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ASTEROID IMPACTS - DOWNWIND AND DOWNSTREAM EFFECTS

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Extended Abstract—

Introduction: Most of the research on the effects of an intermediate-sized asteroid impact or air burst have focused on immediate damage caused by the shock wave and the thermal radiation. Our focus is to quantify additional effects that could disrupt a larger geographical area than the initial blast. We classify these effects as either downwind or downstream. Some of these effects may occur within hours while others may extend to months, adding to the economic and social cost of the impact event. These effects for smaller asteroid impact scenarios are expected to be negligible. *But at what size for an impactor do these effects become important and need to be considered in determining mitigation efforts and post-impact recovery, both downwind and downstream of the impact site?*

Impact scenario: For this abstract, we have selected an impact location, consistent with the PDC2021 initial scenario [1], in the San Juan Mountains, in southwestern Colorado. This is a low-density population area but is part of the watershed system within the Colorado River basin, a major source of water and power for the southwestern United States. Several large cities and major airports are potentially downwind from this area. For the PDC2021 scenario [1], a 120-m impactor is the median expected size. We chose impactor sizes ranging from 42 to 600-m, which covers the 0.1% smallest to largest cases.

Methodology: Our approach to estimate the potential downwind and downstream effects from an impact scenario is to use more common natural disasters as analogs, such as wildfires and volcanic plumes. We use the wildfire analog to determine downstream effects in the watershed and the volcano analog for the downwind debris fall.

Downstream effects: The process to determine the downstream effects is complex and requires several simplifying assumptions and published scenarios based on several models, as described in Sankey et al. [2]. For simplicity, we use an estimated burn area determined by methods described in Collins et al. [3] and Glasstone and Dolan [4] combined with the annual post-fire sediment yields from Sankey et al. [2].

Downwind effects: The process to determine the downwind effects has also been simplified. We assume a distribution of debris up to a height of 40 km. We then use the U.S. Geological Survey volcanic ash transport model, Ash3D [4] to estimate the possible downwind distribution based on wind patterns from 50 randomly selected dates over the last several decades. Two scenarios were run, one for a 120-m impactor and another for a 600-m impactor. Debris from the asteroid was assumed to disperse from an elevation 40 km above sea level in the atmosphere and follow the ambient wind field while falling. The size distribution of debris was assumed to be similar to that of volcanic tephra used in tephra dispersal simulations [6].

Results:

Downstream effects: We estimate that the increase in the post-impact downstream sediment could range from about 4×10^3 to 1.5×10^8 Megagrams (Mg), depending on the estimated burn area (determined from asteroid size) and the annual post-fire sediment yield (specific watershed within which the impact occurs in the San Juan Mountain range). (See Table 1.) Because our objective is to estimate the impactor size threshold when downstream effects become nonnegligible, we will use the highest sediment yield estimate of 60.80 (Mg/ha), resulting in an estimated sediment yield between 3×10^5 (for the 42-m impactor) and 1.5×10^8 Mg (for the 600-m impactor). For context, the annual estimated sediment deposition by the San Juan River into Lake Powell since the reservoir was closed by Glen Canyon Dam in 1963 is 1.83×10^7 Mg/yr [7]. The two models where the post-impact sediment yield exceeded the annual rate were the 350-m impactor (x 2.3 annual sediment rate) and the 600-m impactor (x 8.3 annual sediment rate). The proposed impact location is near a tributary of the San Juan River, located several hundred kilometers upstream of Lake Powell. Whether sediment is even transported from the impact site downstream to the San Juan River, moreover all the way to Lake Powell, would be contingent on precipitation and specifically the timing of the impact relative to large magnitude monsoon storms or snowmelt events. Therefore, the long-term effects of increased sedimentation owing to the asteroid impact on the downstream Lake Powell reservoir, the Glen Canyon Dam and its power-generating capability appear to likely be minimal, even in the case of the 600-m impactor. However, there would be increased flooding and sedimentation risk for the towns that lie near the San Juan River, but outside the initial damage zone (primarily northwestern New Mexico), perhaps for several years. This analysis does not include issues of water quality, turbidity, and toxicity associated with increased sediment and associated nutrients or pollutants in the river(s).

Table 1: Watershed sediment yield from post impact soil erosion. The range of possible annual post-fire sediment yields are shown for the watersheds in the San Juan Mountains.

Diameter (m)	Radius of Ignition (km)	Burn Area (km2)	Burn Area (ha)	Sankey et al. (2017) Annual Post-fire Sediment Yields (Mg/ha)	Watershed Sediment Yield from Post Impact Soil Erosion (Mg)
42	3.90	47.78	4,778.22	0.83	3,966
65	6.50	132.73	13,272.84	0.83	11,016
120	13.40	564.09	56,408.77	0.83	46,819
350	47.20	6,998.76	699,875.94	0.83	580,897
600	89.20	24,995.78	2,499,578.46	0.83	2,074,650
42	3.90	47.78	4,778.22	6.76	32,301
65	6.50	132.73	13,272.84	6.76	89,724
120	13.40	564.09	56,408.77	6.76	381,323
350	47.20	6,998.76	699,875.94	6.76	4,731,161
600	89.20	24,995.78	2,499,578.46	6.76	16,897,150
42	3.90	47.78	4,778.22	60.80	290,516
65	6.50	132.73	13,272.84	60.80	806,989
120	13.40	564.09	56,408.77	60.80	3,429,653
350	47.20	6,998.76	699,875.94	60.80	42,552,457
600	89.20	24,995.78	2,499,578.46	60.80	151,974,370

Downwind effects: Due to the time of year for the PDC2021 exercise impact date (Oct. 20, 2021), downwind deposition of debris is likely to have minimal impact on agriculture. However, short-term disruption in transportation (aviation and ground) and impact on air quality (human and livestock) should be expected. Based on a model run for Oct. 22, 1967, the debris fallout from a 120-m impactor is restricted to southern Colorado (avoiding Denver, but likely affecting visibility along I-25). (Fig. 1.) However, the model run for the 600-m impactor, extend the effects all the way to Lincoln, NE (Fig. 2).

Another example was March 4, 1997. For the 120-m impactor, 0.01 kg/m^2 could be deposited in the Denver area if the winds were from the southwest.

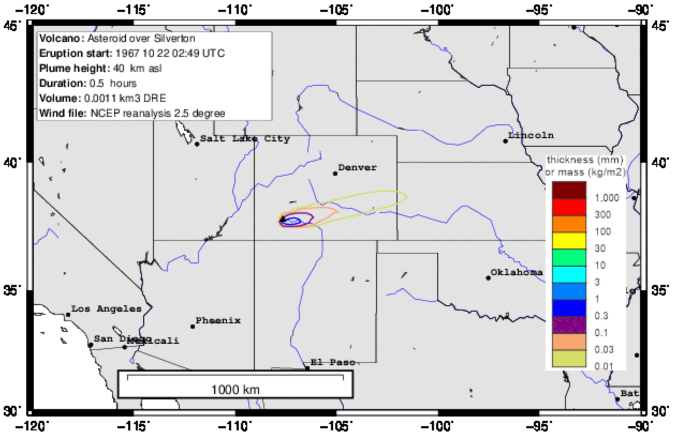

Figure 1: Ash3D Simulation assuming a 120-m impactor and wind patterns from Oct. 22,1997.

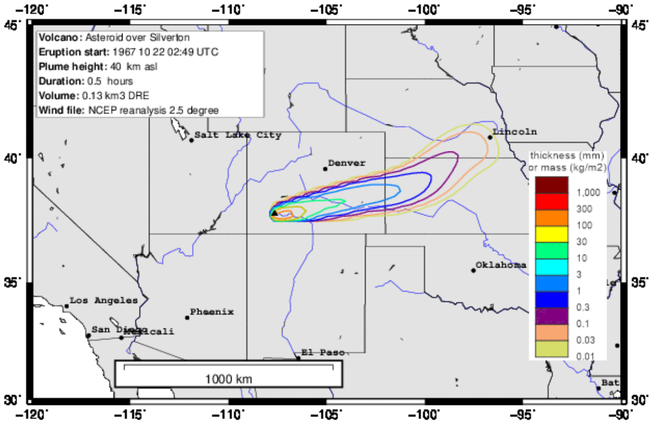

Figure 2: Simulation assuming a 600-m impactor and wind patterns from Oct. 22,1997.

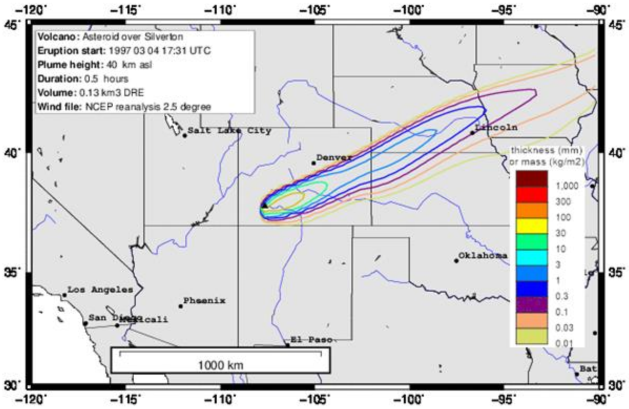

Figure 3: One simulation assuming a 600-m impactor and wind patterns randomly selected from March 4 ,1997. This is one of the more extreme cases where debris from the impactor could travel as far as Wisconsin.

For the 600-m impactor (Fig. 3), the winds are similar, but the effects are more widespread, reaching all the way to Wisconsin.

When the more extreme cases were used, the results in possible outcomes ranged from 0.01 kg/m^2 debris deposition in Oklahoma City or Phoenix to 0.1 kg/m^2 in Denver or Lincoln, NE. Aviation and ground transportation (due to limited visibility) could be disrupted in Utah, Colorado, Arizona, New Mexico, Texas, Oklahoma, Nebraska, Kansas, Iowa, Missouri, and even Wisconsin.

Based on the 50 simulations, the winds generally tended to vary from the southwest to the northwest, potentially causing a disruption in air traffic throughout Colorado, western Nebraska, northern New Mexico, and into the panhandles of Texas and Oklahoma, regardless of the time of year.

Future work: Many assumptions were made to couple the numerous models required to quantify downstream and downwind effects. These assumptions should be validated.

Downstream effects: We used the highest annual post-fire sediment yields as estimated for the watersheds in the San Juan Mountains. However, additional modeling of the effects from thermal radiation and overpressure blast wave should be compared to those derived for wildfires.

Downwind effects: The greatest uncertainty for the distribution of debris fallout is the distribution of the debris grain size. We assumed a similar grain size distribution to volcanic tephra, but this assumption needs to be validated.

Conclusions: The results described here were based on generalized output from asteroid impact and air burst hydrocode simulations, wildfire and watershed erosion models, and downwind volcanic ash transport simulations. Assumptions were made to link these models and previously published scenarios together into a coherent narrative. Simplifying assumptions, such as annual sediment yields and debris size distributions, need further analysis. Based on these preliminary results, an impactor as small as 120 m will immediately disrupt transportation networks, and depending on the time of year of impact, could affect the crop production across a multi-state region. Downstream effects are likely minimal beyond the initial damage zone, but more analysis is needed.

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