APPENDIX 3: MAGNITUDE ESTIMATES FOR VARIOUS TYPES OF ENVIRONMENTAL IMPACTS

Collision of a very large asteroid with the Earth

The collision of a massive asteroid over 10-km in diameter with the Earth would put up a huge dust cloud in the atmosphere that would block out the sun and cause a prolonged winter planet-wide. It has been suggested that a massive asteroid impact near the Yucatan Peninsula 65 million years ago wiped out the dinosaurs along with most other surface life. Natural wealth and biodiversity took tens of millions of years to reemerge.

We start by converting the Earth's surface area to equivalent surface area in terms of significance multipliers:

Area type	Surface area	Multiplier	Equivalent area
Fertile soil	100 Mkm^2	3.0	300 Mkm^2 eq.
Deserts	50 Mkm^2	0.5	25 Mkm^2 eq.
Continental shelves	50 Mkm^2	1.5	75 Mkm^2 eq.
Deep oceans	300 Mkm^2	0.33	100 Mkm^2 eq.
	500 Mkm^2		500 Mkm^2 eq.

We then assume that the event has a 95 % relative impact on dry land, 85 % on the continental shelf areas and 60 % in the deep oceans. Thus, most land-based species vanish.

The recovery of natural wealth and biodiversity is slow at first, then accelerates an slows down again when a new balance is approached. If we assume that recovery is linear takes 30 million years, we get an estimate of environmental impact for the Earth of:

$$I = -0.5 \text{ x } 30{,}000{,}000 \text{ years x } (0.95 \text{ x } 300{,}000{,}000 \text{ km}^2 \text{ eq.} + 0.95 \text{ x } 25{,}000{,}000 \text{ km}^2 \text{ eq.} +$$

$$0.85 \text{ x } 75{,}000{,}000 \text{ km}^2 \text{ eq.} + 0.60 \text{ x } 100{,}000{,}000 \text{ km}^2 \text{ eq.}) = -6.5 \text{ x } 10^{15} \text{ km}^2 \text{ eq. x years}$$

Full-scale nuclear war

The number of declared nuclear weapons is presently about 13,000, with a total destructive force on the order of 5,000 megatons. While the destruction power of explosions in an all-out nuclear war would be massive, it would still be limited. However, it will be followed by the nuclear winter induced by clouds of radioactive dust and smoke thrown up from the explosions and subsequent conflagrations. The ozone layer, which protects surface life, would be severely damaged. Models suggest that the nuclear winter would be followed by a nuclear summer, when the average planetary temperature would be boosted by about 10°C.

The environmental impact scenarios for all-out nuclear war are discussed in detail in references /57/ and /53/. The impacts are strongest in continental areas of the northern hemisphere. Because the seas possess such large heat capacity, they would to some extent protect narrow bands along the coastline from the extremes of temperature fluctuation.

Although these scenarios involve great uncertainty, they form the basis for the following environmental impact scenario.

Most of mankind and most surface life would be destroyed as a result of violent climate change, radiation, and the damage to the ozone layer. We assume life would spread gradually from the least damaged areas back into the worst affected zones. On the other hand, many significant species would go extinct, so the recovery of natural diversity could take millions of years. For the sake of rough estimation, we divide the impacts into two parts.

If we assume that 70 % impact on dry land, 50 % impact on the continental shelves and 30 % impact in the deep oceans, and the reoccupation of damaged areas takes 2,000 years, we calculate an environmental impact for the Earth of:

$I = -(0.7 \times 300{,}000{,}000 \text{ km}^2 \text{ eq.} + 0.7 \times 25{,}000{,}000 \text{ km}^2 \text{ eq.} + 0.5 \times 75{,}000{,}000 \text{ km}^2 \text{ eq.} +$

$0.3 \times 100{,}000{,}000 \text{ km}^2 \text{ eq.}) \times 0.5 \times 2{,}000 \text{ years} = -3.0 \times 10^{11} \text{ km}^2 \text{ eq.} \times \text{year}$

We assume that the disappearance of species has a long-term environmental impact of 20 % on the land, 10 % on the continental shelves and 5 % in the deep oceans (double the amount of species) and the return of biodiversity through evolution takes 4 million years. This would give an environmental impact estimate of:

$I = -(0.2 \times 300{,}000{,}000 \text{ km}^2 \text{ eq.} + 0.2 \times 25{,}000{,}000 \text{ km}^2 \text{ eq.} + 0.10 \times 75{,}000{,}000 \text{ km}^2 \text{ eq.} +$

$0.05 \times 100{,}000{,}000 \text{ km}^2 \text{ eq.}) \times 0.5 \times 4{,}000{,}000 \text{ years} = -1.5 \times 10^{14} \text{ km}^2 \text{ eq.} \times \text{years}$

Extinction of species is a more important factor in this calculation estimate than the repopulation of the destroyed area. We may further note that the loss of complete families of species such as the dinosaurs takes much longer to replace through evolution than the replacement of a single species.

Climate change

These calculations assume that the IPPC climate change predictions and descriptions of consequences are roughly right.

If the temperature change is small (2°C), people and nature would experience limited changes in their living conditions. A large temperature change (5°C) would not only have a large environmental impact in itself, but also escalation of cumulative and combined effects of famine, forced migration, wars, anarchy, melting of ice caps, ocean level rise, and collapse of entire ecosystems. There may be surprises after some thresholds are exceeded like additional release of greenhouse gases to the atmosphere.

We estimate the maximum impact range for the 2 to 5 °C climate change as follows:

Area type	Equivalent area	Relative change	Change in eq. area
Fertile soil	300 Mkm^2	-0.02 … -0.4	-6 … -120 Mkm^2
Deserts	25 Mkm^2	+/- 0	+/- 0
Continental shelves	75 Mkm^2	-0.02 … -0.2	-1.5 … -15 Mkm^2
Deep oceans	100 Mkm^2	-0.01 … -0.1	-1.0 … -10 Mkm^2
			-8.5…-145 Mkm^2eq.

With a minor increase in the temperature (2°C), the environmental impact is assumed to develop linearly for about 100 years and then recover in a linear fashion over another 100 years.

The environmental impact is -8.5 million km^2 eq. x 0.5 x 200 years = -850 million km^2 eq. x years

A large temperature increase (5°C) inflicts long-term damage. Damage build up is assumed to occur in 200 years and recovery is assumed to take place gradually after cooling has started, which means that a new natural balance is established after about 2,000 years.

Here the environmental impact is -145 million km^2 eq. x 0.5 x (200 + 2,000) years =
-160,000 million km^2 eq. x years

If the temperature increase of one degree Celsius has a multiplier effect of 5.7, the greenhouse effect in the basic scenario would be -5,000 million km^2 eq. x years for an average worldwide rise of 3°C.

Due to the polar amplification phenomenon, the average temperature in Northern areas like Finland would increase about twice as much. In tropical areas the average temperature rise would be correspondingly smaller.

Partial destruction of tropical forests

In countries at or near the equator such as Brazil, Nigeria, Indonesia and in Central America, tropical forests have been extensively cut and cleared. The area of tropical forest continues to shrink, with particular concern over the loss of Amazonian forests often characterized as the “lungs of the planet”. Tropical forests feature exceptionally rich and diverse ecosystems.

Let us assume that over a century, 4 million km^2 of virgin tropical rainforest is converted to farm land, lost through commercial forestry or destroyed e.g. by drought. This loss corresponds to about a third of the world’s tropical forests. Ecosystems suffer worst in areas where the forest is destroyed entirely or broken up into a patchwork of forest islands. If the forestry practices are managed, on the other hand, natural diversity could even increase.

We further assume that natural wealth and biodiversity would reemerge gradually in 500 years in also the most damaged areas as a result of re-plantation and proper management or by letting the area to remain undisturbed for a period of 500 years.

We assume that most of the destruction occurs in high value tropical forests, to which we assign a multiplier value of 10 in recognition of its ecological significance. Roughly, the loss of natural wealth and biodiversity is 50 % of a 2 million km^2 area. This gives an environmental impact of:

$I = -2,000,000\ km^2 \times 0.5 \times 10 \times 0.5 \times (100\ years + 500\ years) =$

$-3,000,000,000\ km^2\ eq. \times years$

Historical footprint of Finnish agriculture

Finland practiced slash-and-burn farming as late as in the 18th century. This ancient practice involves cutting and burning the forest, crop cultivation, use of the land as pasture land, reforestation and a new cycle of slash and burn. In the 19th century, the agricultural focus of Finland shifted to the clay soils of Southwestern Finland where field cultivation with crop rotation was introduced.

The population increased in a fairly linear fashion from the beginning of 1600s (around 300,000) to the beginning of the 1800s (800,000). By the start of the 1900s, Finland's population had risen to 2,600,000 and by the year 2000 it had reached 5 million. Due to the gains in agricultural productivity, the area of land under cultivation remained unchanged throughout the 1900s at around 30,000 km^2.

It appears slash-and-burn farming had little impact on natural wealth and biodiversity in sparsely populated areas. Increased biodiversity compensated for the loss of natural wealth. The effects of slash-and-burn practices and field cultivation on natural wealth and biodiversity have been limited mainly to the areas where agriculture dominated and replaced most of the existing plant and animal life. Animal husbandry has both positive and negative environmental impacts. On this basis, we determine the environmental impact of agriculture (not counting the effects of fertilizer use) for 100-year increments starting from 1600:

$I = -5,000\ km^2 \times 0.2 \times 3.0 \times 200\ years - 10,000\ km^2 \times 0.2 \times 3.0 \times 100\ years -$

$15,000\ km^2 \times 0.2 \times 3.0 \times 100\ years = -2,100,000\ km^2\ eq. \times years$

Accident at Chernobyl nuclear power plant

The accident at the Chernobyl nuclear reactor in 1986 in Ukraine led to a reactor explosion, fire, and the atmospheric release of large amounts of radioactive materials for a period of ten days. Over 100,000 people were evacuated from areas near the accident site. 31 power plant employees and rescue workers were lost due to acute radiation exposure. While a large share of radioactive emissions degraded quickly, there is still today a measurable increase in cesium-137 concentrations in soils far from Chernobyl, including in Finland. The half-life of Cs-137 is about 30 years /38/.

Generally, the Chernobyl nuclear accident only contributed a marginal amount to the natural background radiation. Its impact on human mortality in the heaviest fallout areas was at least one order of magnitude lower than deaths due to cigarette smoking, fossil fuel use or medical

X-rays. The relative magnitude of these deaths is discussed in references /44/ and /66/. Farming and fishing, however, are still restricted in certain contaminated areas as food products tend to concentrate radioactive materials and their radioactivity may exceed permitted limits /38/.

In assessing environmental impact, we divide the areas affected into the 30-kilometer protection zone, areas where cesium isotope fallout exceeds 600 kBq/m^2 and areas where the cesium fallout is in the range of 40–600 kBq/m^2. For the purposes of comparison, we give normal land surfaces a radiation value 300 kBq/m^3, which, of course, varies in nature.

Within Chernobyl's 30-kilometer protection zone, there are today no extensive signs of the accident's environmental impact. In fact, wild animal populations have increased substantially as people have been banned from the area. The accident site includes a 4 km^2 forest area destroyed by extremely heavy radiation exposure. The site also includes a dump for radioactively contaminated materials. The environmental risks of the radioactive materials over the long-term are concentrated in this area. The contamination of the area is quite heterogeneous, but the average fallout in the area exceeds 1,500 kBq/m^2.

Considering the half-lives of various isotopes, the area will need to be closed to people for 100 years (emphasizing here the significance of the human contribution to natural wealth and biodiversity, we assign an environmental impact of p = 20 %) and a recognition that the accident has had both direct and indirect impacts on natural wealth and biodiversity (p = 2 % average), we estimate an environmental impact of:

$I = -3.14 \times 30 \text{ km} \times 30 \text{ km} \times 3 \times 0.22 \times 100 \text{ years} = -200{,}000 \text{ km}^2 \text{ eq.} \times \text{years}$

Outside this area, the fallout exceeded 600 kBq/m^2 over an approximately 10,000 square kilometer area and was locally up to an order of magnitude larger. The effects of such levels on agriculture (and to some extent the wealth and diversity of surface life) last for about 100 years. With an initial impact of 1 % the environmental impact estimate would be:

$I = -10{,}000 \text{ km}^2 \times 0.01 \times 3 \times 0.3 \times 100 \text{ years} = -10{,}000 \text{ km}^2 \text{ eq.} \times \text{years}$

The fallout was 40–600 kBq/m^2 in an area over 100,000 km^2 in the former Soviet Union and also areas where rain precipitated radioactive fallout in parts of Austria, Switzerland, Germany and Scandinavia. If the heaviest fallout came down in an area of 25,000 km^2, the effect lasts 30 years and the impact on natural wealth and biodiversity is 0.1 %, we get an environmental impact of:

$I = -25{,}000 \text{ km}^2 \times 0.001 \times 3 \times 0.5 \times 30 \text{ years} = -1{,}000 \text{ km}^2 \text{ eq.} \times \text{years}$

The total environmental impact in this case is more than -200,000 km^2 eq. x years. Much of this comes from the weighting given to the evacuation of the protection zone.

Eutrophication of the Gulf of Finland (assumed recovery time 100 years)

The Gulf of Finland has experienced powerful nutrient loading for more than five decades now. There has always been a significant nutrient load to the Gulf of Finland from natural sources. Recent nutrient load increase originates from farming activities, natural sources, municipalities and industry, traffic, energy production and industrial smokestack emissions. Nutrients may also enter with currents from the Central Baltic Sea. The nutrient loading has started to decline recently.

As on land, nutrients in the water increase plant growth. The increased biological activity, in turn, consumes oxygen in the water, leading to “dead zones” in areas of high biological oxygen demand. Today, large swaths of the bottom of the Gulf of Finland are oxygen-starved or “dead”. In this situation the so called internal loading emerges. Nutrients are released back to the water mass from surface sediments as a result of chemical and biological activity.

Nutrient availability contributes to the appearance of massive blue-algae blooms in summer, increased turbidity, reed growth near shorelines and increased sedimentation. All these factors to some extent influence the Gulf of Finland’s ecosystem.

We give the Gulf of Finland an importance value of 1.5. The relative environmental impact of eutrophication is assumed to be 10 % on a 5,000 km^2 area, 4 % on a 10,000 km^2 area and 1 % on a 15,000 km^2 area. The time that it would take various parts of the Baltic to recover to a preindustrial condition is assumed to average 100 years. The estimated environmental impact would be:

$$I = -(5{,}000 \text{ km}^2 \times 0.10 + 10{,}000 \text{ km}^2 \times 0.04 + 15{,}000 \text{ km}^2 \times 0.01) \times 1.5 \times 0.5 \times$$

$$(50 \text{ years} + 100 \text{ years}) = -120{,}000 \text{ km}^2 \text{ eq.} \times \text{years}$$

The 1991 Persian Gulf War (including oil spills)

After Iraq occupied Kuwait, a coalition of UN-sanctioned international forces from 34 countries entered Kuwait and pushed the Iraqis back across their border in the Persian Gulf War. The main effects on natural wealth and biodiversity were the result of:

- Aerial bombardment and missile strikes
- Ground operations
- Destruction of oil fields and oil infrastructure

Military sources report that during the course of the Persian Gulf War about 220,000 bombs and missiles were detonated, of which about 200,000 were unguided bombs dropped mainly in the desert on Iraqi troops, and 20,000 were guided missiles and smart bombs used in surgical strikes against military targets or infrastructure. The total destructive force of these weapons was purported to be around 100 kilotons.

When an approximately 500-kilo bomb is dropped on flat desert with sparse vegetation, the pressure shock severely damages plant roots and most animals over a broad area. For the sake of discussion, we assume here that the destructive force of a bomb on natural wealth and biodiversity over a one hectare area is 50 %. We further assume that strikes also have reflection effects (such as disturbance effects and the release of hazardous substances into the environment) to which we assign a multiplier of 1.5. If the importance factor for desert is 0.5, and other areas carry a multiplier of 3.0, and the gradual recovery of natural wealth and biodiversity is assumed to average 10 years, the estimated environmental impact from bombing and missile strikes in the desert is:

$$I = -1.5 \times (200{,}000 \times 0.01\ km^2 \times 0.5 \times 0.5 + 20{,}000 \times 0.01\ km^2 \times 0.5 \times 3.0) \times 0.5 \times 10\ years$$

$$= -6{,}000\ km^2\ eq. \times years$$

While most people avoid the areas of unexploded cluster bombs, they constitute a huge danger to Bedouins who must move through the area. Assuming cluster bombs are buried within a 2,000 km^2 desert area, the environmental impact for unexploded bombs is 2 % and the average period of impact is 50 years (impact unchanged), we estimate the environmental impact at:

$$I = -2{,}000\ km^2 \times 0.02 \times 0.5 \times 50\ years = -1{,}000\ km^2\ eq. \times years$$

Ground operations involve the setting of mines and artillery shelling. Dozens of divisions were mobilized and heavy tanks and vehicles damaged vegetation in the area. The operations also left behind large amounts of waste and wreckage, which even today has only partly been cleaned up.

The Iraqis are estimated to have set about 500,000 mines, mostly in the vicinity of Kuwait City and along the Saudi Arabian border. As long as the mines remain active, minefields and their immediate surroundings must remain closed to people and large mammals. While the mines and other explosives in Kuwait have been removed in inhabited areas, we can still assume Kuwait has active mine fields in the desert covering a total area of about 10 km^2. If the relative environmental impact of an active mine field is 25 %, and the period of active danger averages 40 years (the impact over the period is unchanged, until the mine fields are cleared or mines become inactive), the environmental impact of setting mines would be:

$$I = -10\ km^2 \times 0.25 \times 0.5 \times 40\ years = -50\ km^2\ eq. \times years$$

It is hard to get information on points of artillery concentration, heavy vehicle movements and war scrap. The role of aerial bombardment clearly trumped artillery in the Persian Gulf War. The scars left on nature by the movement of heavy vehicles can still be seen from the air, even if they have to some extent been covered by vegetation. In Kuwait, war scrap has reportedly been collected in fenced landfills and covered with sand. The overall environmental impact of ground operations appears to be about one order of magnitude less that the effects of bombs and missiles.

The deliberate oil destruction of the Iraqis is a special feature of the Persian Gulf War /29/. Oil was deliberately released into the sea from at least two terminals and several tankers. The scale of these releases has been estimated at just under 1,000,000 m^3. Much of this oil eventually evaporated or was collected, but part (perhaps 100,000–200,000 m^3) washed up on beaches or sank to the bottom of the sea causing damage to the delicate ecosystems along the coast for about 700 kilometers from the Strait of Hormuz to Abu Ali Island.

About 650 wellheads were also set on fire. At the peak of the crisis, some 500,000 m^3 of oil were burned each day. Huge black clouds of smoke and ash filled the skies, and the toxic smoke, oil, ash and acid rains added to the environmental destruction. It is estimated that nearly half of the oil released in the Persian Gulf was precipitated from the sky in the form of oil rain. The valves to about 82 oil wells were also opened, creating large lagoons of oil surrounding them.

One problem with estimating the environmental impact of oil well destruction is that oil has always been part of Persian Gulf ecosystems. Moreover, oil's role has increased in the area since oil production began. Prior to the war, the Persian Gulf had suffered several major oil spills in the range of 100,000 m^3. The flaring of natural gas is also a common part of oil production in the area. It is estimated that oil released by the oil industry and through natural seepage puts tens or perhaps hundreds of thousands of cubic meters of oil into the Persian Gulf each year.

The extent of deliberate oil releases during the war remains unique in history. Because oil in the environment was not seen as something particularly unusual, attempts to clean up the mess were lackluster. Despite the absence of effort over the past decade, the signs of the oil release in the Persian Gulf region are minimal today.

Natural water circulation in the Persian Gulf and winds from the north concentrated the oil effects on the shallow coastal waters on the Saudi Arabian side /2/. It is estimated that the heaviest effects of the oil involved a sea area of 2,000 km^2 and a 0.5-km-wide shoreline zone for 200 km, as well as a more lightly impacted sea area of 10,000 km^2 and a 0.2-km-wide shoreline zone of 500 km (water birds covered with oil, plankton die-offs and algae blooms, etc.). The reflection effects such as impacts on migratory bird populations are included by assigning a multiplier of 1.5 and the important shoreline ecosystem is given a significance value of 6.0. The estimated short-term environmental impact of oil spills would be:

$$I = -1.5 \text{ x } (2{,}000 \text{ km}^2 \text{ x } 0.2 \text{ x } 1.5 \text{ x } 0.5 \text{ x } 1 \text{ year} + 200 \text{ km x } 0.5 \text{ km x } 6.0 \text{ x } 0.4 \text{ x}$$

$$0.5 \text{ x } 1 \text{ year} + 10{,}000 \text{ km}^2 \text{ x } 0.02 \text{ x } 1.5 \text{ x } 0.5 \text{ x } 1 \text{ year} + 500 \text{ km x } 0.2 \text{ km x } 6.0 \text{ x } 0.1 \text{ x}$$

$$0.5 \text{ x } 1 \text{ year}) = -900 \text{ km}^2 \text{ eq. x year}$$

The long-term effects of oil spills are concentrated in the hardest-hit areas. These various effects are described in reference /43/. The estimate here is:

$$I = -1.5 \text{ x } (2{,}000 \text{ km}^2 \text{ x } 0.05 \text{ x } 1.5 \text{ x } 0.5 \text{ x } 10 \text{ years} + 100 \text{ km}^2 \text{ x } 6.0 \text{ x } 0.2 \text{ x } 0.5 \text{ x } 10 \text{ years} +$$

$$10{,}000 \text{ km}^2 \text{ x } 0.005 \text{ x } 1.5 \text{ x } 0.5 \text{ x } 4 \text{ years} + 100 \text{ km}^2 \text{ x } 6.0 \text{ x } 0.02 \text{ x } 0.5 \text{ x } 4 \text{ years}) =$$

$$-2{,}300 \text{ km}^2 \text{ eq. x years}$$

The effects of smoke, poisonous gases, ash fallout, oil and acid rain on natural wealth and diversity are short-lived over a broad area. If the affected area has an average significance multiplier of 1.0, the estimated impact would be:

$I = -(20{,}000\ km^2 \times 0.1 \times 1.0 \times 0.5 \times 1\ year + 2{,}000\ km^2 \times 0.1 \times 1.0 \times 0.5 \times 10\ years) =$

$-2{,}000\ km^2$ eq. x years

Overall, the estimated environmental impact of the Persian Gulf War would be about 15,000 km^2 eq. x years not counting the impact of carbon dioxide emissions. The effects of bombardment, oil spills and infrastructure destruction dominate this estimate.

City of Helsinki (historical footprint and disturbance effects)

Helsinki was founded in the mid-1500s. The city currently has a land area of 187 km^2 and a water area of about 500 km^2. The population of Helsinki was about 20,000 in 1850, 100,000 in 1900, 350,000 in 1950, and 500,000 in 2000. In 1946, the unincorporated areas in Helsinki were incorporated. These areas contained sizable populations, adding about 50,000 new residents to the city.

According to a current map of the city, the types of areas found in Helsinki and their relative environmental impacts include:

Downtown and industrial areas	20 km^2	- 40 %
Developed suburbs	50 km^2	- 20 %
Commercial fields	20 km^2	- 20 %
Suburbs with single-house lots	50 km^2	- 5 %
Natural areas and parks	40 km^2	- 1 %
Water areas in active use	60 km^2	- 5 %
Other water areas	440 km^2	- 1 %

Assume that in the 1900s, the city's environmental impact developed along with the population. This gives an environmental impact of:

$I = (-3 \times 0.7 \times (20\ km^2 \times 0.4 + 50\ km^2 \times 0.2 + 20\ km^2 \times 0.2 + 50\ km^2 \times 0.05 +$

$40\ km^2 \times 0.01) - 1.5 \times 0.7 \times (60\ km^2 \times 0.05 + 440\ km^2 \times 0.01)) \times 100\ years =$

$-6{,}000\ km^2$ eq. x years

In the 1800s, Helsinki was still a small town. Today's urban areas were once farm land, forest or fishing areas. The environmental impact is estimated to be:

$I = (-3 \times (\ 2\ km^2 \times 0.2 + 20\ km^2 \times 0.2 + 30\ km^2 \times 0.05 + 200\ km^2 \times 0.01) -$

$1.5 \times (60\ km^2 \times 0.01)) \times 100\ years = -880\ km^2$ eq. x years

Prior to 1800, the environmental impacts were small, perhaps a fifth, due to the small population. This gives an environmental impact legacy of $I = -7{,}000\ km^2$ eq. x years

Artificial lake of Vuotos

Clearing the lake area and construction would turn 250 km^2 of mostly forest and marshy wilderness (similar to a large part of Siberia) into a lake environment. The local impact in natural wealth and biodiversity is abrupt but transition occurs in 20 years. The estimated environmental impact is:

$I = -3.0 \times 250\ km^2 \times 0.5 \times 0.5 \times 20\ years = -3{,}750\ km^2\ eq. \times years$

The environmental benefit of clean energy production from lake Vuotos is estimated in Appendix 4.

Exxon Valdez oil spill

The Exxon Valdez oil tanker ran aground in the northern section of the Prince William Sound on March 24, 1989. Widely considered one of the worst oil spills ever, some 42,000 m^3 of crude oil spilled into the sea, contaminating about 2,000 km of shoreline to some extent. The environmental impacts were harshest in Prince William Sound itself, but the oil spread as far as 750 km to the southeast through the Kenai Peninsula, the Kodiak Archipelago and the shorelines of the Alaskan Peninsula. Over time most of the oil dispersed or dissolved in the water. In addition, 14 % was recovered and 13 % is estimated to have sunk to the sea bottom. A 1992 study found that 2 % of the oil was still in the shoreline areas. In 2001, several kilometers of Prince William Sound shoreline were still declared oil contaminated /15/.

The site of the accident has a high natural value. It was especially damaging to the birdlife, mammals and fish stocks, and vegetation of the Prince William Sound area. Some wildlife has not been restored to original levels and some species have not shown clear signs of recovery (Harbor Seal, Pacific Herring, Harlequin Duck, Arctic Loon, Little Auk and three species of cormorants) /15/. The long-term and indirect impacts of the oil spill in the ecosystem are discussed in reference /46/.

Estimating the environmental impacts of the oil spill, we simplify into heavily or moderately damaged shorelines (300 km), lightly impacted shorelines (1,700 km, thin oil film detected or occasional clumps of oil), the worst-hit areas in the Prince William Sound (2,000 km^2), and short-term effects of the oil slick in Prince William Sound and its vicinity. The oil-staining of birds and their poisoning is also seen in this estimate as an impact on natural wealth in nesting areas, which are typically near shorelines. Because shoreline areas have a special significance in local ecosystems, we give it a significance multiplier of 6. Considering various reflection effects (bird migration, fish spawning, plankton drifts, etc.), we apply a multiplier of 1.5. Thus, the estimated environmental impact of the Exxon Valdez oil spill would be:

$I = -1.5 \times (40\ km \times 0.4\ km \times 0.4 \times 6 \times 0.5 \times 10\ years + 260\ km \times 0.4\ km \times 0.1 \times 6 \times 0.5 \times$

$2\ years + 1700\ km \times 0.2\ km \times 0.02 \times 6 \times 0.5 \times 1\ year + 2{,}000\ km^2 \times 0.1 \times 0.5 \times 10\ years +$

$20{,}000\ km^2 \times 0.01 \times 0.5 \times 1\ year) = -2{,}000\ km^2\ eq. \times years$

Mankkaa landfill site (30-year lifespan)

A landfill for municipal waste and excavation waste was operating in the Mankkaa peat bog near Helsinki between the 1950s and the mid-1980s. It initially was used for waste from Espoo, the city directly west of Helsinki, but in its final years, the landfill received waste from all over the greater Helsinki region. At the time of its closure, the landfill covered a total area of about 70 hectares. After closure, the area was landscaped. Today the area teems with plants and animals, and features meadows, shrub areas, and forest belts. Most of the area is dedicated to outdoor recreation, with a small area used for outdoor storage of construction materials.

We assume that the Mankkaa landfill consists of four 10-ha areas and one 30-ha area, and each has had a 10-year active period (construction, filling, covering) as well as a 15-year landscaping period. If the impact on natural wealth and biodiversity in the active landfill-area is 50 %, and the footprint reflection (disturbance effect, transport of hazardous substances, increased gull and crow populations, removal of excess excavation materials, etc.) are considered with a multiplier of 2, the estimated environmental impact of the Mankkaa landfill would be:

$I = -2 \text{ x } (0.7 \text{ km}^2 \text{ x } 0.5 \text{ x } 3 \text{ x } (10 \text{ years} + 0.5 \text{ x } 15 \text{ years})) = -40 \text{ km}^2 \text{ eq. x years}$

Methane generated by the landfill that is recovered for fuel or burning or leaks into the atmosphere is not included in this estimate. Neither is the increase in biodiversity of the area as compared to the original situation (a marsh used for turf lifting).

100 hectare forest farm (100 years)

Finnish forest typically contain many blocks of forest that have been cut at some point in the past, with the quality of forest ranging from recent clear-cuts to virgin old-growth forest. Under current practices, areas near shorelines are protected from commercial cutting and expected to be kept in their natural condition. Some forest areas, for other reasons, are excluded from the forest management program. Forestry practices affect natural wealth and biodiversity only in those areas that are dominated by forestry activity. If the impact of this activity on natural wealth and biodiversity is 5 % over a 0.4 km^2 area, the estimated environmental impact would be:

$I = -0.4 \text{ km}^2 \text{ x } 0.05 \text{ x } 3 \text{ x } 100 \text{ years} = -6 \text{ km}^2 \text{ eq. x years}$

100 MW offshore wind farm

The environmental impacts of an offshore wind farm can be divided into impacts of the construction and impacts of the wind farm while in operation.

The impacts of construction consist of short term noise and suspension effects and footprint effect. Consider a typical windfarm with gravity foundations and some dredging and erosion protection works for foundations and cabling. The disturbance and suspension effect will be very local and short duration. Full recovery of the bottom ecosystem the dredged and filled areas will take longer but may actually grow richer than the original. Ignoring this we get the impact estimate for construction in a shallow water area with importance factor of 2.0:

$I = -2.0 \times 0.2\ km^2 \times 0.05 \times 0.5\ years - 2.0 \times 0.05\ km^2 \times 0.2 \times 0.5 \times 2\ years =$

$-0.03\ km^2$ eq. x years

The wind farm will have disturbance effects for natural life during its operation. Especially migrating birds seem to go around wind turbines from some distance. Local birds seem to get partially used to the turbines. The environmental impact of operating the wind farm is estimated as:

$I = -2.0 \times 10\ km^2 \times 0.002 \times 50\ years = -2\ km^2$ eq. x years

We may note that about 15 000 tons of steel is needed for the wind farm structures. If 75 % of steel is circulated (as typically in Finland) manufacturing of the steel structures will involve 15,000 tons of carbon dioxide emissions. The environmental impact of this is:

$I = -2\ km^2$ eq. x years//kt CO_2 x 15 kt CO_2 = $-30\ km^2$ eq. x years

The basis for this and the benefits of producing clean energy are discussed in Appendix 4.

Wastewater spill accident at the Kaukas pulp mill in June 2003

A malfunction at the wastewater treatment plant of the Kaukas pulp mill in June 2003 led to an inadvertent wastewater spill that exceeded permitted limits. The spill introduced, among other things, detergents and black liquor into the water system. Fish kills were detected within an approximately 3 km^2 area. The contaminated brownish water had a foul smell, and a broad area was covered with foam. According to the maps released by the Lake Saimaa Water Protection Association, the hardest-hit waters covered an area of about 10 km^2. Observations of the detected effects typically varied between several weeks to a few months.

The impact of the release on natural wealth and biodiversity was most intense next to the pulp mill, even if that particular ecosystem had become somewhat tolerant of limited wastewater releases. Within a month after the spill, the waters near the pulp mill had begun to clear up and test fishing showed that the structure of the fish stocks had not been affected. Farther away, the disturbance effect of the spill on the waters was analogous to smoke emissions into the air. The impacts on natural wealth and biodiversity were limited. Assigning a significance multiplier of 1.5, the environmental impact would be:

$I = -1.5 \times (1\ km^2 \times 0.2 \times 0.5 \times 2\ years + 2\ km^2 \times 0.10 \times 0.5 \times 1\ year + 10\ km^2 \times 0.02 \times$

$0.5 \times 1\ year) = -0.6\ km^2$ eq. x years

Family house with garden

Assume a single-family house in the suburbs on a modest-sized lot (0.2 ha). The structure has a 0.01 ha footprint and has a service life of 100 years. The landscaping takes about 20 years. The estimated environmental impact would be:

$I = -(0.002\ km^2 \times 0.05 + 0.0001\ km^2 \times 0.5) \times 3 \times (100\ years + 0.5 \times 20\ years) =$

$-0.05\ km^2$ eq. x years

Landfill waste of a Finnish family (100 years)

The average resident in the Helsinki region generates over 300 kg of trash each year. Thus, a nuclear urban family (e.g. one senior, two working parents and two children all living under the same roof) would produce about 1.5 tons of trash each year. At the landfill, this waste is compressed and encased in a waste mound, which can be up to 40 meters in height. The density of trash in the waste mound is about 700 kg/m^3. About 20 % of the waste mound's total volume is soil.

Modern methods of construction and filling make it possible to recover most of the methane generated by anaerobic decomposition of waste so that it can be burned for energy. Other emissions are minimal from the standpoint of natural wealth and biodiversity. The recognized environmental impacts are largely the footprint effect, the reflection effect of increased gull and crow populations on local ecosystems, and the disturbance effect of landfill activity.

In 100 years, a Finnish family would produce 150 tons of mixed waste. Disposal of this trash would expand the surface area of the waste mound by 15 m^2 over the century. Assuming that the surface area needed for landfill operation is double the surface area of the waste mound, taking into account the disturbance effects and footprint reflection with a multiplier of 2, and assuming that the active life of landfill is 20 years and that landscaping period 10 years, we get the following environmental impact estimate:

$I = -3 \times 0.00006\ km^2 \times 0.5 \times (20\ years + 0.5 \times 10\ years) = -0.002\ km^2$ eq. x years