Potential Long-lasting Effects on Water Resources on Coastal Aquifers from an Asteroid Impact

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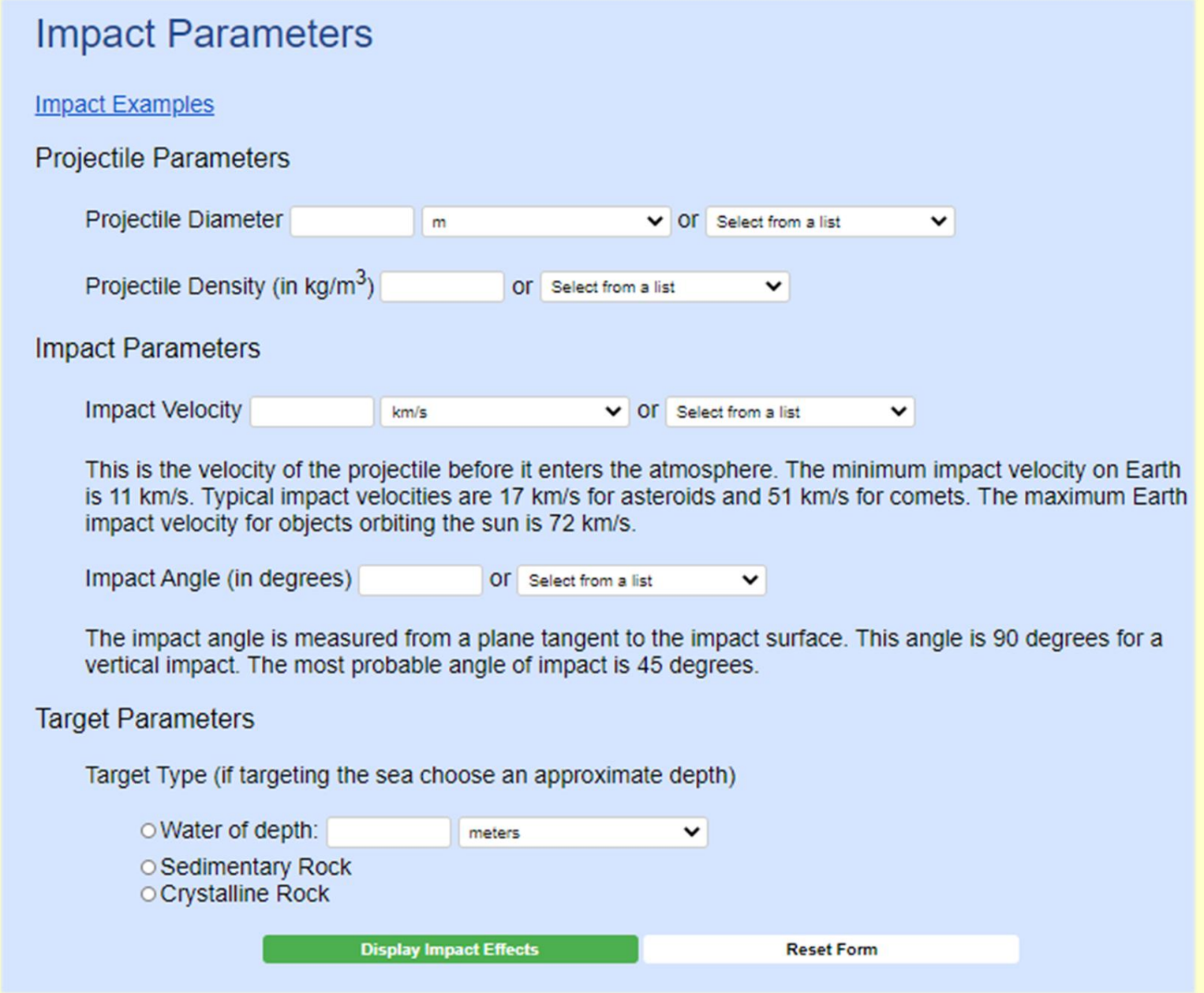
Abstract

A comet or asteroid impact on earth could be a devastating event, from the effects that would immediately take place like destruction of community water infrastructure and long-lasting impacts on hydrological systems in areas near the perimeter of the impact. Although space impacts rarely occur, if one were to strike in a highly populated area, the damage would be so great that the effects would linger for generations. Our water resources, both on the surface and underground, would be affected and disrupted on a massive scale. Approximately 35 million years ago, an asteroid or comet impacted the Chesapeake Bay region of the North American continent and left a crater that influenced the sedimentation patterns in the area that persisted for thousands of years. The impact affected the ground-water flow systems and increased the intrusion of marine water inland. Using the Chesapeake Bay Impact as an analog for future impacts in coastal regions provides perspectives on the disruption of freshwater resources that can predictably occur. In a large city like Los Angeles, which already experiences a shortage of fresh water due to semi-arid climate and drought, a space impact would likely exacerbate water supply problems due to destruction of water delivery infrastructure that would take a long time to repair, leading to unprecedented impacts to the city population. Additionally, saltwater intrusion and possible tsunamis resulting from space impacts creates a recipe for disaster for coastal communities and their access to freshwater post impact.

Methods

Using a web-based computer program (Collins, Melosh and Marcus 2010), the impact of three hypothetical spherical objects was calculated to assess the potential damage to a coastal city, in this case Los Angeles, and thus the effect on water resources in the surrounding area. The different projectile sizes were chosen based on the minimum diameter (30 meters) required to generate a crater on the surface of the earth that would be deep enough to disrupt the water table. Then, in order to compare, the subsequent objects were simply multiplied by a factor of 10 (300 meters and 3,000 meters respectively). Aside from object diameter, density (iron and/or porous rock), impact velocity, angle of impact and type of target floor were considered to assess and compare the impact effects (Figure 1). The results from the 3 hypothetical inputs yield the amount of energy released, crater dimensions (diameter and depth), and major regional or global changes. Several assumptions were made to simplify the scenarios and thus the final crater formation from the impact. These impact results were compiled and then compared (Table I). The mass of each object was calculated to estimate the impact frequency (in years) for a projectile of that size. The impact frequencies computed from the program were compared and matched to Figure 3.



Impact Parameters

Impact Examples

Projectile Parameters

Projectile Diameter ☐ m or Select from a list

Projectile Density (in kg/m^3) ☐ or Select from a list

Impact Parameters

Impact Velocity ☐ km/s or Select from a list

This is the velocity of the projectile before it enters the atmosphere. The minimum impact velocity on Earth is 11 km/s. Typical impact velocities are 17 km/s for asteroids and 51 km/s for comets. The maximum Earth impact velocity for objects orbiting the sun is 72 km/s.

Impact Angle (in degrees) ☐ or Select from a list

The impact angle is measured from a plane tangent to the impact surface. This angle is 90 degrees for a vertical impact. The most probable angle of impact is 45 degrees.

Target Parameters

Target Type (if targeting the sea choose an approximate depth)

○ Water of depth: ☐ meters
○ Sedimentary Rock
○ Crystalline Rock

Figure 1. Impact parameters entered to simulate a crater based on 3 different sizes in a sedimentary basin (Los Angeles, CA), (Collins, Marcus, Melosh 2010)

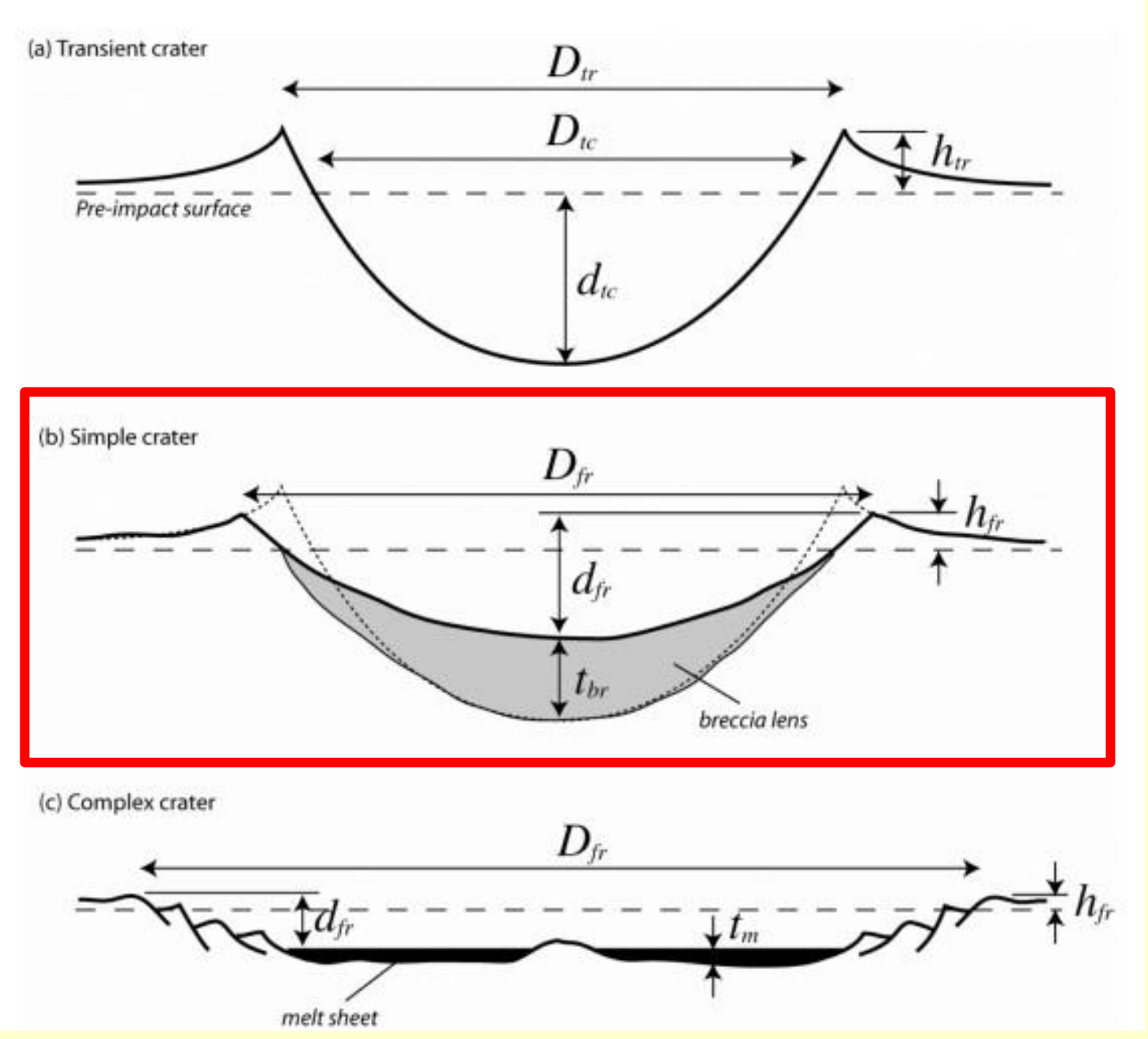


Figure 2. (Collins, Melosh and Marcus 2005) Dimensions of an impact crater a) transient crater; b) Simple crater showing pre-impact surface (dotted line), transient crater (stippled line), and final crater (solid line). Simple crater is assumed for all projectiles.; c) Complex crater.

Object	Object size (m)	Density (kg/m³)	Impact Velocity (km/s)	Impact angle (degrees)	Target Density-Sedimentary rock (kg/m3)	Final Crater Diameter (km)	Final Crater Depth (m)	Impact frequency (yrs)
A	30	8000	12	45	2500	0.825	176	523
B	300	1500	12	45	2500	2.97	411	5.9×10^4
C	3000	1500	12	45	2500	24.6	776	2.1×10^6

Table I. Comparison of 3 hypothetical objects to impact the planet and the final crater diameter. Depth and impact frequency calculated using the web-based computer program in Figure 1.

Impact Parameters and Frequency

Values used for calculations were assumed based on options provided on the web-based program (Collins, Marcus, Melosh 2010). The values chosen for the analysis (i.e. object diameter) were based on values compared to known from previous impacts. The frequency of these events were computed using impact rate estimates provided by Bland and Artemieva (2006) and compared to impact rate given by the computer model. For Object A, the density was assumed to be that of an iron projectile which is a much higher value than Objects B and C. This value allowed for the formation of a crater on the surface. Objects B and C are assumed to be the same density, corresponding to a porous rock object. Velocity and angle of entry of the object are designated as 12 km/s and 45 degrees for all three scenarios.

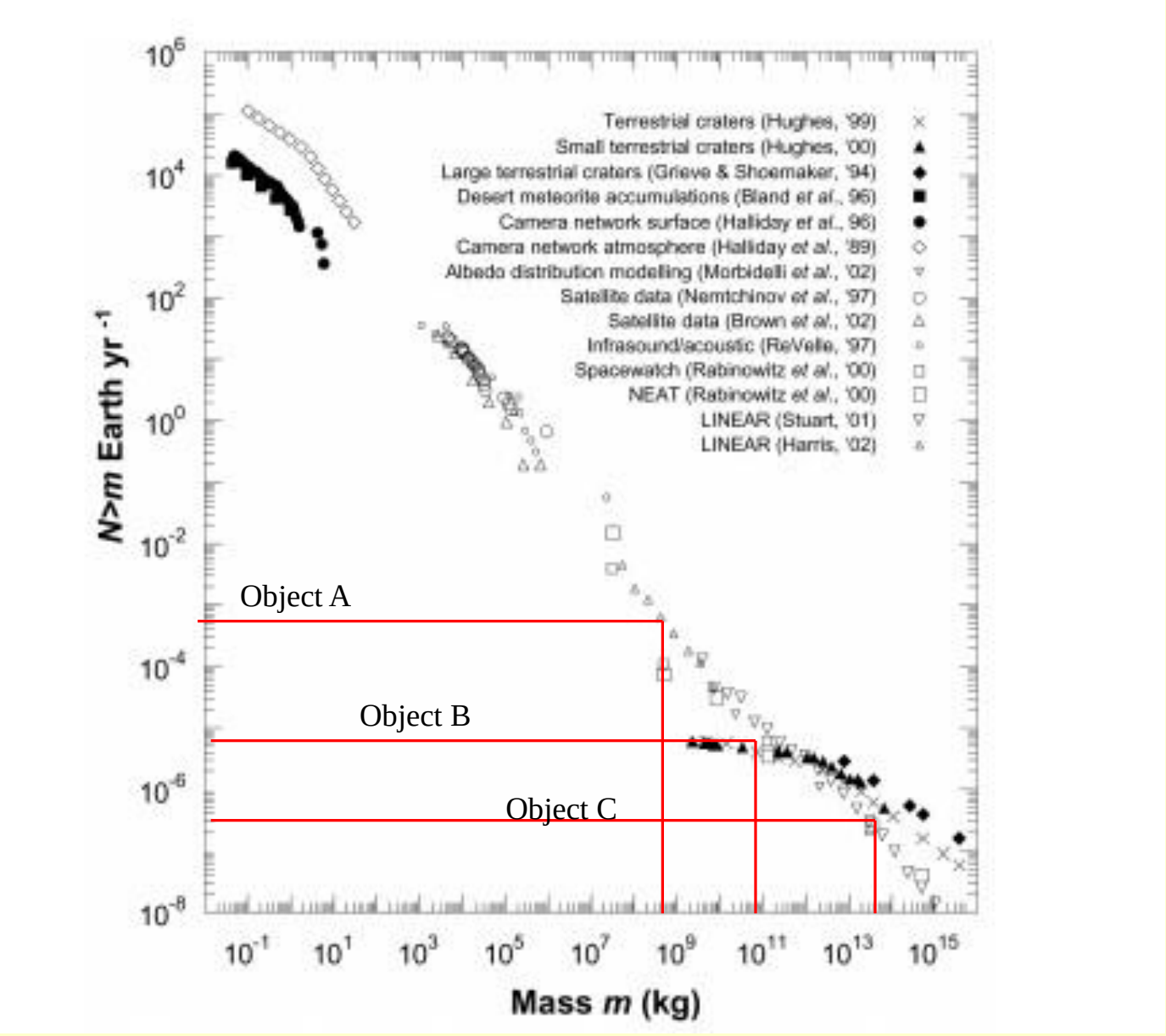


Figure 3. Impact rate estimates for the Earth's surface (closed symbols) presented as the number of events larger than a given mass for the whole Earth per year (Bland and Artemieva 2006). Object A (30-m diameter), Object B (300-m diameter), Object C (3000-m diameter).

Object diameter (m)	Density (kg/m³)	Volume (m³)	Mass (kg)	Impact rate (years)
30	8,000	1.4×10^4	1.13×10^8	1:1,000
300	1,500	1.4×10^7	2.11×10^{10}	1:10,000
3,000	1,500	1.41×10^{10}	2.11×10^{13}	1:1,000,000

Table II. Estimated impact rate based on mass calculated for each object using known diameter and density

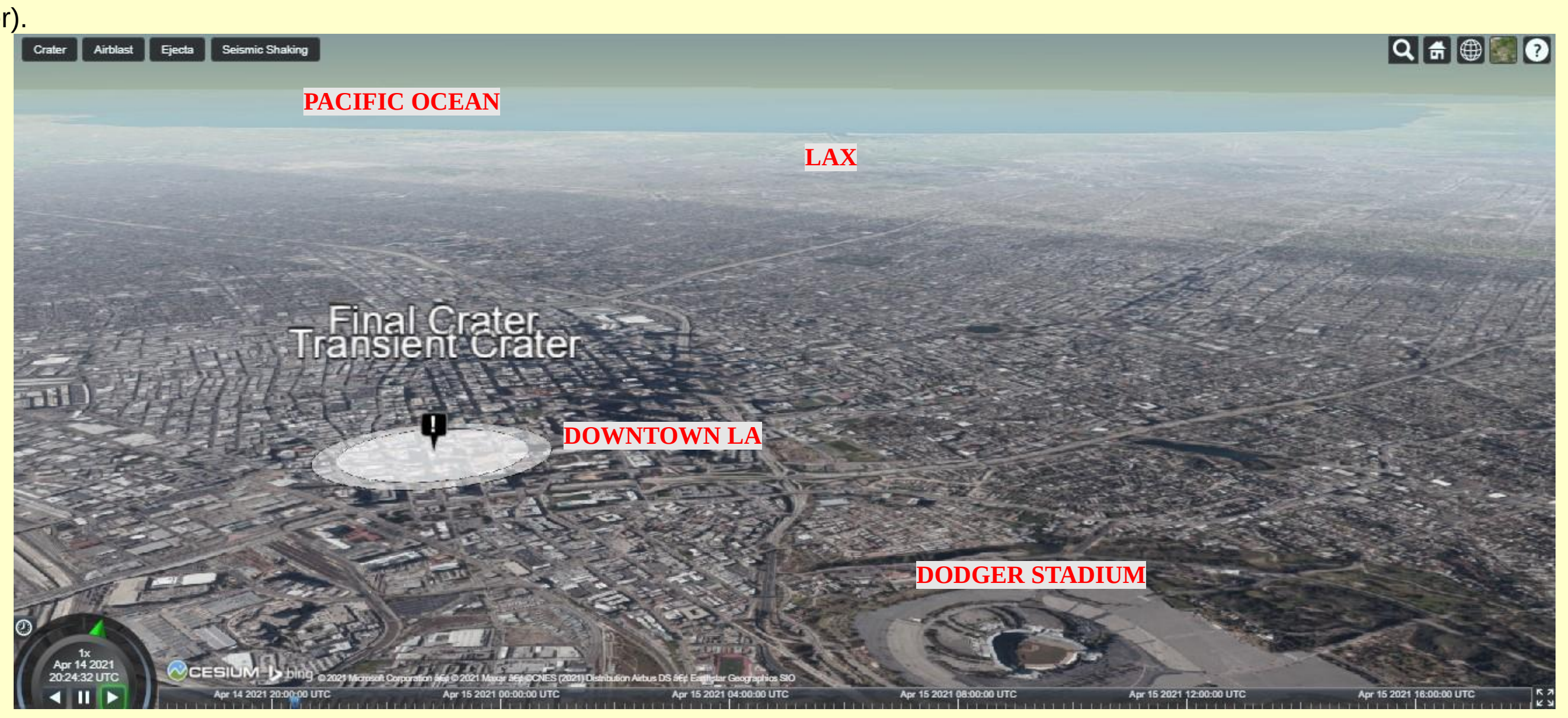


Figure 4. Impact crater of diameter 0.825 km and depth of 176 m formed from a 30-m diameter iron object with a density of 8000 kg/m^3 traveling at 12 km/s in Downtown Los Angeles.

Figure 5. Impact crater of diameter 2.97 km and depth of 411 m formed from a 300-m diameter porous rock object with a density of 1,500 kg/m^3 traveling at 12 km/s in Downtown Los Angeles.

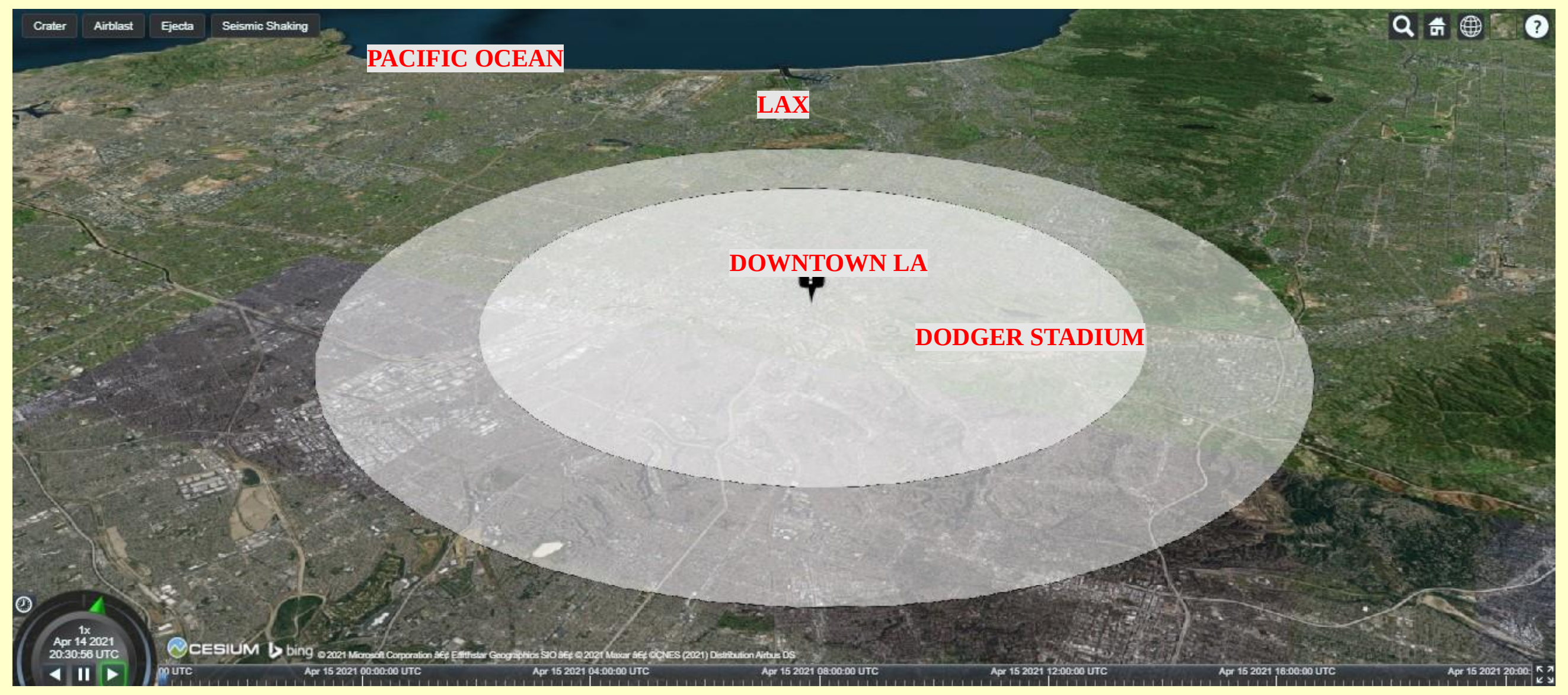


Figure 6. Impact crater of diameter 24.6 km and depth of 776 m formed from a 30000-m diameter porous rock object with a density of 1,500 kg/m^3 traveling at 12 km/s in Downtown Los Angeles.

Effects on Groundwater

Groundwater is one of the most precious natural resources to humans and is an essential piece of our socio-economic fabric. Southern California is a highly populated area which depends on water not only for human consumption, but also for industrial purposes. In the Los Angeles area, in particular, the demand for water is extremely high. Water to this area is brought in from different sources like the Colorado River and the Owens Valley River, with about one-third of the population relying on groundwater. The use of groundwater has increased in an effort to be less dependent on imported sources, however, any major disruption to our watersheds can be catastrophic to the population. The average depth of the watertable in the Los Angeles basin is about 10 meters, according to LA County data (https://dpw.lacounty.gov/general/wells/). All of the scenarios presented show that each impact would penetrate the watertable (>10 m). Disruption to the watertable by a projectile impact would warrant redistribution of sediment which would directly affect the availability of groundwater for consumption. As the subsurface settles recharge to local aquifers could be slow. An impact could also drastically alter already contaminated sites below the surface and allow migration of these contaminants through the aquifer. Development of new contamination sites (such as leakage from gas stations or factories) could be a possibility. Contaminated groundwater remediation may take months, if the object is small, to tens or thousands of years, if a larger impact occurs. Liquefaction and land subsidence can present yet another problem to basin communities as local flooding and structure damages can occur. Another effect on groundwater resources, specifically in coastal aquifers, is saltwater intrusion. This occurs when seawater migrates into freshwater aquifers. The quality of the freshwater degrades as more saline water intrudes. Saltwater intrusion is already a problem in some coastal aquifers and can be exacerbated by a large meteor impact, potentially one 300 meters in diameter with a frequency of 1 in 10,000 years. Using information from the Chesapeake Bay as an analog could shed some light on the potential issues that could arise if a meteor hit Earth today and can be useful to accurately model and evaluate groundwater flow and the potential for saltwater intrusion in the vicinity of the impact crater (Powars 2000). As groundwater use increases in the Los Angeles region and as public water utilities increasingly rely on aquifers as sources of drinking water, additional information and mitigation tools will be needed for future management of these ground-water resources. California's dependence on imported water will continue if steps are not taken to secure its finite groundwater resources.

Conclusions and Further Research

Much research and mitigation has been developed for potential earthquake-caused catastrophies. Infrastructure upgrades and modifications in Southern California have mainly focused on earthquake preparation. Some of these alterations include improved water supply storage reservoirs which would provide clean water for human consumption for a short period of time (6 months). Although these steps point in the right direction, they are short-term and do not address long-term effects. Asteroid impacts occur less frequently than earthquakes, but they can be long lasting high consequence events especially in high populated areas. The scenarios provided herein are highly simplified in nature and general assumptions were made to explain potential effects of an object impact with Earth's surface. The actual results could be worse as the population would not only have to deal with the lack of water for consumption, but also the immediate aftermath of the impact itself in terms of seismic activity, material ejected and the airblast from the event. As groundwater use increases in the Los Angeles basin and as public water utilities increasingly rely on aquifers as sources of drinking water, additional information about the infrastructure updates is needed for future management of these groundwater resources. Further investigations on the specific effects on groundwater resources and their extent over long periods of time due to a meteor impact are needed to prepare emergency response teams as well as the public.

References

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