HHS Public Access

Author manuscript

*Pediatrics*. Author manuscript; available in PMC 2022 April 12.

Published in final edited form as:

*Pediatrics*. 2021 April ; 147(4): . doi:10.1542/peds.2020-027037.

# Societal Costs of a Measles Outbreak

**Jamison Pike, MS, PhD**[1], **Alan Melnick, MD**[2], **Paul A. Gastañaduy, MD**[1], **Meagan Kay, DVM**[3], **Jeff Harbison**[2], **Andrew J. Leidner, PhD**[1], **Samantha Rice, MPH**[4], **Kennly Asato, MBA**[4], **Linda Schwartz**[3], **Chas DeBolt, RN, MPH**[4]

[1]Centers for Disease Control and Prevention, National Center for Immunization and Respiratory Disease, Immunization Services Division, Atlanta, GA

[2]Clark County Public Health, Vancouver, WA

[3]Public Health Seattle King County, Seattle, WA

[4]Washington Department of Health, Olympia, WA

## Abstract

**Background and Objective:** Between December 31, 2018 and April 26, 2019, 72 confirmed cases of measles were identified in Clark County. Our objective was to estimate the economic burden of the measles outbreak from a societal perspective, including public health response costs, as well as direct medical costs and productivity losses of affected individuals.

**Methods:** To estimate costs related to this outbreak from the societal perspective, three types of costs were collected or estimated: public health response (labor, material and contractor costs used to contain the outbreak), direct medical (third-party or patient out-of-pocket treatment costs of infected individuals), and productivity losses (costs of lost productivity due to illness, home isolation, quarantine, or informal caregiving).

**Results:** The overall societal cost of the 2019 Clark County measles outbreak was approximately $3.4 million ($47,479 per case or $814 per contact). The majority of the costs (≈$2.3 million) were incurred by the public health response to the outbreak, followed by productivity losses (≈$1.0 million), and direct medical costs (≈$76,000).

**Conclusions:** Recent increases in incident measles cases in the US and across the globe underscore the need to more fully understand the societal cost of measles cases and outbreaks, and the economic consequences of undervaccination. Our estimates can provide valuable inputs for policy makers and public health stakeholders as they consider budget determinations and the substantial value associated with increasing vaccine coverage and outbreak preparedness, as well as the protection of society against vaccine preventable diseases, such as measles, which are readily preventable with high vaccination coverage.

## Article Summary:

**Address correspondence to:** Jamison Pike, Immunization Services Division, National Center for Immunization and Respiratory Disease, Centers for Disease Prevention and Control, 1600 Clifton Road NE, Atlanta, GA 30329, jpike@cdc.gov, 404-639-4702.

**Conflict of Interest Disclosures:** The authors have no conflicts of interest relevant to this article to disclose. The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of the Centers for Disease Control and Prevention.

We estimate the economic burden of a measles outbreak from a societal perspective, including public health response costs, direct medical costs and productivity losses.

## Introduction

On December 31, 2018, Clark County Public Health (CCPH) in Washington State was notified of a suspected case of measles in an unvaccinated child who had recently arrived from Ukraine to visit the US. The case was laboratory-confirmed on January 3, 2019 by Washington State Department of Health (WADOH) Public Health Laboratories [1]. Only one case was diagnosed in Washington State outside of Clark County (in King County). Other cases related to the Clark County outbreak occurred in Oregon and Georgia but are not included in this study. Twelve subsequent cases were confirmed by January 16. Clark County declared a public health emergency in response to the measles outbreak on January 18, and the governor of Washington State declared a state of emergency on January 25. The last reported case of the outbreak occurred on March 13, 2019, and six weeks later, on April 26, 2019, the outbreak was declared over. Over the course of the outbreak, a diagnosis of measles was confirmed among 71 Clark County residents and one King County resident. In a collaborative effort, CCPH, WADOH, Public Health Seattle King County (PHSKC), Centers for Disease Control and Prevention (CDC), and volunteers from the community as well as from various public health departments and Medical Reserve Corps throughout Washington State, Idaho, and Oregon, worked to respond to and contain the measles outbreak.

During a measles outbreak, substantial costs can be incurred by public health departments and the individuals in the community. The resources needed to identify cases and prevent measles among contacts can strain public health resources at the local, state and national levels. In addition to the costs of responding to and controlling an outbreak, direct medical costs and productivity losses are incurred by individuals who have contracted measles or who were subject to quarantine. Several recent studies have assessed the economic burden of responding to measles outbreaks in the US from a public health perspective [2-4], or have evaluated costs incurred by providers, such as hospitals and ambulatory care providers [5,6]. These studies focused on outbreak response activities, such as identification of exposed contacts and vaccination of susceptible individuals [7]. These studies [2-5] did not include direct medical costs associated with health care for a patient diagnosed with measles, or productivity losses for those who were diagnosed with measles or under quarantine and, as such, do not capture the total societal costs incurred during measles outbreaks. Our study endeavors to estimate measles outbreak costs more comprehensively, by accounting for both public health response costs as well as the burden of disease incurred by individuals whose lives are disrupted by infection or quarantine. We estimate the economic burden of the 2019 Clark County measles outbreak from the societal perspective, in terms of public expenditures to address the measles outbreak, private expenditures incurred as direct medical costs, and productivity losses.

## Methods

### Setting

Clark County is located south of King County (the most populated county in the state and where Seattle, Washington is located) in the southwestern part of Washington State and shares a border with Oregon. The estimated 2018 population of Clark County, the fifth largest county in the state, was 481,857 [8]. State-wide vaccination coverage with two doses of measles-mumps-rubella (MMR) among children enrolled in kindergarten during the 2018-19 school year was 90.8% in Washington and 93.0% in Oregon, compared to the national average of 94% [9]. In Clark County, at the end of 2018, 81% of 1- to 5-year-olds had received one dose of measles-mumps-rubella (MMR) vaccine, and 78% of 6- to 18-year-olds had received two doses (Washington State Immunization Information System (IIS)) [10]. All children born in Washington are entered into the system at the time of birth. Healthcare providers report voluntarily into the system. Currently, over 94% of public sites that participate in the Vaccines for Children (VFC) program share data with the IIS[11].

### Outbreak

From late December to April 2019, 71 patients with confirmed measles were reported in Clark County. Among these patients, 52 (73%) were less than 10 years old, and 61 (86%) were unvaccinated [1]. The one patient reported in King County was a 52-year-old adult with an unknown vaccination status.

CCPH's Incident Management Team was activated on January 15, 2019. Suspected measles cases were investigated through patient interviews, electronic medical records review, and consultation with health care providers. Possible exposure settings and contacts were identified, and the vaccination status of contacts was assessed through review of vaccination registries or vaccination cards [1]. Self-reporting was not considered sufficient for vaccination status ascertainment. A total of 4,011 persons were identified and contacted from 46 known exposures at numerous locations that included Clark County healthcare facilities, workplaces, churches, schools, childcare centers, social gatherings, and households. Of the 4,011 contacts, 839 (20.8%) were considered to be potentially susceptible to measles (i.e., lacked presumptive evidence of measles immunity) and were quarantined. Acceptable presumptive evidence of immunity to measles includes written documentation of age-appropriate vaccination, laboratory evidence of immunity, laboratory confirmation of disease, or birth before 1957. In King County, over 100 contacts were identified and investigated from exposures in one household, one workplace, two health care facilities, and two schools.

Measles diagnostic testing (i.e., detection of measles-specific IgM and/or measles virus RNA) took place at WADOH (548 samples), CDC (52 samples), and Oregon Health Authority (OHA) laboratories (84 samples). Forty-two cases were laboratory-confirmed and 30 were epidemiologically-linked to confirmed cases. Of the 42 laboratory-confirmed cases, 13 were reverse-transcription-polymerase chain reaction (RT-PCR) positive, 3 were IgM-positive, and 26 were both RT-PCR-positive and IgM-positive.

## Cost Evaluation

To estimate costs related to this outbreak from the societal perspective, three types of costs were collected or estimated: response (labor, material, and contracted costs incurred containing the outbreak), direct medical (third-party or patient out-of-pocket costs incurred in the treatment of infected individuals), and productivity losses (costs incurred from lost productivity due to illness and home isolation, exposure and quarantine, or providing care to infected or quarantined family members). All costs were converted to 2019 first quarter dollars. We defined the outbreak period starting December 31, 2018, when CCPH was notified of the first suspected case of measles, through April 26, 2019, 42 days (or two maximum incubation periods) after rash onset of the last reported case.

**Response—**Response costs consist of containment and laboratory testing costs incurred while investigating and controlling the outbreak. These costs are divided into two sub-categories: (1) labor, which includes the hours worked by staff from several public health agencies who conducted response activities such as contact tracing, testing, and surveillance, and (2) materials and contracted services, which includes laboratory supplies related to testing, office supplies and administrative services. These two sub-categories were partially an extension of our data collection process which largely consisted of administrative record summaries generated by the accounting or finance departments of each entity that participated in the outbreak response. Contracted costs included contracted labor, but this was listed as a lump sum material cost to the respective public health department. A detailed description of the methods used to estimate public health and volunteer time and wages is available in Appendix A.

## Labor

Time spent (hours) incurred by personnel responding to the outbreak, along with associated wages, were collected from CCPH, WADOH, PHSKC, OHA, and CDC through each entity's accounting or finance department or for CDC, individual time sheets. For CCPH, this included volunteer personnel from other public health departments and medical reserve corps in Washington State, Idaho, and Oregon, as well as unaffiliated personnel who volunteered during the response. Time spent (hours) incurred by laboratory personnel, along with associated wages, were collected only from WADOH, OHA, and CDC.

## Materials and contracted services

Material costs incurred responding to the outbreak include laboratory supplies and diagnostic tests, incident supplies (e.g., computer hardware), contractual/temporary staff support (e.g., interpreters, call center), shipping/mailing (largely measles information to exposed or potentially exposed persons), transportation, printing, communication services, and travel. These costs were collected from CCPH, WADOH, PHSKC, OHA, and CDC through each entity's accounting or finance department.

**Direct Medical—**Direct medical costs are costs associated with outpatient visits, hospitalizations, healthcare laboratory tests, prescription drugs, and over-the-counter drugs paid by a third-party or out-of-pocket. To estimate direct medical costs, we used measles-related outpatient visit and measles-related hospitalization cost estimates previously reported

[12,13]. These costs were extracted from claims databases and thus, are the payments of actual reimbursements by insurers to providers, and not billed charges to insurance companies or families. Reported cost per hospitalization ranged from $4,032-46,060 and per outpatient visit from $88-526. In our base analyses, we applied the midpoint of the range of outpatient costs to the 70 patients who had outpatient encounters, and the midpoint of the range of hospitalization costs to the 2 patients who were hospitalized during the Clark County outbreak.

**Productivity Losses—**Productivity losses are the "indirect" cost of forgone activities that are caused by disability, disease, injury of affected individuals, or premature death. These costs include lost paid employment, but also the value of nonmarket activities such as unpaid household services (e.g., informal caregiving) [14]. In this analysis, productivity losses included both lost employment pay and nonmarket production by age and gender. These losses were calculated for patients diagnosed with measles and for persons who were home quarantined because of an exposure and lack of presumptive evidence of immunity, as well for caregivers of patients diagnosed with measles or persons quarantined. Additional details on the methods used to compute productivity losses are in Appendix C.

For patients diagnosed with measles, we used previously reported estimates of time spent at home due to measles illness from a study that took place in the United Kingdom [15]. Individuals with confirmed measles reported spending a mean of 9.6 days (95% CI: 9.3 – 11.7) away from work or school due to illness. We converted annual productivity estimates by age and gender from Grosse et. al.[16] to daily productivity estimates. For patients under age 15 years, we assumed zero productivity loss for the child with illness, but we calculated the productivity loss estimate for caregiver time using combined gender and combined age specific estimates.

CCPH recommends a 21-day quarantine period for exposed persons who lack presumptive evidence. Data on the exact length of quarantine, as well as the age of those quarantined, was available for 630 of 839 persons quarantined (productivity losses were not calculated if age or length of quarantine was not included in the data). To estimate the costs associated with quarantine, we computed daily age and gender stratified productivity estimates for persons 15 years of age and older from annual estimates in Grosse et al. [16]. Productivity losses of 82 children aged 10-14 years were assumed to be zero. For children aged 9 years and younger (173 of 630 quarantined persons), we assumed a caregiver would be needed and that productivity losses would be incurred for the caregiver, using combined gender and combined age specific estimates. We further assumed there would be a caregiver-child ratio of 1:3, due to the possibility that children within a single family would be quarantined at the same time and have the same caregiver.

**Sensitivity Analyses—**Sensitivity analyses were performed by varying costs related to direct medical care, productivity losses due to illness, and productivity losses due to quarantine. We recalculated costs using the upper and lower bound of ranges for outpatient and hospitalization costs, the 95% lower and upper confidence interval bounds of school or work days missed, and varying caregiver to quarantined children ratios assumption from 1:2 and 1:4.

## Results

Using base case assumptions, the overall societal cost of the 2019 Clark County, Washington measles outbreak was estimated to be $3.4 million ($47,479 per case or $814 per contact) (Table 1). The largest component of the overall societal cost was incurred as part of the public health response to the outbreak (≈$2.3 million), followed by productivity losses costs (≈$1.0 million), followed by direct medical costs (≈$76,000).

### Response

**Labor—**A total of 451 personnel participated in the outbreak response, with the majority from WADOH (260 personnel) (Table 2). CCPH had 84 personnel and 66 volunteers participating. A total of 33,845 hours were spent responding to the outbreak, with over 17,000 hours and 13,500 hours accrued by CCPH and WADOH, respectively. Hours of labor included efforts related to investigating approximately 4,100 contacts and processing close to 700 laboratory tests.

Labor costs comprised the majority of expenditures associated with responding to the outbreak (approximately $1.9 million of the $2.3 million in response costs), and among labor costs, containment costs totaled approximately $1.8 million. Labor costs changed over the course of the outbreak, peaking in February (Figure 1).

**Materials and contracted services.—**Response material costs were approximately $380,000; just over half of material costs were incurred by contractual and temporary staff support, such as administrative support, nurses, and interpreter services. The material costs of the laboratory testing of 684 specimens, which was incurred by WADOH, OHA, and CDC, was approximately $16,000 (Table 2).

### Direct Medical

Direct medical costs were estimated at $76,000 ($23,000 for 70 outpatient visits and nearly $53,000 for 2 hospitalized cases) (Table 1).

### Productivity Losses

Total productivity losses were estimated to be $1.0 million, primarily due to 548 individuals who were quarantined because they were exposed and lacked presumptive immunity in Clark County ($935,000). This includes productivity losses for 375 persons aged 15 years or older and the caregivers of 173 children aged 9 years or younger. Productivity losses from missed work for the 72 patients (8 were aged 15 years or older, and 64 were for caregivers of patients aged 14 years or younger) in both Clark County and King County were approximately $94,000 (Table 1).

### Sensitivity analyses

The total cost of the outbreak varied from $3.3 million using the lower bounds to $3.5 million using the upper bounds of the inputs evaluated in the sensitivity analyses. Results are reported in Appendix C.

## Discussion

The Clark County outbreak lasted approximately four months and cost over $3 million from the societal perspective. This corresponds to a cost per case and per contact (a contact of an identified case) of over $47,000 and $800, respectively. A recent literature review of the available data on the cost of outbreak responses, examining 10 studies and 11 estimates, focused primarily on response costs and costs from the public health perspective (not capturing full societal costs), reported a median of $32,805 per case and $223 per contact [7]. Our results add to the literature on the costs of measles outbreaks and emphasize the considerable resources needed to stop measles virus transmission[7]. In addition to costs directly incurred by public health agencies in outbreak response, there are significant productivity losses to consider among ill individuals, unvaccinated persons who were quarantined due to exposure and lack of presumptive evidence of immunity, and the caregivers of ill and quarantined children. Finally, costs related to healthcare encounters and medical treatment are also steep. The highest annual number of US measles cases in over 25 years was reported in 2019, and a 3-fold increase in global cases was reported the first three months of 2019 compared to 2018. These increases in measles cases in the US and globally underscore the need to more fully understand the societal cost of measles cases and outbreaks, and the economic consequences of undervaccination [17,18].

Within response costs, 79% were containment-related labor costs, demonstrating the significant amount of time and resources needed to track and trace all cases and contacts for such a highly infectious disease. Our results highlight the need to invest in local and state health departments', as well as federal institutions', capacity to prepare for and respond to measles outbreaks and outbreaks of other vaccine-preventable diseases[19-21]. This may be particularly important in jurisdictions with known pockets of undervaccination [2,22-25]. Lack of or limited public health containment efforts could translate to exponentially higher direct medical costs and productivity losses. Of utmost importance is the need to identify the potentially numerous and dispersed pockets of undervaccination across the US. Identifying and closing these gaps in immunity would reduce the size and duration of outbreaks.

This study has several limitations. First, these costs are limited to only societal costs related to cases within Washington State and do not include additional societal costs related to cases outside the state. Although the majority of response costs were provided directly from the participating institutions, some costs needed to be estimated using reasonable assumptions and information from peer-reviewed literature. Volunteer staff included community volunteers and volunteers from the medical and health sectors, but the wages we used to value volunteer time was an average wage for the county, and so likely an underestimate for any public health and medical professionals who served as volunteers. Collecting volunteer time from time logs has limitations. For example, in some cases, DOH or CDC volunteer hours may not have been attributed correctly to the affiliated agency. Labor costs were collected retrospectively and through public health finance departments, rather than directly from the participants during the response. It is possible that some hours spent on the response were not captured if they were not coded to the response in the public health agency's financial administration system. In economic evaluations, there are often discrepancies in how costs are reported and in methods used for cost accounting (often due

to a different original purpose of collecting the data) and may lead to incomplete reporting of costs in evaluations such as the current study [26]. Direct medical costs were derived from commercial insurance inpatient and outpatient claims data, and were not the actual expenses incurred treating patients diagnosed with measles in this outbreak or what the patient paid. Certain cost items could not be ascertained and incorporated into our estimates, these items include specific types of direct medical costs, such as over-the-counter drug expenses and out-of-pocket medical costs, and direct non-medical costs, such as travel costs incurred seeking care. Furthermore, no opportunity costs of public health staff diverted from primary work to this response were collected. Productivity losses of quarantined persons were limited to certain age-groups, and were based on age, gender, and duration of quarantine, so if any of these variables were missing, these costs were not included in the analyses. If persons were initially quarantined but subsequently released from quarantine after their immune status was verified, these individuals were not included in the quarantine list, and assumed to have no productivity losses. For productivity losses due to measles illness, time spent at home was based on a survey that took place in the United Kingdom. The time spent away from school or work due to illness might vary by disease severity and public health recommendations (which might differ from country to country) and thus, results from this survey may not accurately reflect time spent at home in this outbreak. For future research, ideally, surveys would be distributed prospectively at the beginning of the outbreak to all individuals (employees and volunteers) participating in the response to log daily response related time, wages (including benefits and overtime), and material costs. It would also be ideal to survey patient, individuals quarantined, and caregivers to assess lost productivity. Finally, our study focused on the monetary costs of measles outbreaks and so we did not capture information necessary to estimate health-related utilities or quality-adjusted life-years associated with measles outbreaks [15].

## Conclusion

Increases in the number of measles cases and outbreaks seen globally translate to increasing costs to society in terms of both disease and economic burden. The potential rippling effects to the local economy when a large number of people are out of work or missing school due to outbreaks can be significant, as experienced during the current COVID-19 pandemic [27-29]. In 2019, the US experienced the greatest number of cases reported since 1992 and since measles was declared eliminated in 2000 resulting in nearly losing elimination status [30,31]. It is likely outbreaks of measles and other vaccine preventable diseases will continue to occur in the future, particularly in areas with insufficient vaccination coverage. Our estimates of the economic burden a measles outbreak from the societal perspective, in terms of public expenditures to address the measles outbreak, private expenditures incurred as direct medical costs, and productivity losses, indicate that undervaccination can carry a substantial cost for individuals, communities, and public health institutions, and underscore the value of vaccination. These estimates can provide valuable inputs for policy makers and public health stakeholders as they consider budget determinations and the substantial value associated with increasing vaccine coverage and outbreak preparedness, as well as the protection of society against vaccine preventable diseases, such as measles, which are readily preventable with high vaccination coverage.

## Data Sharing Statement:

Deidentified individual participant data will not be made available.

## Appendix A

## Volunteer Time

Our model calculates volunteer time for three types of individuals: (1) staff of public health agencies other than Clark County Public Health (CCPH), Washington Department of Health (WADOH), Public Health Seattle King County (PHSKC), Centers for Disease Control and Prevention (CDC) who worked on the outbreak response due to temporary reassignment or agency volunteer programs, (2) medical reserve corps, and (3) community volunteers who were not affiliated with any public health agencies. For all types of volunteers, de-identified daily sign-in sheets for time in and time out were used to estimate hours worked on the response. When possible, the individuals affiliated public health agency was also identified. Because agency was not always identified, we used the Washington State mean hourly wage for 'All Occupations'*. If WADOH or CDC was identified as an agency, these hours were removed because they are already captured in hours reported by WADOH and CDC.

## Labor

All labor costs include premium pay (higher wages given to employees who work less desirable hours, such as holidays, weekends, or anything over eight hours a day), overtime, and fringe benefits. For all types of volunteers, de-identified daily sign-in sheets for time in and time out were used to estimate hours worked on the response. To estimate wages associated with volunteer time, May 2018 State Occupational Employment and Wage Estimates for Washington State were collected from the Bureau of Labor Statistics [32].

Hours and cost (inclusive of fringe benefits and overtime) for each employee participating in the response were provided by CCPH. CCPH employees participating included administrators, communication specialists, public health nurses, epidemiologists, and environmental specialists. WADOH provided the cost of labor (inclusive of fringe benefits and overtime) and a total number of hours worked over the duration of the outbreak. Hours and cost (inclusive of fringe benefits and overtime) for each employee participating in the response were provided by PHSKC. Employees participating included administrators, communication specialists, public health nurses, epidemiologists, information technology specialists, and environmental specialists. OHA provided total labor laboratory costs (inclusive of fringe benefits and overtime) of testing both Washington and Oregon residents' specimens, as well as administration time. They also provided the number of Washington (84) and Oregon (37) residents' specimens. The percentage of Washington residents' specimens (69%) was applied to the total labor costs to estimate OHA costs of the Clark County outbreak. CDC provided hours worked on the outbreak for both response and laboratory testing. Actual or a proxy annual salary (inclusive of fringe benefits) was taken

*Fringe benefit costs were collected directly from CCCPH, WADOH, PHSKC, and OHA. An estimated fringe benefit rate of .35 was used for volunteers.

from the Feds Data Center or the US Office of Personnel Management and then converted to a daily cost to compute total CDC cost of response [33,34].

## Appendix B

## Productivity losses - cases

For weekdays (5/7 days), we used paid employment and non-market productivity estimates and for weekends (2/7 days) we used only non-market productivity. For persons under age 15, we assumed zero productivity loss for the child with illness but we assumed the productivity estimate for all ages (15-99) and both genders as an estimate for caregiver time. For ages 15-99, if gender was not identified, we used the estimate for both genders combined. If age or length of quarantine was not included in the data, productivity losses were not calculated.

## Productivity losses - quarantined

If gender was not available (95/630), we used the combined estimate for both genders. We multiplied these daily productivity estimates by the number of days these persons were quarantined (375 of 630 quarantined persons were aged 15 years or older), and then multiplied estimated productivity by 5/7 to account for working days.

## Appendix C

**Table 1.**

Multivariate Sensitivity Analysis

| | Base | Low | High |
|---|---|---|---|
| Response | $2,313,473 | $2,313,473 | $2,313,473 |
| Productivity | $1,029,378 | $1,002,654 | $1,097,580 |
| Direct Medical | $75,672 | $15,037 | $136,308 |
| Total | $3,418,523 | $3,331,164 | $3,547,360 |

## Abbreviations:

| | |
|---|---|
| **MMR** | measles-mumps-rubella |
| **CCPH** | Clark County Public Health |
| **WADOH** | Washington State Department of Health |
| **PHSKC** | Public Health Seattle King County |
| **CDC** | Centers for Disease Control and Prevention |
| **OHA** | Oregon Health Authority |
| **MV** | measles virus |
| **IgM** | immunoglobulin M |

| | |
|---|---|
| **IgG** | immunoglobulin G |
| **PRN** | plaque reduction neutralization |
| **PCR** | polymerase chain reaction |

## References


1. Carlson A, Riethman M, Gastañaduy P, et al. Notes from the field: Community outbreak of measles —Clark County, Washington, 2018–2019. Morbidity Mortality Weekly Report. 2019;68(19):446. [PubMed: 31095534]
2. Rosen JB, Arciuolo RJ, Khawja AM, Fu J, Giancotti FR, Zucker JR. Public health consequences of a 2013 measles outbreak in New York City. JAMA pediatrics. 2018;172(9):811–817. [PubMed: 30073293]
3. Marx GE, Chase J, Jasperse J, et al. Public health economic burden associated with two single measles case investigations—Colorado, 2016–2017. Morbidity and Mortality Weekly Report 2017;66(46):1272. [PubMed: 29166368]
4. McCullough JM, Fowle N, Sylvester T, et al. Cost Analysis of 3 Concurrent Public Health Response Events: Financial Impact of Measles Outbreak, Super Bowl Surveillance, and Ebola Surveillance in Maricopa County. Journal of Public Health Management and Practice. 2019.
5. Wendorf KA, Kay M, Ortega-Sanchez IR, Munn M, Duchin J. Cost of measles containment in an ambulatory pediatric clinic. The Pediatric infectious disease journal. 2015;34(6):589–593. [PubMed: 25973936]
6. Helmecke MR, Elmendorf SL, Kent DL, Pauze DK, Pauze DR. Measles investigation: a moving target. American journal of infection control. 2014;42(8):911–915. [PubMed: 24939517]
7. Pike J, Leidner A, Gastañaduy P. A review of measles outbreak cost estimates from the US in the post-elimination era (2004-2017): Estimates by perspective and cost type. Clinical Infectious Diseases: an Official Publication of the Infectious Diseases Society of America. 2020.
8. United States Census Bureau, QuickFacts, Clark County, Washington. https://www.census.gov/quickfacts/clarkcountywashington. Accessed 08/29/19.
9. 2018-19 School Year Vaccination Coverage Report, Estimated vaccination coverage among children enrolled in kindergarten by state and the United States, School Vaccination Assessment Program, 2018-19 school year. https://www.cdc.gov/vaccines/imz-managers/coverage/schoolvaxview/data-reports/coverage-reports/2018-19.html. Accessed 11/5/19.
10. Clark County Public Health, What are the immunization rates for children in Clark County? Accessed 08/29/19.
11. Washington State Department of Health Immunization Data –Technical Notes. 2019; https://www.doh.wa.gov/Portals/1/Documents/Pubs/348-565-ImmunizationDataTechnicalNotes.pdf.
12. VFC Publications: Supplement. 2014; https://www.cdc.gov/vaccines/programs/vfc/pubs/methods/index.html. Accessed 07/02/20.
13. Whitney CG, Zhou F, Singleton J, Schuchat A. Benefits from immunization during the vaccines for children program era—United States, 1994–2013. MMWR Morbidity mortality weekly report. 2014;63(16):352. [PubMed: 24759657]
14. Pike J, Grosse SD. Friction cost estimates of productivity costs in cost-of-illness studies in comparison with human capital estimates: a review. J Applied health economics and health policy. 2018;16(6):765–778.
15. Thorrington D, Ramsay M, van Hoek AJ, et al. The effect of measles on health-related quality of life: a patient-based survey. PloS one. 2014;9(9):e105153. [PubMed: 25202905]
16. Grosse SD, Krueger KV, Pike J. Estimated annual and lifetime labor productivity in the United States, 2016: implications for economic evaluations. Journal of medical economics. 2019;22(6):501–508. [PubMed: 30384792]
17. Immunization, Vaccines and Biologicals, New measles surveillance data for 2019. https://www.who.int/immunization/newsroom/measles-data-2019/en/. Accessed 07/02/20.

18. Patel M, Lee AD, Clemmons NS, et al. National Update on Measles Cases and Outbreaks - United States, January 1-October 1, 2019. MMWR Morbidity and mortality weekly report. 2019;68(40):893–896. [PubMed: 31600181]
19. Pike J, Schwartz S, Kay M, et al. Cost of Responding to the 2017 University of Washington Mumps Outbreak: A Prospective Analysis. Journal of Public Health Management. 2019.
20. Pike J, Marin M, Guo A, Haselow D, Safi H, Zhou F. 2016–2017 Arkansas mumps outbreak in a close-knit community: Assessment of the economic impact and response strategies. Vaccine. 2020;38(6):1481–1485. [PubMed: 31818532]
21. Duchin JS. US public health preparedness for Zika and other threats remains vulnerable. Disaster medicine and public health preparedness. 2016;10(2):298–299. [PubMed: 26952646]
22. McDonald R, Ruppert PS, Souto M, et al. Notes from the field: measles outbreaks from imported cases in Orthodox Jewish communities—New York and New Jersey, 2018–2019. Morbidity and Mortality Weekly Report. 2019;68(19):444. [PubMed: 31095533]
23. Banerjee E, Griffith J, Kenyon C, et al. Containing a measles outbreak in Minnesota, 2017: methods and challenges. Perspectives in Public Health. 2020;140(3):162–171. [PubMed: 31480896]
24. Zucker JR, Rosen JB, Iwamoto M, et al. Consequences of Undervaccination—Measles Outbreak, New York City, 2018–2019. New England Journal of Medicine. 2020;382(11):1009–1017.
25. Gastañaduy PA, Budd J, Fisher N, et al. A Measles Outbreak in an Underimmunized Amish Community in Ohio. New England Journal of Medicine. 2016;375(14):1343–1354.
26. Špacírová Z, Epstein D, García-Mochón L, Rovira J, de Labry Lima AO, Espín J. A general framework for classifying costing methods for economic evaluation of health care. The European Journal of Health Economics. 2020;21(4):529–542. [PubMed: 31960181]
27. Lempel H, Epstein JM, Hammond RA. Economic cost and health care workforce effects of school closures in the US. PLoS currents. 2009;1.
28. Smith RD, Keogh-Brown MR, Barnett T. Estimating the economic impact of pandemic influenza: an application of the computable general equilibrium model to the UK. Social science & medicine. 2011;73(2):235–244. [PubMed: 21708419]
29. Adda J Economic activity and the spread of viral diseases: Evidence from high frequency data. The Quarterly Journal of Economics. 2016;131(2):891–941.
30. Measles Cases and Outbreaks, Centers for Disease Control and Prevention, National Center for Immunization and Respiratory Diseases, Division of Viral Diseases https://www.cdc.gov/measles/cases-outbreaks.html. Accessed 10/20/2020.
31. Measles Elimination, Centers for Disease Control and Prevention, National Center for Immunization and Respiratory Diseases, Division of Viral Diseases. https://www.cdc.gov/measles/elimination.html. Accessed 10/20/2020.
32. US Department of Labor, Bureau of Labor Statistics. May 2018 State Occupational Employment and Wage Estimates, Washington. 2019; https://www.bls.gov/oes/2018/may/oes_wa.htm. Accessed 10/28/19.
33. Feds Data Center: Federal Employee Salaries. 2016; http://www.fedsdatacenter.com/. Accessed 2019.
34. US Office of Personnel Management, 2019 General Schedule (GS) Locality Pay Tables. https://www.opm.gov/policy-data-oversight/pay-leave/salaries-wages/salary-tables/pdf/2019/ATL.pdf. Accessed 2019.

**What's Known on This Subject:**

Recent studies have assessed the economic burden of responding to measles outbreaks in the US from a public health perspective or have evaluated costs incurred by providers. These studies focused on outbreak response activities, such as identification of exposed contacts.

**What This Study Adds:**

Our study endeavors to estimate measles outbreak costs more comprehensively, by accounting for both public health response costs as well as the burden of disease incurred by individuals whose lives are disrupted by infection or quarantine.

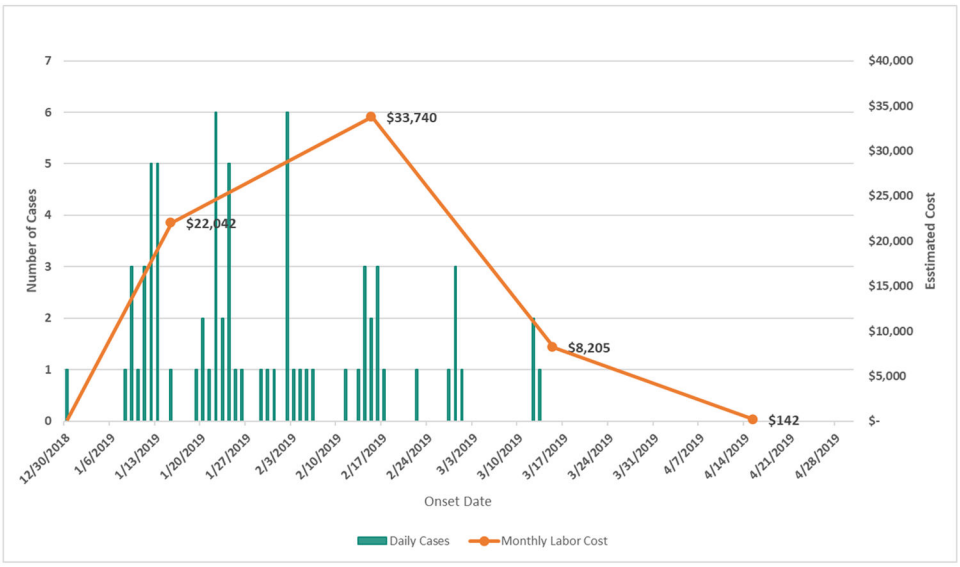


**FIGURE 1.**

Daily case count and estimated public health monthly labor costs for containment-related activities for 2019 Clark County measles outbreak

**Table 1.**

Summary of estimated societal costs incurred during the 2019 Clark County Measles Outbreak*

| | Total Societal Cost | Per Case Cost | Per Contact Cost |
|---|---|---|---|
| Response | $2,313,473 | $32,132 | $551 |
| Productivity loss | | | |
| *Cases* | $94,429 | | |
| *Isolated cases and quarantined contacts* | $934,948 | | |
| | $1,029,378 | $14,297 | $245 |
| Direct Medical | | | |
| *Outpatient* | $22,718 | | |
| *Hospitalized* | $52,954 | | |
| | $75,672 | $1,051 | |
| Total | $3,418,523 | $47,479 | $814 |

* All costs were converted to 2019 first quarter dollars

**Table 2.**

Estimated response activities, materials, and costs incurred during the 2019 Clark County Measles Outbreak

| | CCPH** | WADOH | PHSKC | CDC | OHA | Total |
|---|---|---|---|---|---|---|
| Activities and materials associated with the outbreak response | | | | | | |
| *Personnel or Volunteer* * | | | | | | |
| Number | 150 | 260 | 29 | 8 | 4 | **451** |
| Hours | 17,288 | 13,554 | 1,735 | 1,179 | 90 | **33,845** |
| *Contacts* | 4003 | | 108 | | | **4,111** |
| *Cases* | | | | | | |
| Outpatient | 70 | 0 | 0 | 0 | 0 | **70** |
| Hospitalized | 1 | | 1 | 0 | 0 | **2** |
| *Isolated cases and quarantined contacts* *** | 839 | 0 | 0 | 0 | 0 | **839** |
| *Laboratory Tests* | 0 | 548 | 0 | 52 | 84 | **684** |
| MV IgM | | 91 | | 14 | | **105** |
| MV IgG | | 69 | | 14 | | **83** |
| MV avidity | | | | 12 | | **12** |
| MV PRN | | | | 12 | | **12** |
| MV PCR | | 367 | | | 84 | **451** |
| MV sequence | | 21 | | | | **21** |
| Costs associated with the outbreak response | | | | | | |
| *Public health and govt agency labor* | | | | | | |
| Containment | $784,598 | $829,942 | $174,072 | $40,458 | $0 | $1,829,070 |
| Laboratory | $0 | $57,536 | $0 | $16,849 | $30,014 | $104,399 |
| *labor subtotal* | $784,598 | $887,478 | $174,072 | $57,307 | $30,014 | $1,933,469 |
| *Materials and contracted services* | | | | | | |
| Goods and Services | $34,563 | $6,577 | $1,005 | $0 | $0 | $42,146 |
| Travel | $21,585 | $88,937 | $0 | $11,943 | $0 | $122,465 |
| Laboratory | $0 | $8,112 | $0 | $1,390 | $6,514 | $16,016 |
| Contractual/Temporary support | $169,659 | $28,113 | $1,606 | $0 | $0 | $199,377 |
| *material subtotal* | *$225,807* | *$131,739* | *$2,611* | $13,333 | $6,514 | $380,004 |
| **Response Cost Total** | *$1,010,405* | *$1,019,217* | *$176,683* | $70,640 | $36,528 | $2,313,473 |

Abbreviation: CCPH, Clark County Public Health; WADOH, Washington Department of Health; PHSKC, Public Health Seattle King County; CDC, Centers for Disease Control and Prevention; OHA, Oregon Health Authority; MMR, measles-mumps-rubella; MV, measles virus; IgM, Immunoglobulin M; IgG, Immunoglobulin G; PRN, plaque reduction neutralization; PCR, polymerase chain reaction.

All costs were converted to 2019 first quarter dollars.

* Does not include contracted personnel

** CCPH had 84 personnel and 66 volunteers participating

*** Productivity losses were estimated for 548 of 839 persons quarantined or isolated based on age, gender, and availability of data.