

# HUMAN IMPACTS by the numbers

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## ABSTRACT

The greatest experiment of the last 10,000 years is the presence and action of modern human beings on planet Earth. At this point, the consequences of this experiment are being felt on many fronts. Yet, many people still hold the view that because the world is so "huge", humans cannot really make a substantial impact. One way to organize our thinking about what these impacts might be, with tongue in cheek, is to focus on Empedocles's classic elements, earth, air, water and fire, with the idea being to explore how humans have altered the land and its inhabitants, the atmosphere, the oceans and how our quest for cheaper and cheaper energy (fire) from the world around us has altered that world. This snapshot represents a small collection of numbers that summarize the broad reach of human action across the planet, presenting a view of the impact of human presence on Earth.

## UNITS OF REFERENCE

human population		$\approx 7 \times 10^9$	mass of a pick-up truck		$\approx 1\text{ t}$
area of soccer pitch		$\approx 3000\text{ m}^2$	power of a lightbulb		$\approx 100\text{ W}$
volume of olympic pool		$\approx 2000\text{ m}^3$			

## A MELT WATER

glacial melt volume	$\approx 3 \times 10^{11}\text{ m}^3/\text{yr}$	$\approx 150\text{ million} \times$		$\text{/yr}$
arctic sea-ice melt volume	$\approx 3 \times 10^{11}\text{ m}^3/\text{yr}$	$\approx 150\text{ million} \times$		$\text{/yr}$
ice-sheet melt volume	$\approx 4 \times 10^{11}\text{ m}^3/\text{yr}$	$\approx 200\text{ million} \times$		$\text{/yr}$
total melt volume	$\approx 10^{12}\text{ m}^3/\text{yr}$	$\approx 500\text{ million} \times$		$\text{/yr}$

## B POWER DERIVED FROM RENEWABLES

wind	$\approx 360\text{ GW}$	$\approx 4\text{ billion} \times$	
solar	$\approx 200\text{ GW}$	$\approx 2\text{ billion} \times$	
biofuels	$\approx 150\text{ GW}$	$\approx 1.5\text{ billion} \times$	
total	$\approx 875\text{ GW}$	$\approx 9\text{ billion} \times$	

## C SEA LEVEL RISE

rise from melt-water	$\approx 1.6\text{ mm}/\text{yr}$
rise from thermal expansion	$\approx 1.2\text{ mm}/\text{yr}$
total annual sea-level rise	$\approx 3\text{ mm}/\text{yr}$

## F POPULATION OF LIVESTOCK

chicken population	$\approx 2 \times 10^{10} \approx 3 \times$	
cattle population	$\approx 2 \times 10^9 \approx 0.3 \times$	
pig population	$\approx 1 \times 10^9 \approx 0.1 \times$	
total livestock population	$\approx 30\text{ billion} \approx 4 \times$	

## D NITROGEN FIXATION

reactive nitrogen produced via Haber-Bosch	$\approx 2 \times 10^8\text{ t}/\text{yr}$	$\approx 200\text{ million} \times$		$\text{/yr}$
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## G EXTENT OF TERRESTRIAL LAND USAGE

agriculture	$\approx 5 \times 10^{13}\text{ m}^2 \approx 15\text{ billion} \times$	
urban	$\approx 4 \times 10^{12}\text{ m}^2 \approx 1\text{ billion} \times$	

## I MATERIAL OF HUMAN ORIGIN

concrete production	$\approx 3 \times 10^{10}\text{ t}/\text{yr}$	$\approx 30\text{ billion} \times$		$\text{/yr}$
steel production	$\approx 2 \times 10^9\text{ t}/\text{yr}$	$\approx 2\text{ billion} \times$		$\text{/yr}$
plastic production	$\approx 4 \times 10^6\text{ t}/\text{yr}$	$\approx 4\text{ million} \times$		$\text{/yr}$

## L GLOBAL POWER CONSUMPTION

global power usage	$\approx 20\text{ TW}/\text{yr}$	$\approx 200\text{ billion} \times$		$\text{/yr}$
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## M OCEAN WARMING

power deposited into oceans	$\approx 160\text{ TW} \approx 1.5\text{ trillion} \times$	
change in surface temperature	$\approx 0.03^\circ\text{C}/\text{yr}$	

## Q CORAL REEF LOSS

Great Barrier Reef coral coverage	$\approx 30\%$
decrease in 2016	

mass of coal extracted	$\approx 8 \times 10^9\text{ t}/\text{yr}$	$\approx 8\text{ billion} \times$		$\text{/yr}$
power derived from coal	$\approx 5\text{ TW}/\text{yr}$	$\approx 50\text{ billion} \times$		$\text{/yr}$

## N GREENHOUSE GAS PRODUCTION

anthropogenic CO <sub>2</sub> release	$\approx 42 \times 10^9\text{ t}$	$\approx 42\text{ billion} \times$		$\text{/yr}$
anthropogenic CH <sub>4</sub> release	$\approx 4 \times 10^8\text{ t}$	$\approx 400\text{ million} \times$		$\text{/yr}$

## R EROSION

intentional soil movement	$\approx 4 \times 10^{10}\text{ t}/\text{yr}$	$\approx 40\text{ billion} \times$		$\text{/yr}$
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## S NUCLEAR FALLOUT

plutonium radioactivity from nuclear weapons testing	$\approx 1\text{ decay/sec/kg}$
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## O

## OIL & NATURAL GAS EXTRACTION

volume of natural gas extracted	$\approx 4 \times 10^{12}\text{ m}^3/\text{yr}$	$\approx 2\text{ billion} \times$
volume of oil extracted	$\approx 5.5 \times 10^9\text{ m}^3/\text{yr}$	$\approx 3\text{ million} \times$
power derived from natural gas	$\approx 4\text{ TW}$	$\approx 40\text{ billion} \times$
power derived from oil	$\approx 6\text{ TW}$	$\approx 60\text{ billion} \times$

oil & natural gas mineral resources

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## THE ANTHROPOCENE

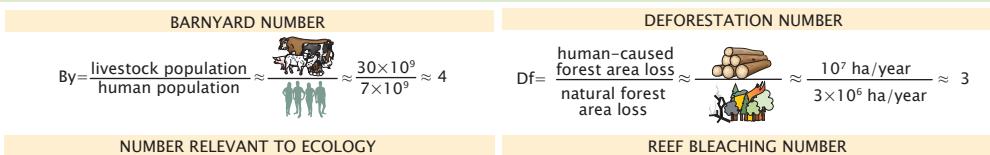
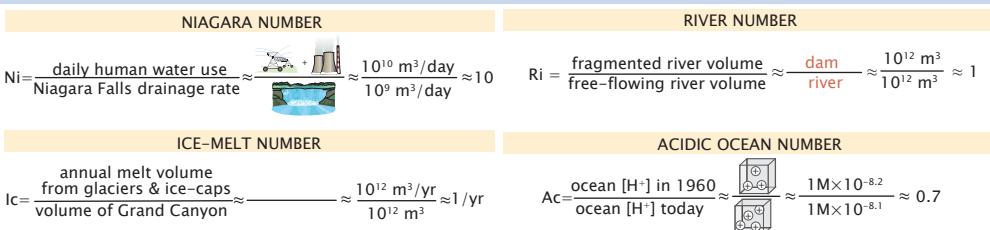
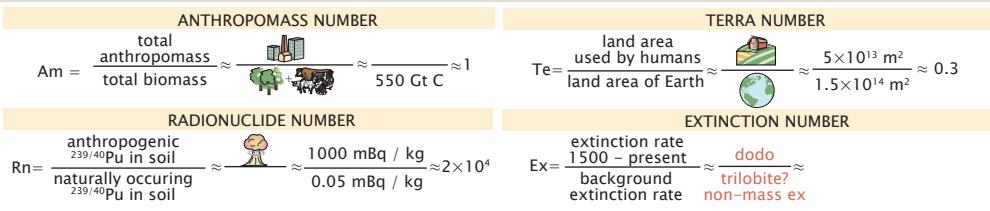
A visit to any natural history museum will reveal that much about Earth's history can be learned by examining the geological and fossil record. As humans have made extensive changes to the Earth's chemistry and biology, in addition to the physical changes to the Earth's crust, the record of our existence will similarly be preserved in the geological record. The **Anthropomass Number** reveals that, as of 2020, the total mass of human-derived material (concrete, plastic, steel, etc.) is now approximately equal to the mass of the entire biosphere. The **Terra Number** illustrates that humans occupy or directly control  $\approx 30\%$  of the terrestrial surface area, meaning artifacts of human society is widespread across the planet. The **Radionuclide Number** describes a radioactive signature of nuclear weapons testing in a 20,000 fold enrichment in plutonium isotope radioactivity that will be detectable in stratified soil several hundred thousand years into the future. Finally, the **Extinction Number** shows that the current extinction rate is at least several hundred times above the background extinction rate for plant and animal species, dictating the future fossil record. While incomplete, these dimensionless numbers represent the magnitude to which human activity will be evident in Earth's geological record beyond the existence of our species as we currently know it.

## THE MAGNITUDE OF HUMAN WATER USAGE

Humans use more water than any other substance on the planet. Our requirement for water, both for personal use and for industrial purposes, coupled with changes in our atmospheric chemistry have substantially altered the hydrosphere from many angles. The **Niagara Number** captures the magnitude of human water usage, revealing that on a daily basis, humans use approximately and order of magnitude more water than falls over Niagara Falls in a single day. This use is dominated by power-plant usage (for cooling) and agriculture. The flow of water from high to low elevations can be used to generate hydroelectricity via river damming. The **River Number** reveals that there is an approximately equal volume global river water used by hydroelectric dams as there are free-flowing rivers on Earth, which has strong implications on stability of watersheds and river ecosystems. Anthropogenic emission of CO<sub>2</sub> has lead to widespread warming of the climate, resulting in melting of glaciers and ice-caps. The **Ice-Melt Number** summarizes the extent as this melting as releasing  $\approx 1$  Grand Canyon's worth of water into the hydrosphere per year. Approximately 40% of CO<sub>2</sub> emissions are absorbed by Earth's oceans and seas, ultimately shifting the equilibrium of carbonic acid. The **Acidic Ocean Number** captures the extent of this effect, revealing a  $\approx 30\%$  increase in hydrogen ion concentration in the oceans over the 60 year period of 1960 – present.

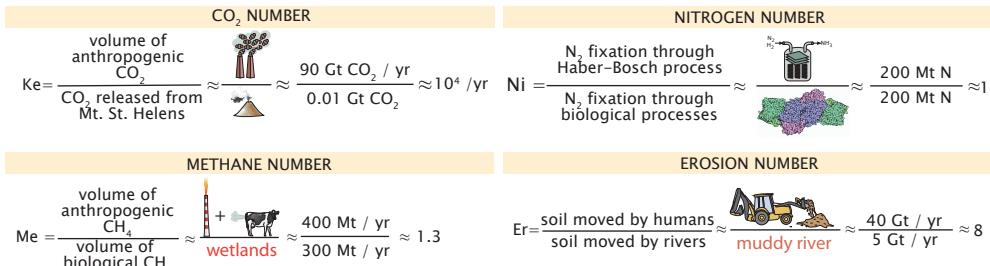
## HUMANS AS THE EARTH'S GREATEST EVOLUTIONARY FORCE

Biology's greatest idea is evolution, the fact that over time, the living world has always and will continue to always change. Species come and species go. Natural forces, such as the closing of the Isthmus of Panama, result in profound changes to the living world. As humans have increased in population and technological prowess, so too has their impact on the evolutionary process. The **Barnyard Number** captures the magnitude of animal husbandry by humans by measuring the relative population sizes of the entirety of our domesticated animals relative to the size of the human population itself. Natural habitats across the globe have been altered significantly by human action. The **Deforestation Number** compares the loss of forest resulting from human activity to that which occurs naturally.



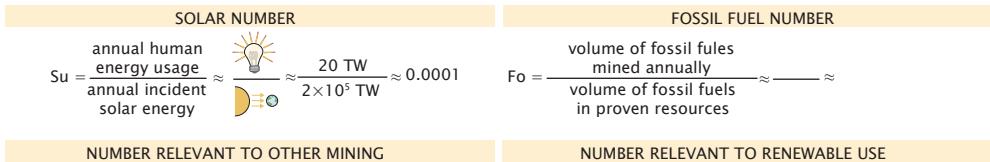
## HUMAN IMPACTS ON ATMOSPHERIC AND BIOGEOCHEMICAL CYCLES

The Keeling curve has the same iconic status as the DNA double helix. Beginning in the 1950s, we have had a largely uninterrupted quantitative glimpse into the atmospheric concentration of CO<sub>2</sub>. To get an impression of the human-induced increase in atmospheric CO<sub>2</sub>, the **CO<sub>2</sub> Number** compares the total anthropogenic CO<sub>2</sub> released in comparison with the CO<sub>2</sub> released from the eruption of Mt. St. Helens, revealing humans have released 200,000 times the amount of CO<sub>2</sub> as this infamous eruption. Perhaps even more dramatic than our impact on the CO<sub>2</sub> budget of the atmosphere is our role in nitrogen fixation. The **Nitrogen Number** measures the ratio of atmospheric nitrogen fixed through the Haber-Bosch process to that occurring naturally in the rhizosphere due to microbes. The **Methane Number** characterizes a less well-known example, namely, the volume of anthropogenic methane in comparison with the methane of XXXX. The **Erosion Number** compares the volume of soil moved by humans to that moved by rivers.



## THE MAGNITUDE OF HUMAN ENERGY USAGE

Finding new ways to extract useful work from the world is one of the signature achievements of the human condition. And yet, this act of learning how to extract energy from the environment is a large part of the story of human impacts, whether in the burning of various fuels that change the atmosphere, or the damming of the world's rivers to produce electricity. The **Solar Number** is one of the most important human impacts numbers of all and compares the 20 TW per year energy use of humans to the 10,000 fold higher incident power from the sun. The **Fossil Fuel Number**



# HUMAN IMPACTS by the numbers

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## SUPPORTING INFORMATION

### A MELTWERTER

glacial melt rate **HuID: 32459**

**Data Source(s):** Intergovernmental Panel on Climate Change (IPCC) 2019 Special Report "The Ocean and Cryosphere in a Changing Climate." Table 2.A.1 on pp. 199–202. **Notes:** Value corresponds to the trend of annual mass loss from major glacierized regions (2006–2015). Volume loss was calculated from mass loss.

ice-sheet melt rate **HuID: 44746; 88530**

**Data Source(s):** NASA JPL Physical Oceanography Distributed Active Archive Center. **Notes:** Value corresponds to the trend of annual mass loss from the Greenland and Antarctic Ice Sheets (2002–2020). Volume loss was calculated from mass loss.

arctic sea ice melt rate **HuID: 89520**

**Data Source(s):** PIOMAS Arctic Sea Ice Volume Reanalysis, original method source: Schweiger et al. 2011 DOI: 10.1029/2011JC007084. **Notes:** Value reported corresponds to the the trend of decadal volume loss from Arctic sea ice (1979–2020) which was converted to annual volume loss.

total melt rate **HuID: 89075**

**Data Source(s):** Sum of glacial, ice sheet, and sea ice melt rate. **Notes:** Antarctic sea ice loss is not included due to data sparsity. The periods of analysis are not the same, therefore this rate represents an approximation rather than an exact calculation.

### B POWER DERIVED FROM RENEWABLES

wind **HuID: 30581**

solar **HuID: 99885**

biofuels **HuID: 89506**

total **HuID: 20246**

**Data Source(s):** bp Statistical Review of World Energy, 2020. **Notes:** Reported values correspond to estimates for the 2019 calendar year. Renewable resources are defined as wind, geothermal, solar, biomass and waste, and does not include hydroelectric power generation.

### C SEA LEVEL RISE

rise due to meltwater **HuID: 97108**

rise due to thermal expansion **HuID: 97688**

total annual sea-level rise **HuID: 81373**

**Data Source(s):** Table 1 of Frederikse et al. 2020. DOI:10.6689. **Notes:** Values correspond to the average global sea level rise of the years 1993 – 2018. Meltwater is defined as the global annual sea level rise due to melt of glaciers, the Greenland ice sheet, and antarctic ice sheet.

### D NITROGEN FIXATION

fixed mass of nitrogen **HuID: 60580; 30310; 78152**

**Data Source(s):** USGS Mineral Commodities Summaries (Fixed Nitrogen), January 2020; Table 2 of "World fertilizer trends and outlook to 2022" Food and Agricultural Organization of the United Nations, 2019, ISBN: 978-92-5-131894-2. Smit et al. 2010, DOI:10.1039/c9ee02873k. **Notes:** The approximate mass of contained nitrogen in salient ammonia produced globally in 2018 as reported by the USGS is  $\approx 144$  Mt. This value is in moderate agreement with the forecast of  $\approx 160$  Mt of nitrogen-contained ammonia as forecast for 2018 by the FAO. Approximately all of this mass is produced by the Haber-Bosch process ( $>96\%$ , Smith et al. 2020).

### E RIVER FRAGMENTATION

fragmented river volume **HuID: 00000**

**Data Source(s):** CSV dataset: DOI: 10.5281/zeno. do.3875115, original data source: Grill et al. 2019 DOI: 10.1038/s41586-019-1111-9. **Notes:**

large-scale forestry operations occurring within managed forests and tree plantations with evidence of forest regrowth in subsequent years." Forest land disruption due to urbanization is defined as "forest and shrubland conversion for the expansion and intensification of existing urban centers." Total value of deforested and disrupted forest land includes wildfires of both human and natural causes. Values correspond to calendar year 2015 and are calculated from the statistic that  $\approx 25\%$  of total deforested and disrupted forest land sums to  $\approx 5$  Mha/yr. See Table 1 and Figure 3 of Curtis et al. 2018.

### I MATERIAL OF HUMAN ORIGIN

concrete production **HuID: 25488**

steel production **HuID: 51453**

**Data Source(s):** USGS 2020, Mineral commodities. DOI:10.3133/mcs2020; Monteiro et al. 2017, DOI:10.138/nmat4930. **Notes:** Concrete production value corresponds to approximate value from multiple sources. USGS 2020 Mineral Commodities Survey reports mass of cement produced in 2019. This is converted to concrete using a multiplicative conversion factor of  $\approx 7$  as described in Monteiro et al. 2017. Steel production corresponds to the USGS 2019 value.

plastic production **HuID: 97241**

**Data Source(s):** Table S2 of Geyer et al. 2017. DOI:10.1126/sciadv.1700782. **Notes:** Value represents the sum total global production of plastic fibers and plastic resin during calendar year 2015.

### J OCEAN pH

yearly change in  $[H^+]$  **HuID: 19394**

**Data Source(s):** Figure 2 of European Environment Agency report CLIM 043 (2020). Original data source of report is "Global Mean Sea Water pH" from Copernicus Marine Environment Monitoring Service. **Notes:** Reported value is calculated from the average annual change in pH over years 1985–2018. Annual change in pH is  $\approx 0.001$  pH units, corresponding to a change in  $[H^+]$  of  $\approx 0.2\% / yr$ .

### K HUMAN WATER USE

agriculture **HuID: 43593**

power generation **HuID: 78784**

domestic **HuID: 69424**

total **HuID: 27342**

**Data Source(s):** Figure 1 of Qin et al. 2019. DOI:10.1038/s41893-019-0294-2. **Notes:** "Agricultural use" is defined as water used for irrigation, maintenance of livestock, and water used in the management of irrigation via damming. "Power generation" is defined as water used for thermal power generation (coal, nuclear, gas, biomass, oil, and other/waste) and hydroelectric generation. "Domestic" is defined as water directly used by humans and water used in the maintenance of municipal water supply. "Total" water use includes the above categories as well as other uses of water in reservoir management including flood control and other unannotated uses. All values pertain to estimates for 2016.

### L GLOBAL POWER CONSUMPTION

global power consumption **HuID: 31373**

**Data Source(s):** bp Statistical Review of World Energy, 2020. **Notes:** Reported values correspond to estimates for the 2019 calendar year. Represents the sum total consumed energy from oil, natural gas, coal, nuclear energy, hydroelectric, and renewables.

### M OCEAN WARMING

power deposition **HuID: 59201**

ocean surface warming **HuID: 87228**

**Data Source(s):** Intergovernmental Panel on Climate Change (IPCC) 2019 Special Report "The Ocean and Cryosphere in a Changing Climate." Table 5.1 on pp. 458 and footnote 4 on pp. 457. **Notes:** Value is calculated from the reported annual heat uptake of  $\approx 5$  ZJ/yr over the time period of 2005 – 2017. This assumes a constant value for deposition into the ocean surface (0 – 700 m depth) and deep ocean (700 – 2000 m depth) where heat deposition is lower. Ocean surface temperature change is calculated from  $\approx 5$  ZJ/yr heat uptake by noting that deposition of  $\approx 144$  ZJ/yr raises the temperature of the top 100 m of ocean by  $\approx 1^\circ$  C. See the complete report or section 5.2.2 of the source material for more information.

### N GREENHOUSE GAS EMISSIONS

yearly  $CO_2$  released **HuID: 47200; 98043**

**Data Source(s):** Friedlingstein et al. 2019, DOI: 10.5194/essd-11-1783-2019. Original data sources relevant to this study compiled in Friedlingstein et al.: 1) Gilfillan et al. <https://energy.appstate.edu/CDIAC>; 2) Average of two bookkeeping models: Houghton and Nassikas 2017 DOI: 10.1002/2016GB005546; Hansis et al. 2015 DOI: Dlugokencky and Tans, NOAA/GML <https://www.esrl.noaa.gov/gmd/ccgg/trends/>.

**Notes:** Value corresponds to  $CO_2$  emissions from fossil fuel combustion, industrial emissions (predominantly cement production), and land-use change during calendar year 2018.  $CO_2$  was added to the atmosphere at a rate of  $\approx 18.8$  Gt / yr in 2018 (HuID: 98043); most of the remainder is taken up by the land sink and ocean sink.

yearly  $CH_4$  released **HuID: 96837; 56405; 30725**

**Data Source(s):** Table 2 of Saunois, et al. 2020. DOI: 10.5194/essd-12-1561-2020. **Notes:** Value corresponds to  $CH_4$  emissions from anthropogenic sources in the calendar year 2017. Represents emissions from agriculture and waste, fossil fuels, and biomass and biofuel burning. Value is not simply the sum of these sources but is based on a full anthropogenic inventory of emissions. Natural emissions amount to  $\approx 0.3$  Gt / yr in 2017.  $CH_4$  was added to the atmosphere at a rate of  $\approx 17$  Mt/yr in 2017; most of the remainder is taken up by the chemical loss sink and soil sink.

### O OIL & NATURAL GAS EXTRACTION

power derived from nat. gas **HuID: 49947**

power derived from oil **HuID: 42121**

volume of nat. gas extraction **HuID: 11468**

volume of oil extraction **HuID: 66789**

**Data Source(s):** bp Statistical Review of World Energy, 2020. **Notes:** Values pertain to 2019 estimates only. Oil volume includes crude oil, shale oil, oil sands, condensates, and natural gas liquids separate from specific natural gas mining. Natural gas value excludes gas flared or recycled and includes natural gas produced for gas-to-liquids transformation.

### P HUMAN CAUSED EXTINCTION

animal species recently extinct **HuID: 44641**

plant species recently extinct **HuID: 86866**

**Data Source(s):** The IUCN Red List of Threatened Species. Version 2020-2. **Notes:** Values correspond to absolute lower-bound measurements of extinctions caused over the past  $\approx 500$  years. Of the predicted  $\approx 8$  million animal species, The IUCN databases catalogues only  $\approx 900,000$  with only  $\approx 75,000$  being assigned a conservation status. Representation of plants and fungi is even more sparse with only  $\approx 40,000$  and  $\approx 285$  being assigned a conservation status, respectively....

The number of extinct animal species is undoubtly higher than these reported values, as signified by an inequality symbol ( $>$ ).

### Q CORAL REEF LOSS

2016 GBR cover loss **HuID: 90720**

**Data Source(s):** Figures 1A, S1, and S2 of Hughes et al. 2018, DOI:10.1038/s41586-018-0041-2.

**Notes:** Value corresponds to measured loss in coral coverage on members of the Great Barrier Reef using field meausrements and satellite imaging. Time period considers the total area loss of coral between March and November of 2016. See methods section "Longer Term Mortality" of source publication.

### R EROSION

soil moved **HuID: 59841**

**Data Source(s):** Table 1 and Figure 4 of Hooke 2000, DOI:10/10/bdnqv9. K-Tec Earthmovers Inc. March 2018 Newsletter. Grand View Research Construction Industry Analysis, April 2020. **Notes:** Hooke 2000 estimates  $\approx 35$  Gt of soil moved annually in latter years of 20<sup>th</sup> century. This is in agreement with reported soil volume moved by industry member (K-Tec) and total revenue of soil movement and construction industry as reported by Grand View Research in April 2020. This value accounts for intentional soil movement only (such as mining and construction) and does not include agricultural soil movement.

### S NUCLEAR FALLOUT

$^{239+240}Pu$  activity **HuID: 38748; 91171**

**Data Source(s):** Figure 4 and Figure 5 in Hancock et al. 2014, DOI:10.1144/SP395.15. Figure 3 (col. 2, rows 3 – 5) of Ciszewski and Łokas, 2019, DOI:10.1015/geo-chr-2015-0111. **Notes:** Value corresponds to current-day detectable combined radioactivity of  $^{239}Pu$  and  $^{240}Pu$  present in cores of stratified soil with estimated date of  $\approx 1963$  CE during the peak of atmospheric nuclear weapons testing. Reported is approximate average activity from sediment samples in SE Australia (Hancock et al.) and Polish river basins (Ciszewski and Łokas).

### T COAL EXTRACTION

mass of coal extracted **HuID: 78435**

power derived from coal **HuID: 10400**

**Data Source(s):** bp Statistical Review of World Energy, 2020. **Notes:** Values includes 2019 value exclusively for solid commercial fuels such as bituminous coal and anthracite, lignite and sub-bituminous coal, and other solid fuels. This includes coal used directly in power production as well as coal used in coal-to-liquids and coal-to-gas transformations.