Countdown to Apophis Close Approach—Cascading Hazards from Asteroid Impacts

"Near-Earth Objects like Apophis represent a potential hazard to Earth, not just from the primary impact but also from hazards caused by a primary hazard or as part of a series of events."

—Timothy Titus, Research Space Scientist, U.S. Geological Survey

Introduction

Apophis (officially 99942 Apophis, pronounced "uh-PAW-fiss") is a Near-Earth Object (fig. 1). Primarily composed of the materials that make up the leftover building blocks of the solar system, Near-Earth Objects are small solar system bodies in an orbit around the Sun that brings them close to the Earth. Apophis has been classified as a "potentially hazardous object," a Near-Earth Object that may be large enough to cause significant damage in the event of an impact. Apophis is not projected to hit the Earth, but it will come close. The U.S. Geological Survey (USGS) is working with other Federal partners, industry, academic institutions, and international cooperators to characterize Apophis, prepare for the flyby on Friday, April 13, 2029, and develop investigative and mitigation strategies for potential impacts from other Near-Earth Objects.

Close approaches of objects the size of Apophis (approximately 340 meters in diameter) or larger are considered rare events, occurring every few thousand years or so. Although Apophis will not impact Earth, the Specific Action Team was convened and included USGS participation, to (1) identify and quantify effects on Apophis from its close flyby with Earth; (2) assess the importance of measuring these effects; (3) categorize these effects according to different tiers of detectable limits; and (4) assess the risk to Earth of a spacecraft rendezvous with Apophis (Dotson and others, 2022).

On Friday, April 13, 2029, asteroid Apophis, named after the Egyptian god of chaos and destruction, will pass close to the Earth.

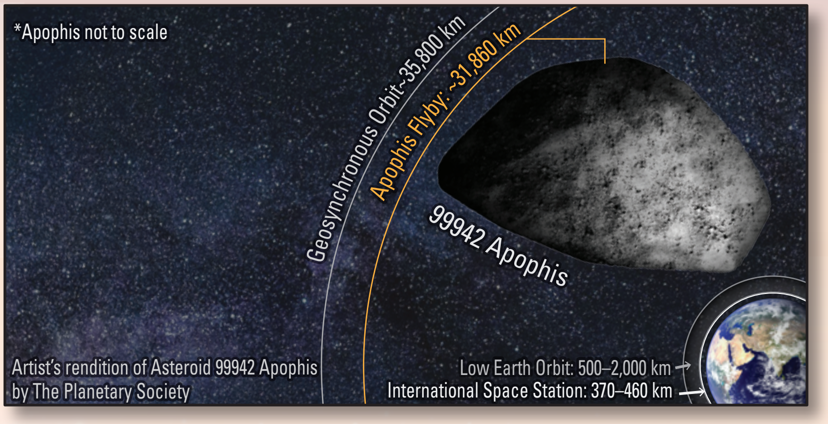

Figure 1. Computer-simulated image of 99942 Apophis (right) based on a hypothetical shape model of the asteroid. Orbit lines are to scale by diameter, but Apophis will not orbit in this way. Instead, it will fly by, approaching from below the plane of geosynchronous orbit and exiting Earth space above the plane of orbit (fig. 2). Abbreviation: km, kilometer.

The USGS also undertakes research to understand the potential hazards of and mitigation strategies for asteroid impacts. Scientists are likely to detect asteroids the size of Apophis, but much smaller asteroids may arrive with little to no warning. Apophis will also be close enough to Earth (31,860 kilometers) to pass within the orbit of geosynchronous satellites (35,800 kilometers), but it is unlikely to pose a risk due to its geometry relative to their locations (fig. 2).

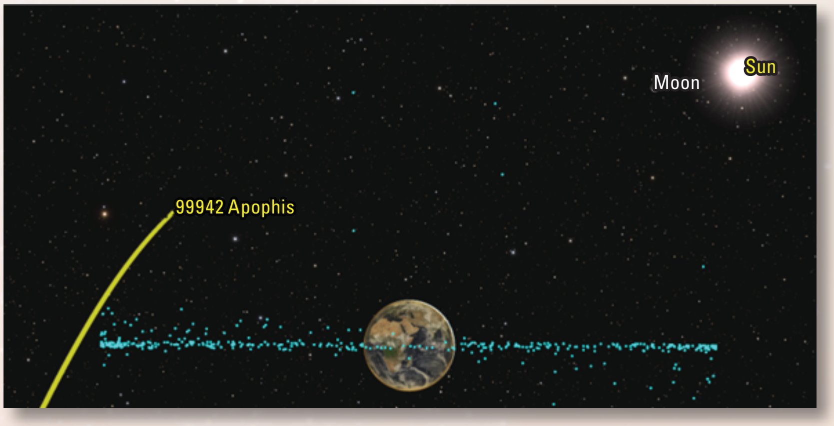

Figure 2. The relative geometry of Apophis's approach with respect to the Earth, Moon, and Sun and a teal ring of geosynchronous satellites from the Specific Action Team report (Dotson and others, 2022).

Apophis will not impact Earth.

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May 2025

> “Preparedness is key. For the future, it’s better to have a mitigation strategy in hand, rather than wait until there is an actual crisis to develop a plan.”
>
> —Timothy Titus, Research Space Scientist, U.S. Geological Survey

Asteroid impacts can have a range of effects depending on the magnitude and location of impact. Earthquakes, tsunamis, blast waves, and heat are typical primary effects. Secondary and longer-term effects are generally poorly studied, and USGS undertakes novel and cutting-edge research in these areas. The USGS provides a wealth of data in wildfire, volcano, landslide, and water quality that can be used in complex models to evaluate the long-term effects of an asteroid impact. These “cascading hazards,” or secondary and (or) long-term hazards triggered by initial primary events, can extend beyond the initial impact area and can be significant for global agriculture and public health, potentially requiring long-term monitoring.

Cascading hazards from an asteroid impact can be lumped into two main categories: downwind effects (blow) and downstream effects (flow). Downwind effects include debris plumes blown by the wind and ejected dust that reaches the stratosphere. Downstream effects include landslides and flooding impacts. Both types of hazards can be serious and lead to regional or greater impacts, create long-term damage, and pose risks to life, agriculture, transportation, and property. As of 2025, cascading and long-term hazards are not well characterized, but the USGS is working to better understand the cascading hazards from asteroid impacts.

Visualizing Cascading Hazards

Figure 3 shows many of the regional and cascading hazards from an asteroid impact. The primary hazard (asteroid impact) is in the middle, with secondary impacts (for example, tsunamis, thermal radiation, blast winds, and dust plumes) shown following arrows around the impact. Other cascading hazards from these effects can be seen following arrows from these secondary impacts, including flooding, landslides, crop failure, and wildfires. Research in many of the USGS mission areas can inform and enhance mitigation strategies in asteroid impact modeling.

The USGS also is involved with asteroid characterization as part of planetary defense strategies to understand potentially hazardous objects. Software developed by the Astrogeology Science Center is used to process data and create shape models of asteroids like Bennu, Eros, and Itokawa. Knowing the size, shape, composition, and physical properties of an asteroid is crucial for modeling the effects of a potential impact, and missions sent to these asteroids are designed to collect these types of data.

Missions like the Origins, Spectral Interpretation, Resource Identification, and Security-Regolith Explorer (OSIRIS-REx) spacecraft have imaged and sampled asteroids, in this case Bennu, to understand the origins of near-Earth asteroids. After dropping off a sample collected from Bennu, OSIRIS-REx was renamed OSIRIS-APEX and will visit Apophis after the asteroid’s close flyby in 2029. Much was learned from the OSIRIS-REx mission, and much more will continue to be gained from the OSIRIS-APEX mission and future spacecraft visiting Near-Earth Objects.

The USGS is a national and international partner in many such missions, collecting, processing, and archiving critical asteroid information for current and future use. The Astrogeology Science Center also hosts and manages the Imaging Sciences Node of the NASA Planetary Data System, ensuring free and open access to image data for continued planetary science research.

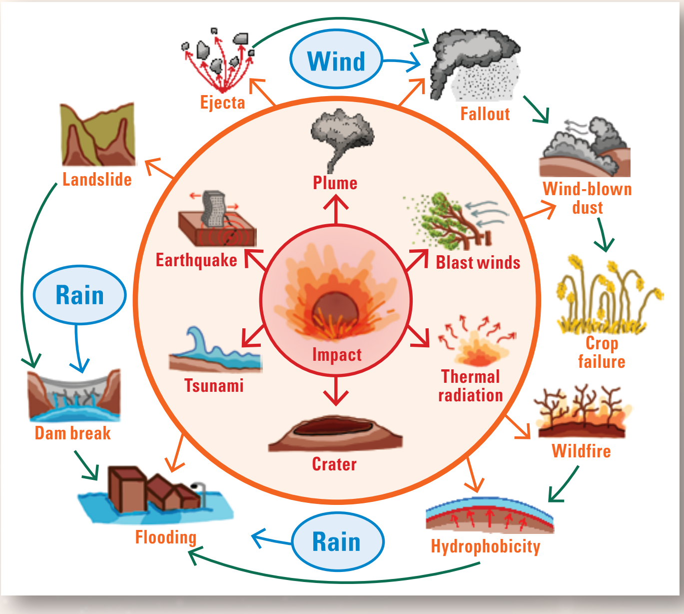

Figure 3. The connection among initial effects and a chain of cascading hazards. The asteroid impact, or “primary hazard,” is in the middle, and hazards related to the primary event or triggered by the primary or secondary hazards are around the outside. This illustration shows the interconnectedness of cascading hazards from a large asteroid impact (modified from Titus and others, 2023).

References Cited

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ISSN 2327-6932 (online)
ISSN 2327-6916 (print)

https://doi.org/10.3133/fs20253028