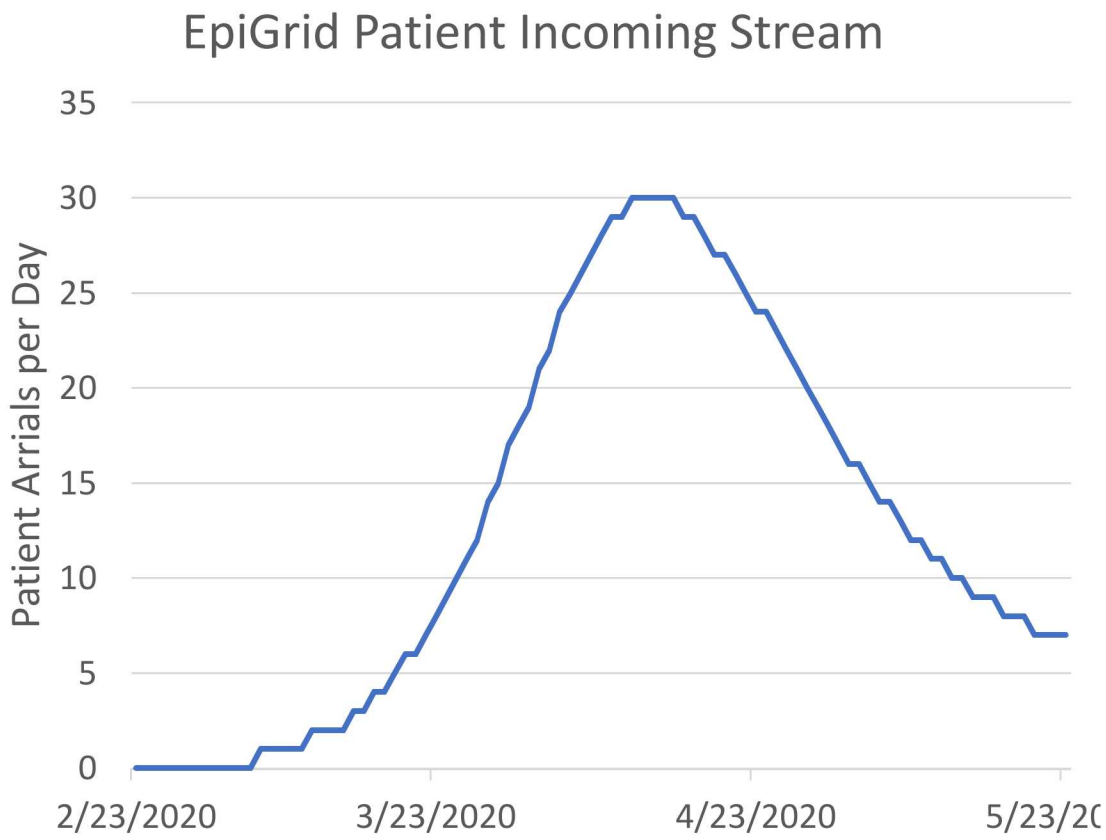
New Mexico EpiGrid Input (4/21)

Inputs

Local | IHME | EpiGrid

Outputs

Committed Resources Need Over Time | Consumable Resources Need Over Time | Personnel Need Over Time



Total patient arrivals: 1,184

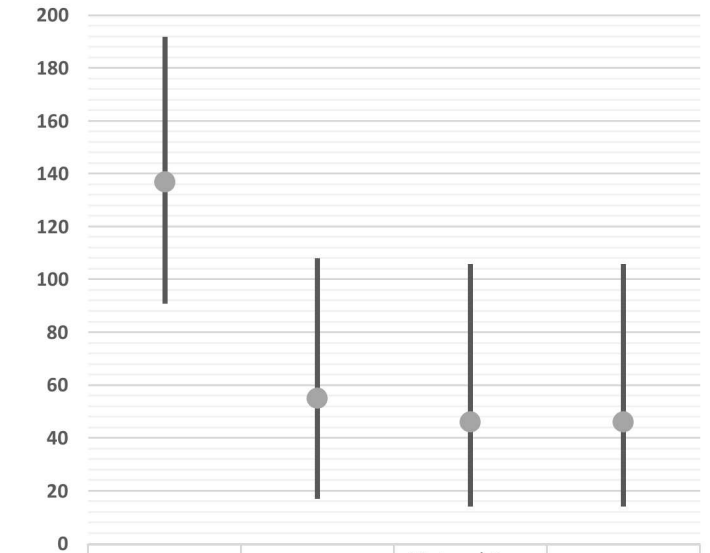
New Mexico Results Using EpiGrid Input (4/21)

Inputs

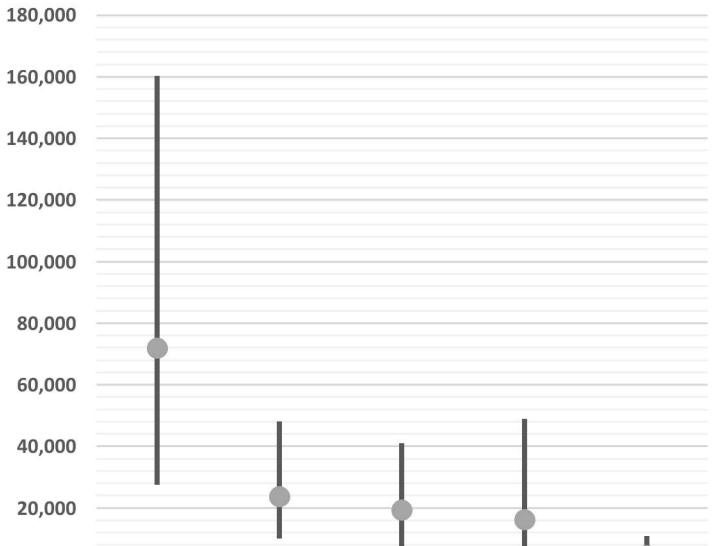
Local | IHME | EpiGrid

Outputs

Committed Resources Need Over Time | **Consumable Resources Need Over Time** | **Personnel Need Over Time**



	Bed	ICU Bed	Metered Dose Inhaler	Ventilator
	Committed Resources			
Min	91	17	14	14
Max	192	108	106	106
Mean	137	55	46	46



	Gloves	Gown	N95	Face Shield	Sedatives
	Consumable Resources				
Min	27,631	10,191	6,756	4,513	1,373
Max	160,348	48,161	41,159	48,950	11,062
Mean	71,803	23,602	19,310	16,138	4,587

Ranges in demand are dictated by uncertainties in parameters (e.g., probability the patient goes into the ICU, needs a ventilator, length of stay)

New Mexico Timeseries Results Using EpiGrid Input (4/21)

Inputs

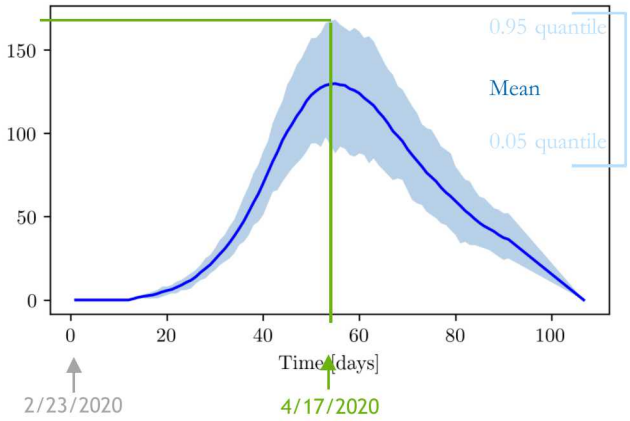
Local | IHME | EpiGrid

Outputs

Committed Resources Need Over Time | Consumable Resources Need Over Time | Personnel Need Over Time

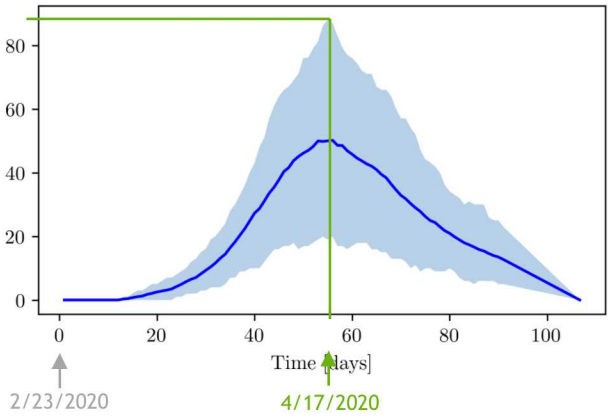
Shows the daily demand up to the "max" number reported on the dot charts/table previously

Bed



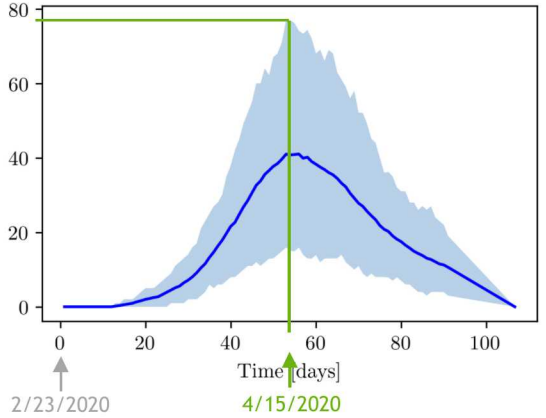
Will most likely need at most 168 beds by **4/17**, but reported statewide capacity is 2403 beds (without surge)

ICU Bed



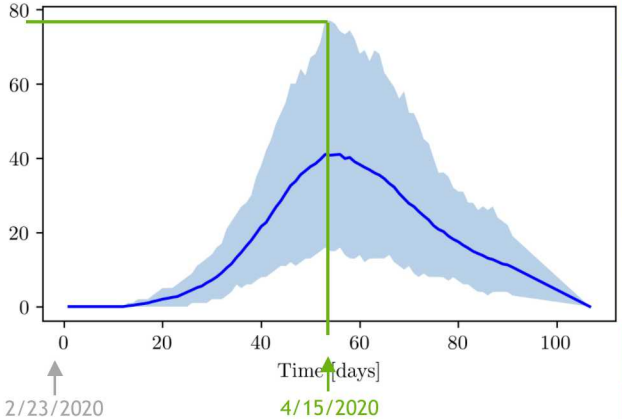
Will most likely need at most 88 ICU beds by **4/17**, but reported statewide capacity is 546 ICU beds (without surge)

Metered Dose Inhaler



Will most likely need at most 77 metered dose inhalers by **4/15** (no known reported capacity)

Ventilator



Will most likely need at most 77 ventilators by **4/15**, but reported statewide capacity is 328 adult ventilators (not counting transport, anesthesia, or BIPAP units)

Ranges in demand (illustrated by the light blue quantiles) are dictated by uncertainties in parameters (e.g., probability the patient goes into the ICU, needs a ventilator, length of stay)

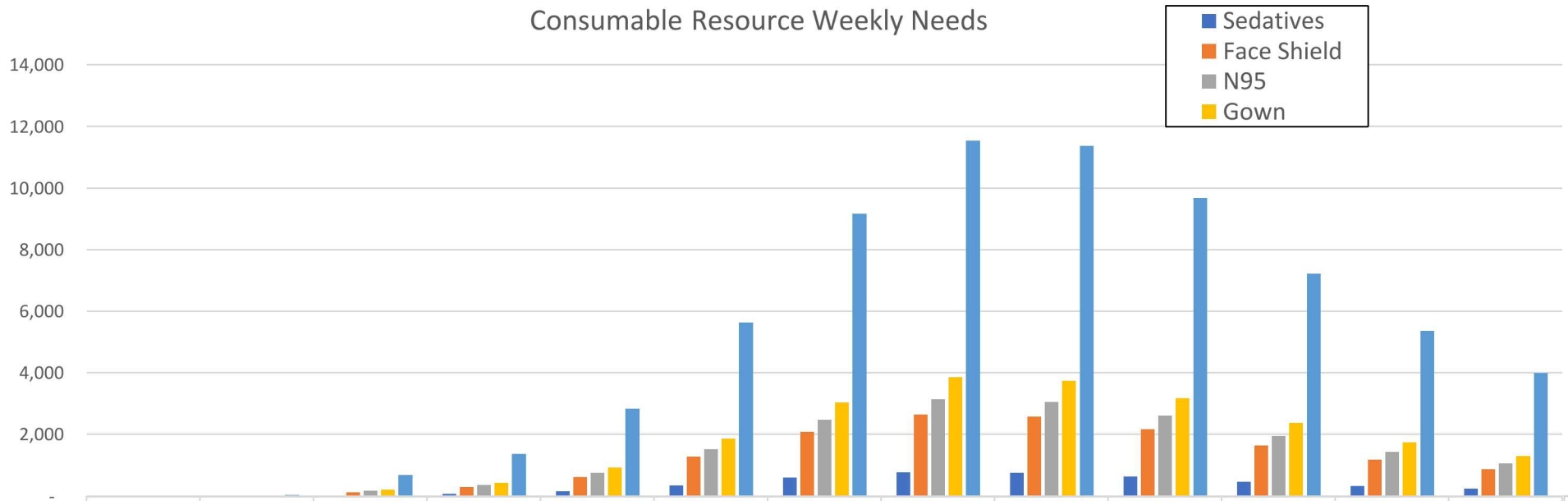
New Mexico Results Using EpiGrid Input (4/20)

Inputs

Local | IHME | EpiGrid

Outputs

Committed Resources Need Over Time | **Consumable Resources Need Over Time** | Personnel Need Over Time



	2/23/2020	3/1/2020	3/8/2020	3/15/2020	3/22/2020	3/29/2020	4/5/2020	4/12/2020	4/19/2020	4/26/2020	5/3/2020	5/10/2020	5/17/2020	Totals
Sedatives	-	1	22	69	165	357	599	771	759	642	474	337	245	**4,441**
Face Shield	-	8	133	293	631	1,286	2,089	2,650	2,579	2,184	1,642	1,192	884	**15,571**
N95	-	12	182	363	753	1,522	2,476	3,146	3,061	2,615	1,949	1,435	1,061	**18,575**
Gown	-	13	205	433	929	1,862	3,045	3,858	3,753	3,185	2,385	1,755	1,304	**22,727**
Gloves	-	45	690	1,377	2,846	5,641	9,169	11,553	11,384	9,679	7,231	5,377	3,999	**68,991**

New Mexico County-Level Results Using EpiGrid Input

County Results – EpiGrid (4/21)

Inputs

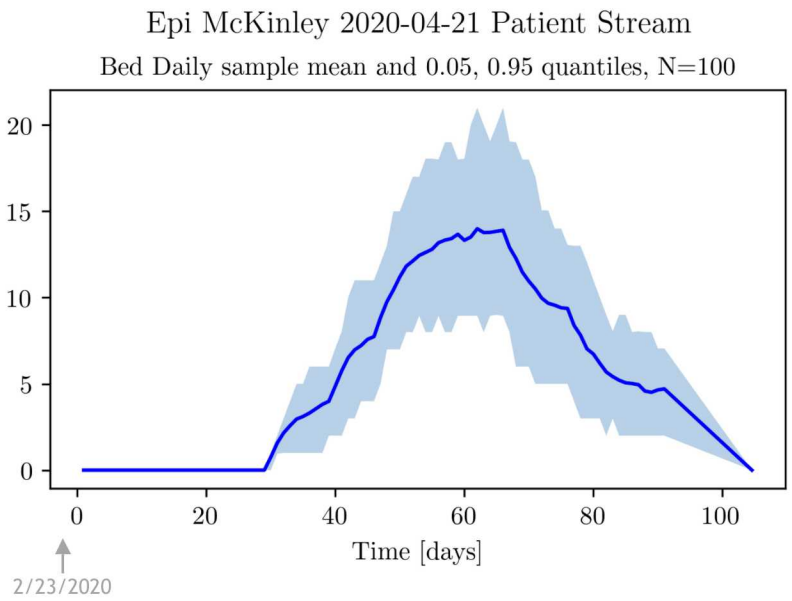
Local | IHME | EpiGrid

Outputs

Committed Resources Need Over Time | **Consumable Resources Need Over Time** | **Personnel Need Over Time**

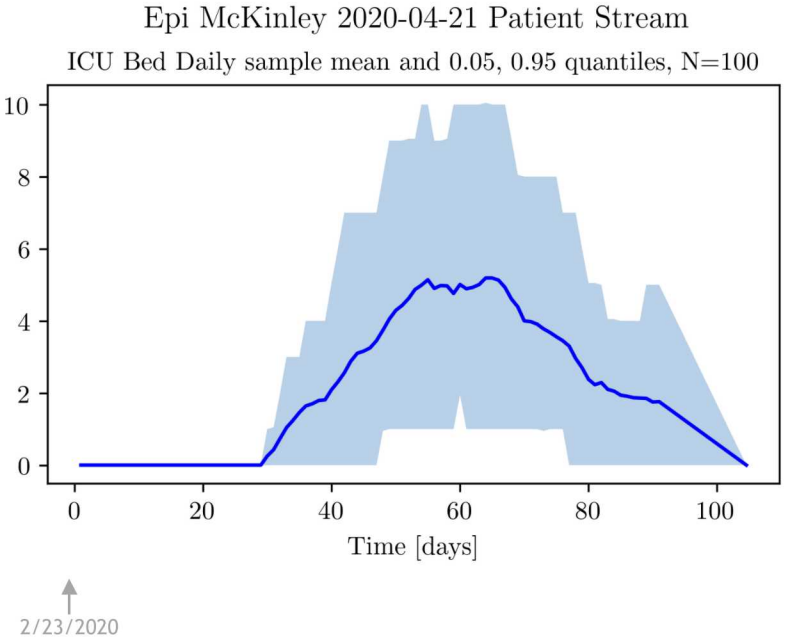
			Committed Resources (Max Needed)				Consumable Resources (Total Needed)				
County	Patient Arrivals	Statistic	Bed	ICU Bed	Metered Dose Inhaler	Ventilator	Gown	N95	Face Shield	Gloves	Sedatives
Bernalillo	390	Mean	53	22	19	19	8575	7032	5847	26,651	1,549
		Std. Dev.	8	7.4	7.3	7.3	2542	2536	2573	10,021	682
Dona Ana	9	Mean	5	3	2	2	418	379	266	1442	42
		Std. Dev.	1.2	1.4	1.1	1.1	172	168	147	660	40
McKinley	119	Mean	17	8	7	7	3,206	2,682	2,141	10,496	473
		Std. Dev.	2.8	2.6	2.6	2.6	904	829	806	3,568	228
San Juan	124	Mean	18	8	7	7	3,307	2,777	2,195	10,751	492
		Std. Dev.	3	2.9	2.7	2.7	897	1,216	789	3,603	236
Sandoval	53	Mean	10	5	4	4	1,702	1,460	1,112	5,778	210
		Std. Dev.	1.8	1.7	1.7	1.7	443	432	391	1,794	115

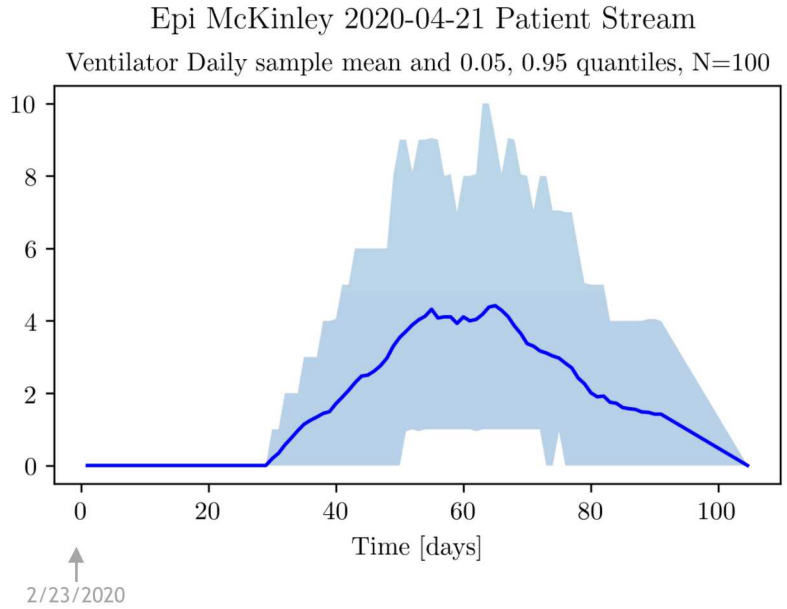
McKinley County



Capacities
From Presbyterian on 4/3/20

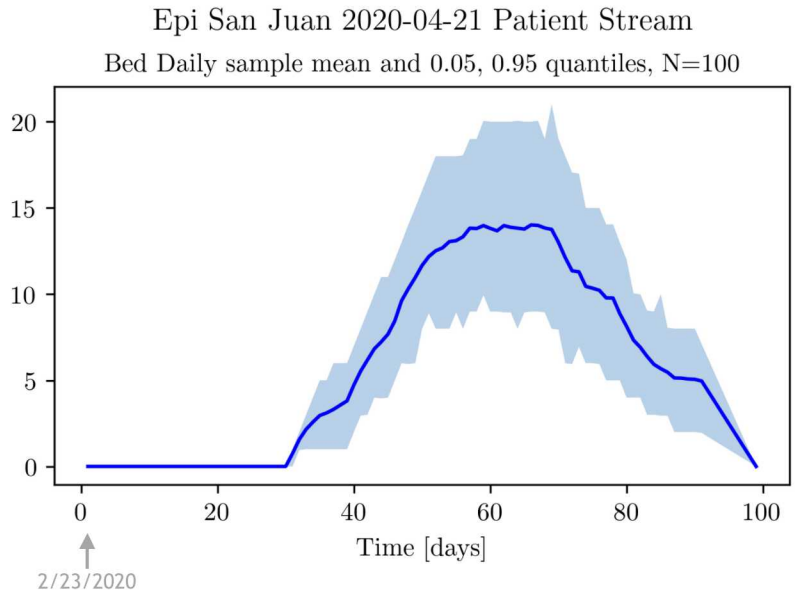
	Beds		ICU Beds	
Hospital	**Routine**	**Surge**	**Routine**	**Surge**
IHS	150	210	28	40
RMCHCS	63	63	16	16
Total	**213**	**273**	**44**	**56**





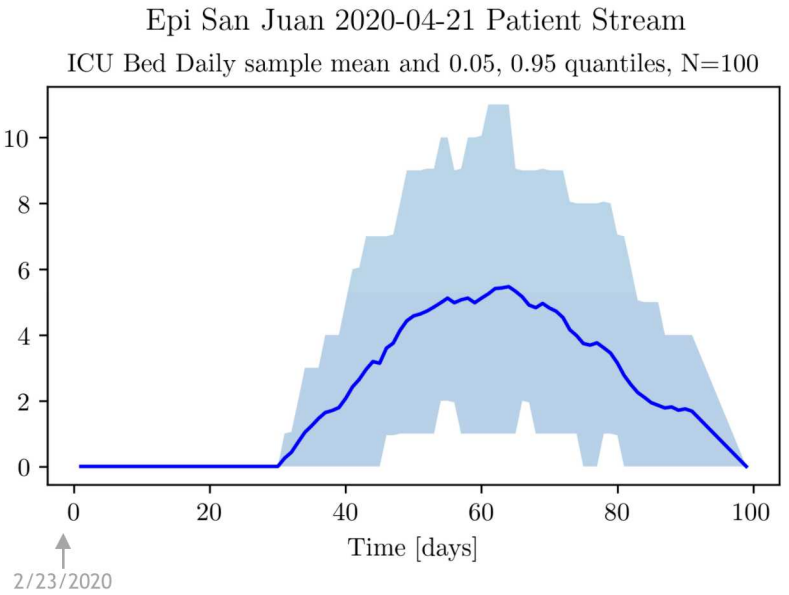
Similar plots for all resources and all counties are available

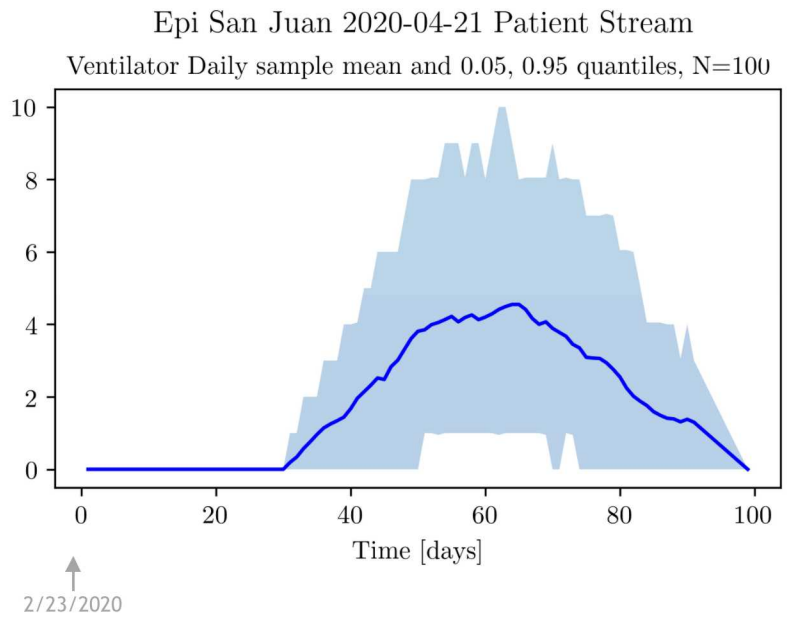
San Juan County



Capacities
From Presbyterian on 4/3/20

Hospital	Beds		ICU Beds	
	Routine	Surge	Routine	Surge
SJRMC	224	224	23	23





Similar plots for all resources and all counties are available

New Mexico Results
Using Presbyterian Input

New Mexico Results Using Presbyterian Input

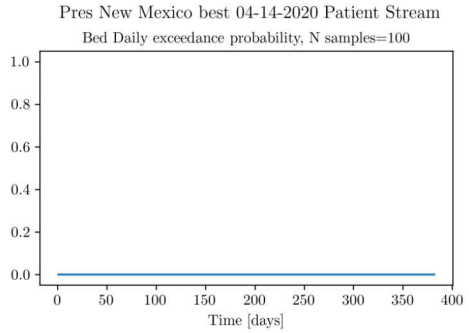
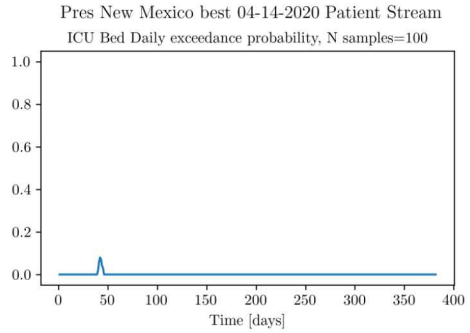
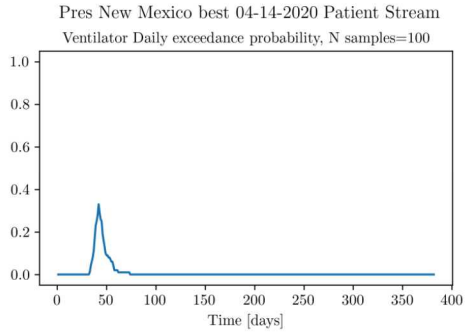
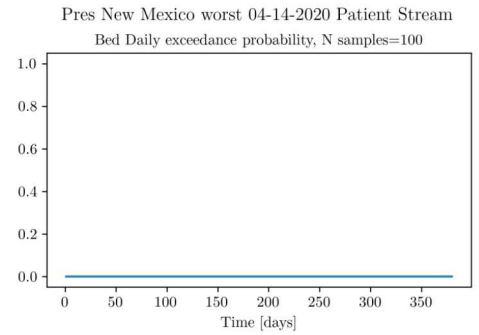
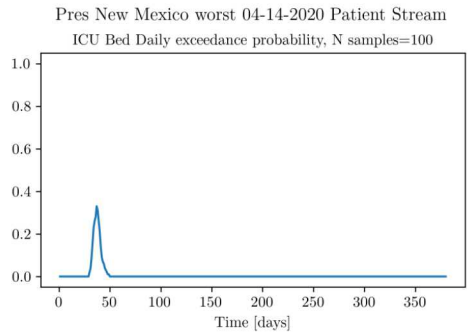
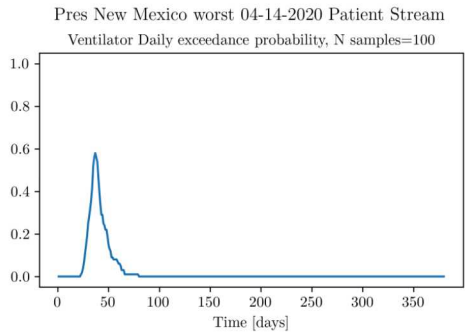
Inputs

Local | IHME | EpiGrid

Outputs

Committed Resources Need Over Time | Consumable Resources Need Over Time | Personnel Need Over Time

Probability of exceeding state-wide capacity for each Presbyterian scenario

Presbyterian Scenario	Beds	ICU Beds	Ventilators
Best Case	 0% chance of exceeding state-wide bed capacity	 10% chance of exceeding state-wide ICU bed capacity around 5/25	 35% chance of exceeding state-wide ventilator capacity around 5/25
Worst Case	 0% chance of exceeding state-wide bed capacity	 36% chance of exceeding state-wide ICU bed capacity around 5/20	 60% chance of exceeding state-wide ventilator capacity around 5/20

New Mexico County-Level Results Using Presbyterian Inputs

County Results – Local Model

Inputs

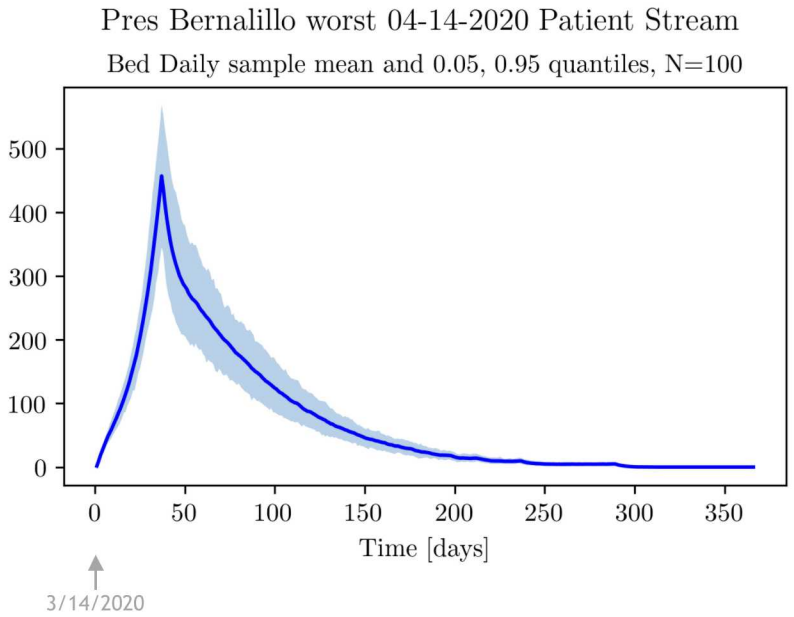
Local | IHME | EpiGrid

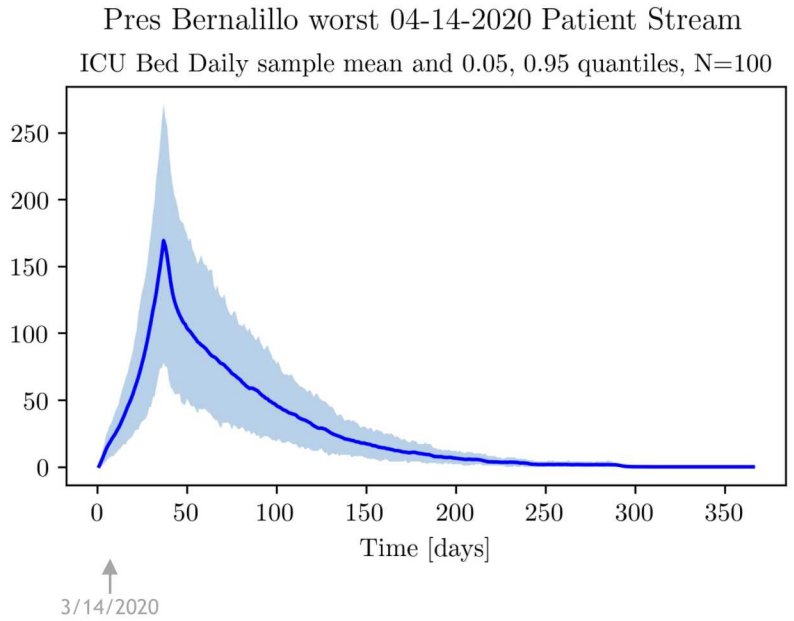
Outputs

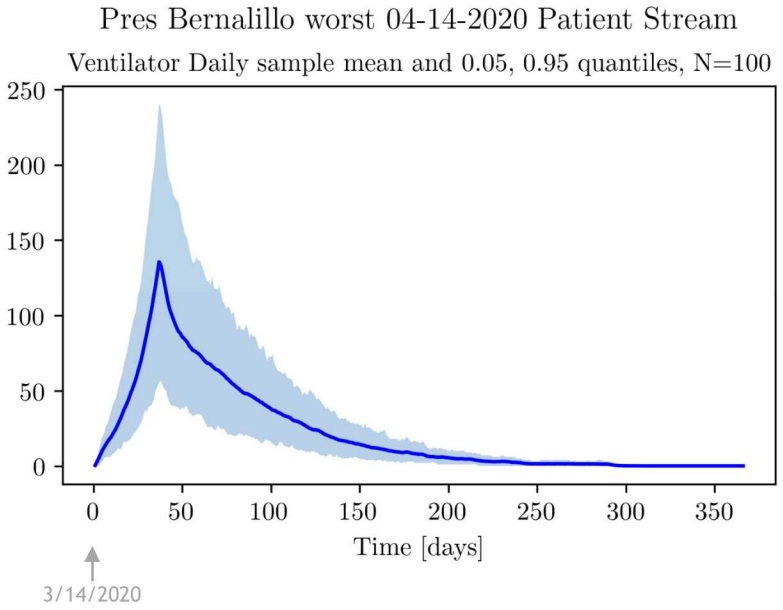
Committed Resources Need Over Time | Consumable Resources Need Over Time | Personnel Need Over Time

			Committed Resources (Max Needed)				Consumable Resources (Total Needed)				
	Presbyterian Scenario	Statistic	Bed	ICU Bed	Metered Dose Inhaler	Ventilator	Gown	N95	Face Shield	Gloves	Sedatives
Bernalillo	Best	Mean	344	129	104	104	98,194	80,187	67,290	297,323	19,112
		St. Dev.	50	47	43	43	40,388	32,457	32,789	119,640	8,109
	Worst	Mean	458	171	138	138	114,295	93,349	78,448	344,771	22,485
		St. Dev.	66	60	56	56	39,270	29,824	38,629	138,870	9,536
San Juan	Best	Mean	122	47	38	38	27,458	22,585	18,747	84,721	5,074
		St. Dev.	18	17	15	15	8,802	8,674	8,587	32,508	2,143
	Worst	Mean	155	61	50	50	31,089	25,481	21,241	95,197	5,871
		St. Dev.	24	23	22	22	10,247	10,018	9,942	37,404	2,532
McKinley	Best	Mean	159	62	50	50	30,284	24,842	20,675	92,787	5,692
		St. Dev.	25	22	21	21	10,001	9,861	9,791	36,209	2,429
	Worst	Mean	196	75	62	62	33,687	27,622	23,004	10,286	6,446
		St. Dev.	30	28	25	25	11,390	11,225	11,132	41,339	2,795
Rio Arriba	Best	Mean	9	5	5	5	3,663	3,156	2,418	12,506	448
		St. Dev.	1	1	1	1	875	876	832	3,645	222
	Worst	Mean	10	5	5	5	4,524	3,876	2,970	15,346	550
		St. Dev.	2	1	1	1	1,074	1,052	965	4,202	263
Cibola	Best	Mean	28	12	10	10	8,343	6,943	5,587	27,056	1,279
		St. Dev.	5	4	4	4	2,161	2,124	2,052	8,479	554
	Worst	Mean	36	15	13	13	9,082	7,560	6,105	29,178	1,455
		St. Dev.	7	5	5	5	2,580	2,561	2,461	9,949	648

Bernalillo County – Using Pres Worst Case Patient Stream

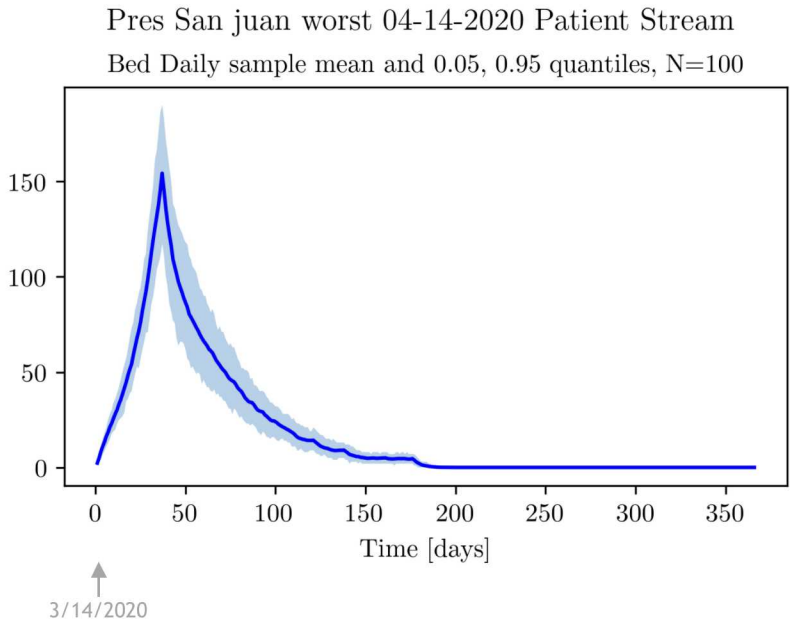


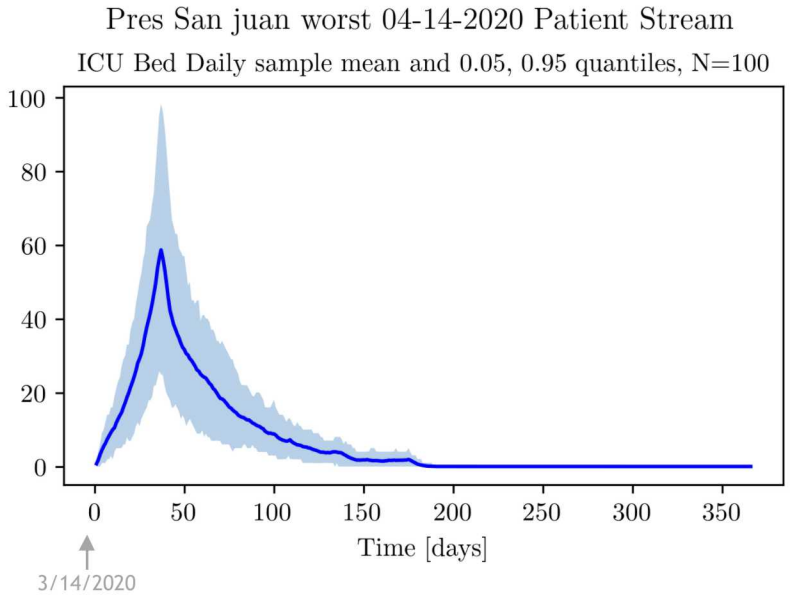


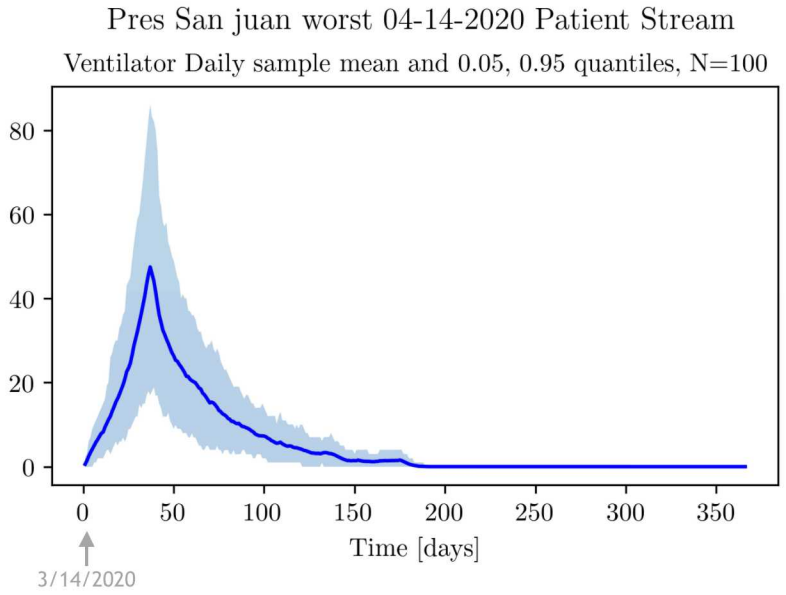


Similar plots for all resources and all counties are available

San Juan County – Using Pres Worst Case Patient Stream

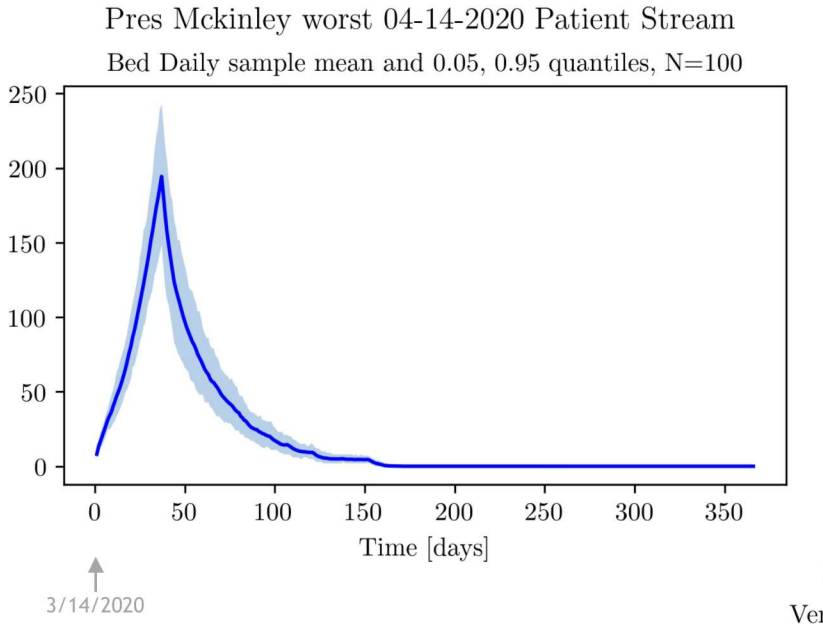


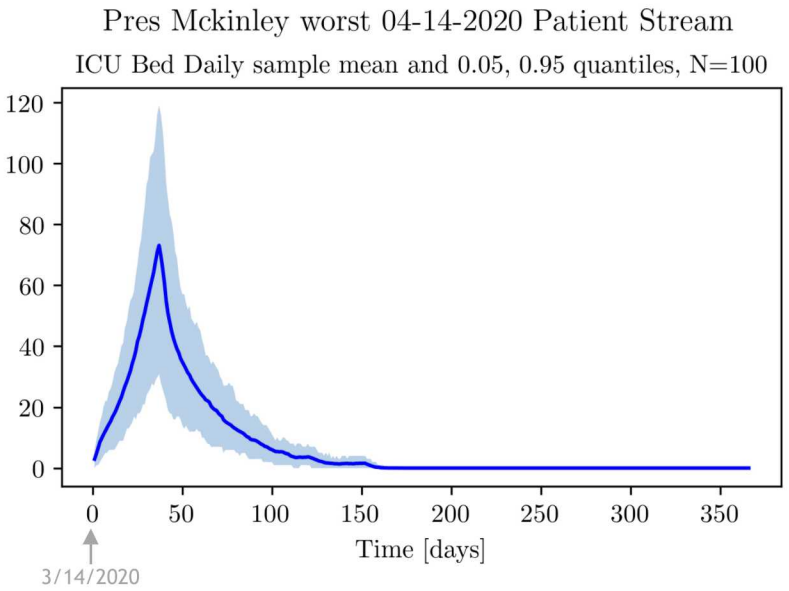


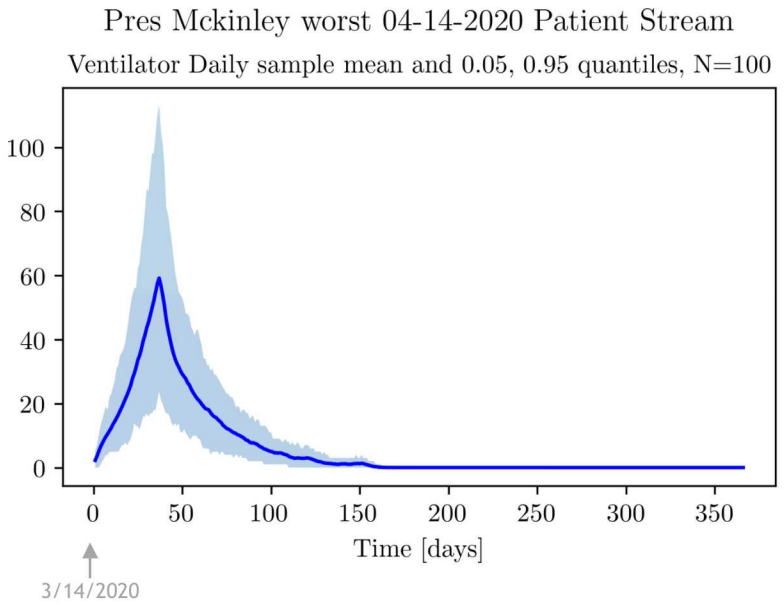


Similar plots for all resources and all counties are available

McKinley County – Using Pres Worst Case Patient Stream

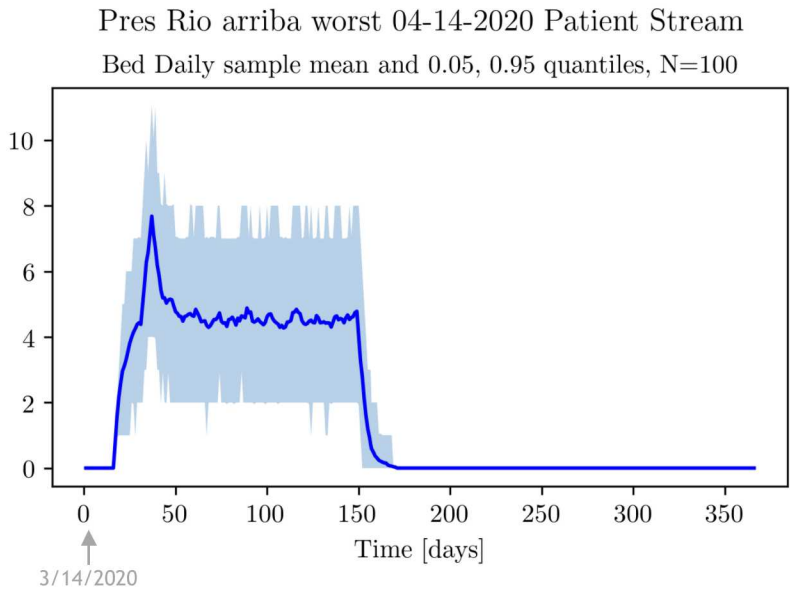


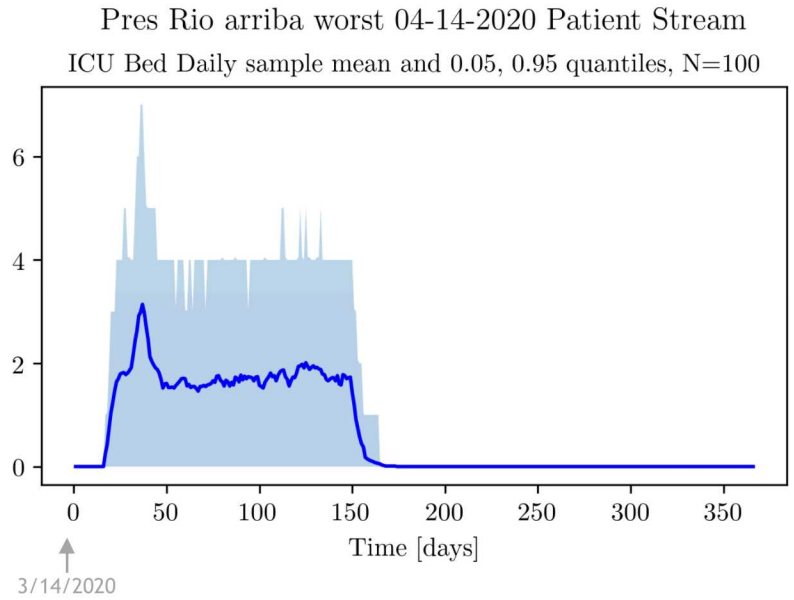


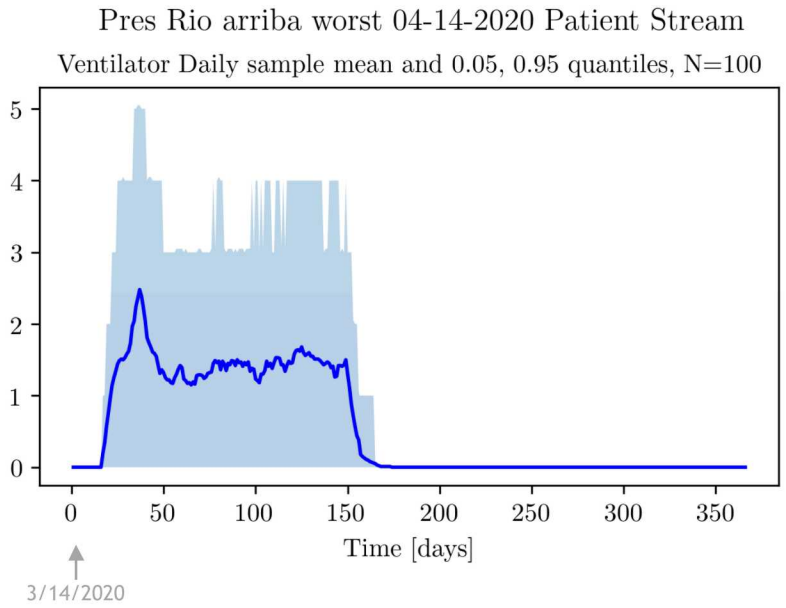


Similar plots for all resources and all counties are available

Rio Arriba County – Using Pres Worst Case Patient Stream

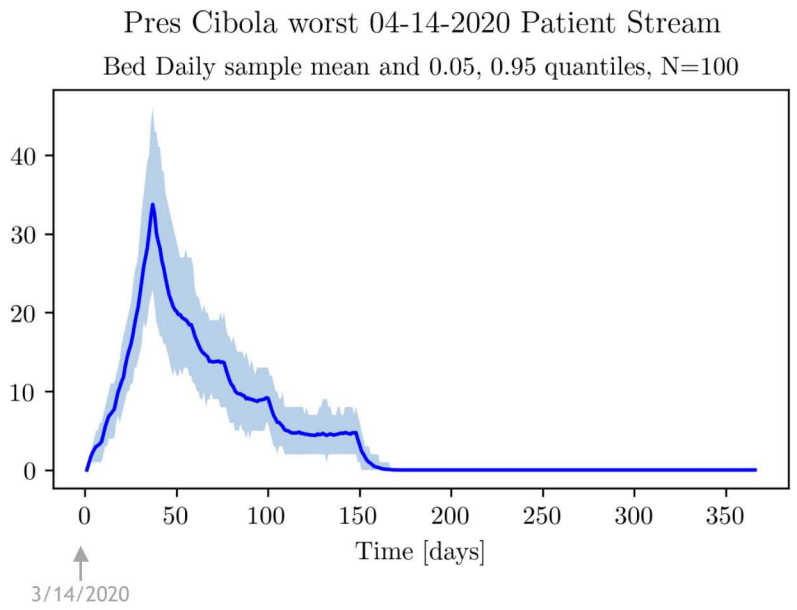


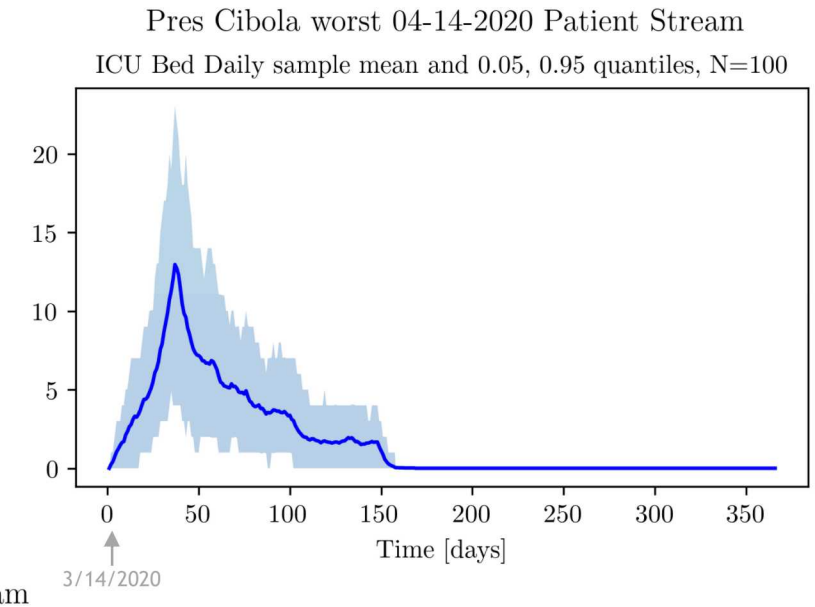


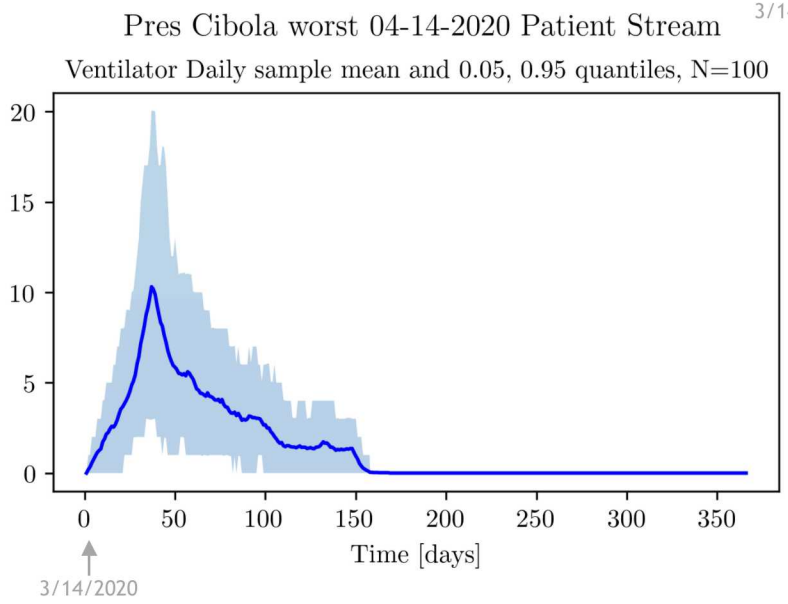


Similar plots for all resources and all counties are available

Cibola County – Using Pres Worst Case Patient Stream







Similar plots for all resources and all counties are available

ICU Bed Needs

Considerations for Additional ICU Bed Needs

Presbyterian Worst Case Scenario

Only including NW counties in the Presbyterian worst case scenario, it appears that Sandoval and then McKinley county will need additional ICU beds before San Juan county

Backup

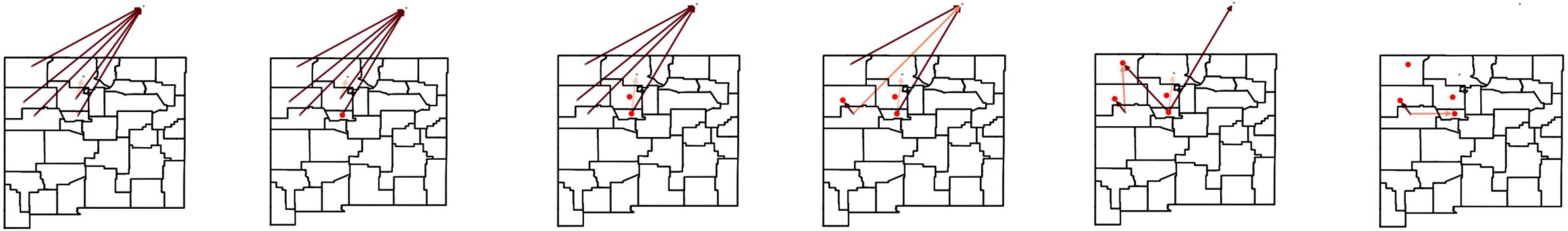
ICU Bed Analysis Using Presbyterian Worst Case Scenario (NW counties only)

Where should ICU beds be placed to minimize patient travel within the state?

Between now and 5/17, we do not expect the state to have a shortfall in ICU beds. However, some counties do have a shortfall.

Assumption: Using routinely staffed (not surge) ICU bed capacity in each county

With no added ICU beds	Choose 1 location to add 50 ICU beds	Choose 2 locations to add 50 ICU beds each	Choose 3 locations to add 50 ICU beds each	Choose 4 locations to add 50 ICU beds each	Choose 5 locations to add 50 ICU beds each
	Bernalillo	Bernalillo; Sandoval	Bernalillo; Sandoval; McKinley	Bernalillo; Sandoval; McKinley; San Juan	Bernalillo (x2); Sandoval; McKinley; San Juan
208 people must travel between counties or states	158 people must travel between counties or states	108 people must travel between counties or states	63 people must travel between counties or states	30 people must travel between counties or states	7 people must travel between counties



Arrows show direction patients must travel to overcome a shortfall in ICU beds (darker color = more travel)

Out of state location is arbitrary

Red dot shows optimal county to place more ICU beds within the state

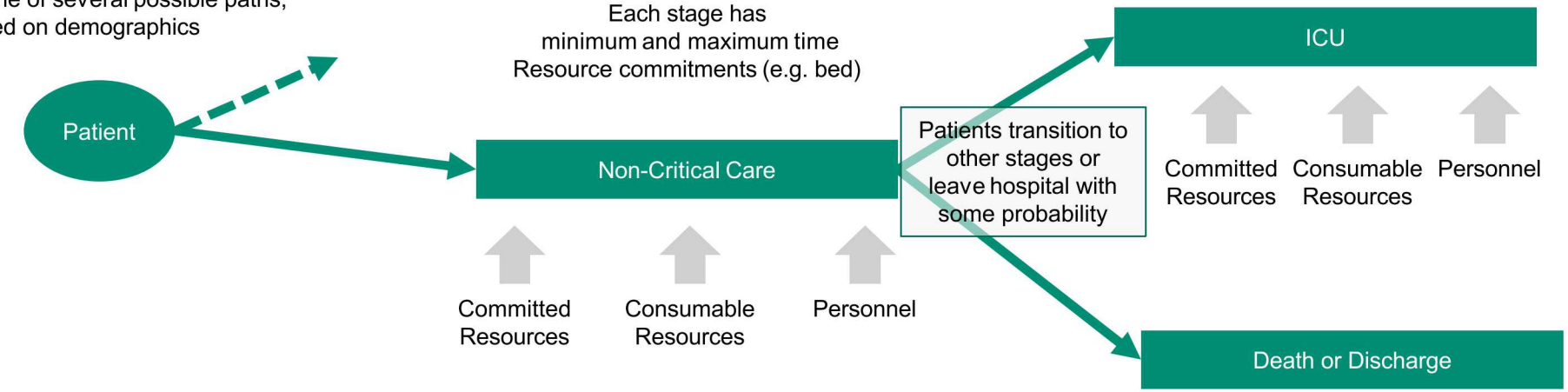
Takeaway: Consider adding ICU beds in Bernalillo, then Sandoval, McKinley, San Juan

Model Formulation

Patients take one of several possible paths, potentially based on demographics

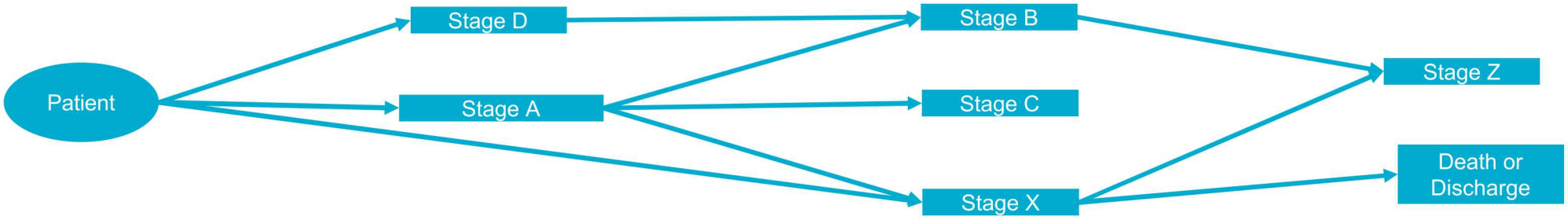
Each path is made of one or more ***stages***

Each stage has minimum and maximum time Resource commitments (e.g. bed)



Stages model administration of a specific kind of treatment (e.g. ICU, ICU with Ventilation, General)

All resource consumption occurs in treatment ***Stages***



A **treatment path** is a specific sequence of stages for a patient, e.g. A -> B -> Z. Patients follow this path, unless they die are discharged at the end of one of its stages

Model Parameters

Group	Parameter	Range	Source
Treatment paths, probabilities, times	Probability of going to ICU	10% to 40%	Guan WJ, Ni ZY, Hu Y, et al; China Medical Treatment Expert Group for Covid-19. Clinical characteristics of coronavirus disease 2019 in China. *N Engl J Med*. doi:10.1056/NEJMoa2002032 Wang D, Hu B, Hu C, et al. Clinical Characteristics of 138 Hospitalized Patients With 2019 Novel Coronavirus-Infected Pneumonia in Wuhan, China. JAMA. 2020;323(11):1061-1069. doi:10.1001/jama.2020.1585 Clinical course and outcomes of critically ill patients with SARS-CoV-2 pneumonia in Wuhan, China: a single-centered, retrospective, observational study. Yang X, Yu Y, Xu J, Shu H, Xia J, Liu H, Wu Y, Zhang L, Yu Z, Fang M, Yu T, Wang Y, Pan S, Zou X, Yuan S, Shang Y
	Probability of needing a ventilator (if in ICU)	50-100%	
	Maximum time any patient would require ventilation	14 to 28 days	
	Maximum time in ICU if not on a ventilator	3 to 14 days	

Staffing		Location	
		ICU	General
Practitioner	ICU Nurse	Uniform 1-2	N/A
	Doctor	Uniform 2-10	Uniform 20-50
	Nurse	N/A	Uniform 4-10
	Respiratory Therapist	Uniform 2-6	N/A

Units used per shift in ICU		Resource			
		Gowns	N95 Mask	Gloves	Face Shield
Practitioner	ICU Nurse	2-4	1-4	4-12	1-4
	Doctor	1-2	1	1-12	1
	Nurse	N/A	N/A	N/A	N/A
	Respiratory Therapist	1-2	1	6-12	1

Units used per shift in General		Resource			
		Gowns	N95 Mask	Gloves	Face Shield
Practitioner	ICU Nurse	N/A	N/A	N/A	N/A
	Doctor	1-2	1	1-12	1
	Nurse	2-3	1-3	3-12	1
	Respiratory Therapist	N/A	N/A	N/A	N/A

Epi inputs drive results more than these parameter values