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Surface mineral resources

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ABSTRACT

Dutch Quaternary and Neogene unconsolidated clastic deposits constitute major resources of aggregates and clay that are used in building and construction. Fine sand is available all over the country (including offshore), and is used mainly for filling, coastal nourishment and land reclamation. Coarse sand, which roughly occurs in the southeastern half of the country, is mainly used in concrete and masonry mortars. Gravel occurs in the southeasternmost part of the country, and is used in concrete and a variety of unbound applications. In addition to home-produced sand and gravel, the Netherlands uses significant amounts of imported and secondary aggregates. High-grade silica sand of Miocene age, occurring in the southeasternmost parts of the country, is used in several process industries. Clay is used for the production of structural ceramics (bricks and rooftiles), dyke building and maintenance, landfill covering and landscaping. Most ceramic clay is extracted from Holocene overbank deposits of the central/eastern Rhine-Meuse Delta. Clay for other applications is available all over the Holocene fluvial and coastal lowlands, except where peat is prevalent. Dutch carbonate resources include Cretaceous chalk in the southeasternmost part of the country, Triassic limestone and dolomite in the central-east, and Holocene shell deposits in the northern and southwestern tidal basins. Until recently, the chalk has been extracted to produce cement. The Triassic carbonates are grinded to powder and used in a variety of industrial and agricultural applications. The shells are used as drainage, paving and insulation material, or grinded for use in animal fodder.

<< Silica sand (*zilverzand*) of the Heksenberg Member in the De Groot quarry in Abdissenbosch (southeast Netherlands). Photo: Rudolf Bak.

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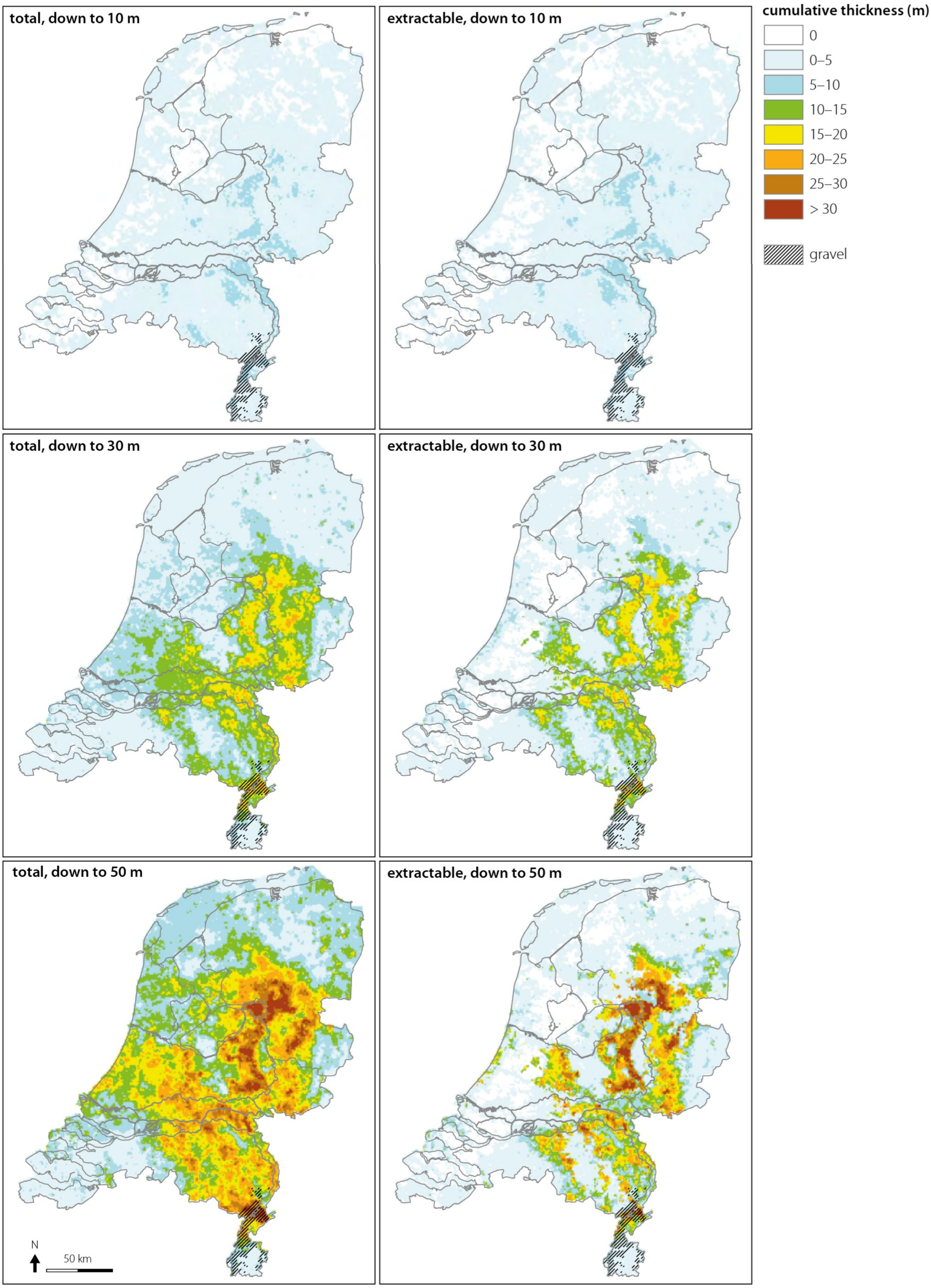
total, down to 10 m
extractable, down to 10 m
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N
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cumulative thickness (m)
0
0–5
5–10
10–15
15–20
20–25
25–30
> 30
gravel

Introduction

Definitions

The production of geological resources in the Netherlands is governed by two laws. The Mining Act (Mijnbouwwet; Anonymous, 2002) applies to any use of the subsurface, including mining in the broadest sense, at depths greater than 100 m (or deeper than 500 m for geothermal energy). Over the past decades, this has mainly concerned the exploration and production of hydrocarbons and salt, but it has been extended to the storage of CO_2 (amendment of 2011) and geothermal energy (amendment of 2022). Classical underground mining has not taken place in the Netherlands since domestic coal production was terminated in 1975.

Surface mining, i.e. quarrying, excavating and dredging operations, is governed by the Environment and Planning Act (*Omgevingswet*; Anonymous, 2016). The legal distinction between surface and deep mining in Dutch policy recognizes the category of 'surface mineral resources' (*oppervlaktedelfstoffen*), the subject of the present chapter. It is based on depth of occurrence only and does not correspond to any common mineral categorization. Currently exploited Dutch surface mineral resources include aggregates, clay, silica sand and carbonates, all of which are industrial minerals, used mainly in construction. The only industrial mineral produced in the Netherlands that is not included in the surface mineral resource category is rock salt, which is treated in a separate chapter (Groenenberg et al., 2025, this volume).

Constitutionally, the Netherlands proper includes three municipalities in the Caribbean (the islands of Bonaire, Sint Eustatius and Saba), while the Kingdom of the Netherlands contains three additional constituent countries (the Caribbean islands of Aruba, Curaçao and Sint Maarten). Currently known mineral resources in the Caribbean parts of the Kingdom include building materials (in all six islands); gold (mined in Aruba from the early 1800s till the early 1900s); phosphate (mined in Aruba and Curaçao from the late 1800s till the early 1900s); copper (mined in Curaçao in the 1700s); and sulphur (mined in Saba from late 1800s till the early 1900s). The present chapter focusses on the Netherlands in Europe, including the Dutch sector of the North Sea and excludes the geologically unrelated Caribbean parts of the Kingdom.

Geological setting

The shallow subsurface of the Netherlands consists largely of unconsolidated Quaternary clastic deposits, which are discussed in Busschers et al. (2025, this volume). Their general physiographic setting is determined by uplifted sediment source areas in the catchments of the rivers Rhine, Meuse, Scheldt, and Eridanos (the Eocene-Pleistocene Baltic river system; Overeem et al., 2001), together with a few smaller rivers in the south and east of the country, as well as by the subsiding North Sea Basin in the west and north. Accordingly, Quaternary sediments generally grade from coarse-grained to fine-grained in a northwestward direction. Glaciations affected deposition, erosion and geomorphology repeatedly through the effects on sea level and vegetation, as well as directly by advancing ice sheets. Occurrences of Mesozoic and older solid rock at or near the surface are limited to the province of Limburg (southeast Netherlands) and the easternmost parts of the provinces of Gelderland and Overijssel (mid-east Netherlands), where they are related to the exhumation of the Ardennes massif towards the south and the Münsterland Cretaceous Basin towards the east, respectively. In both areas, Mesozoic carbonates are quarried for a variety of purposes or have been up until recently.

Aggregates

Introduction

Aggregate is the catch-all term for granular matter used in construction, either as such (e.g. as constructional fill, railway ballast, in slit drainage systems and for coastal nourishment) or with some binder (e.g. in concrete, asphalt, masonry mortars, etc.). In terms of mass and volume, they represent the most-used mineral resource worldwide (UNEP, 2019). The Netherlands is more or less self-sufficient in sand, resources of which are abundant (Fig. 18.1). However, as resources of gravel are comparatively limited and there is hardly any crushable rock at or near the surface, the Netherlands imports about 75% of these coarser aggregates.

Sometimes confusingly, the terms sand and gravel have different meanings in geology and in the extractive industry. In geology, they refer to either nominal grain-size fractions, or clastic sedimentary deposits having sand or gravel

← ***Figure 18.1.*** *Resources of coarse sand and gravel down to 10, 30 and 50 m below the surface, based on a nationwide 3D lithological model (Van der Meulen et al., 2005, 2007). The left panel shows the total cumulative resource thickness within the depth range indicated in the upper left corner. The right panels show cumulative extractable resource thickness. Aggregates are considered extractable according to criteria explained in the text. Grey hatching in the southeasternmost part of the country indicates the occurrence of gravel. The abundance of fine sand is more or less inversely proportional to that of coarse sand and gravel at depths >10 m in most of the country.*

as the dominant fraction. Regardless of the sediment classification scheme of choice, 2 mm is the limit between the sand and gravel fractions (cf. Wentworth, 1922; see Van der Meulen et al., 2005, 2007 and 2009; Jones et al., 2021 for a discussion). In industry, sand and gravel refer to specific types of aggregate products that are each, depending on the application, defined primarily by grain-size distribution. Processing of natural sand and gravel (classification, sieving) is generally required in order to meet specifications. Depending on the application, the lower grain size limit of gravel and corresponding crushed aggregates varies between 4 mm and 8 mm while the upper limit varies between 16 mm and 32 mm. Sand has a lower limit of 63 to 125 µm and an upper limit of 4 to 8 mm (Van der Meulen et al., 2005). In addition to grain size, aggregate specifications may include criteria for shape, physical or mineralogical properties of grains, or for bulk properties such as the friction angle.

For permitting and reporting purposes, the wide range of aggregate products is categorized into gravel and crushed rock, concreting and masonry sand, sand for sand-lime bricks, filling sand, sand for coastal nourishment, sand for land reclamation, and secondary aggregates. These aggregate types are discussed below in terms of applications, supplies and resources. Silica sand, which is used for its chemical composition in the process industry rather than for its physical properties in construction, does not belong to the aggregates family and is discussed separately.

Figure 18.2 shows Dutch aggregate consumption from 1980 to 2020. A clear correlation with the overall performance of the Dutch economy (expressed as GDP growth) reveals some of the main drivers behind minerals consumption and this is also evident in the statistics for individual commodities discussed below. Five major crises occurred in the time span represented in Figure 18.2. The global debt crisis of the early 1980s (Bakker, 1999) resulted in a marked decrease of aggregates consumption. The crisis was followed by almost two decades of more or less continuous growth in aggregate consumption, affected only by the mild European recession of 1991-1993 (e.g. Roy & Kemme, 2020). Aggregates consumption peaked in 2001, after which the Dutch economy came to a virtual standstill during the global recession of the early 2000s (Roy & Kemme, 2020) and aggregate consumption levels dropped accordingly. The Dutch economy was then hit by the Great Recession of 2007-2009 and the ensuing European Sovereign Debt Crisis (2009-2014; Kickert, 2012;

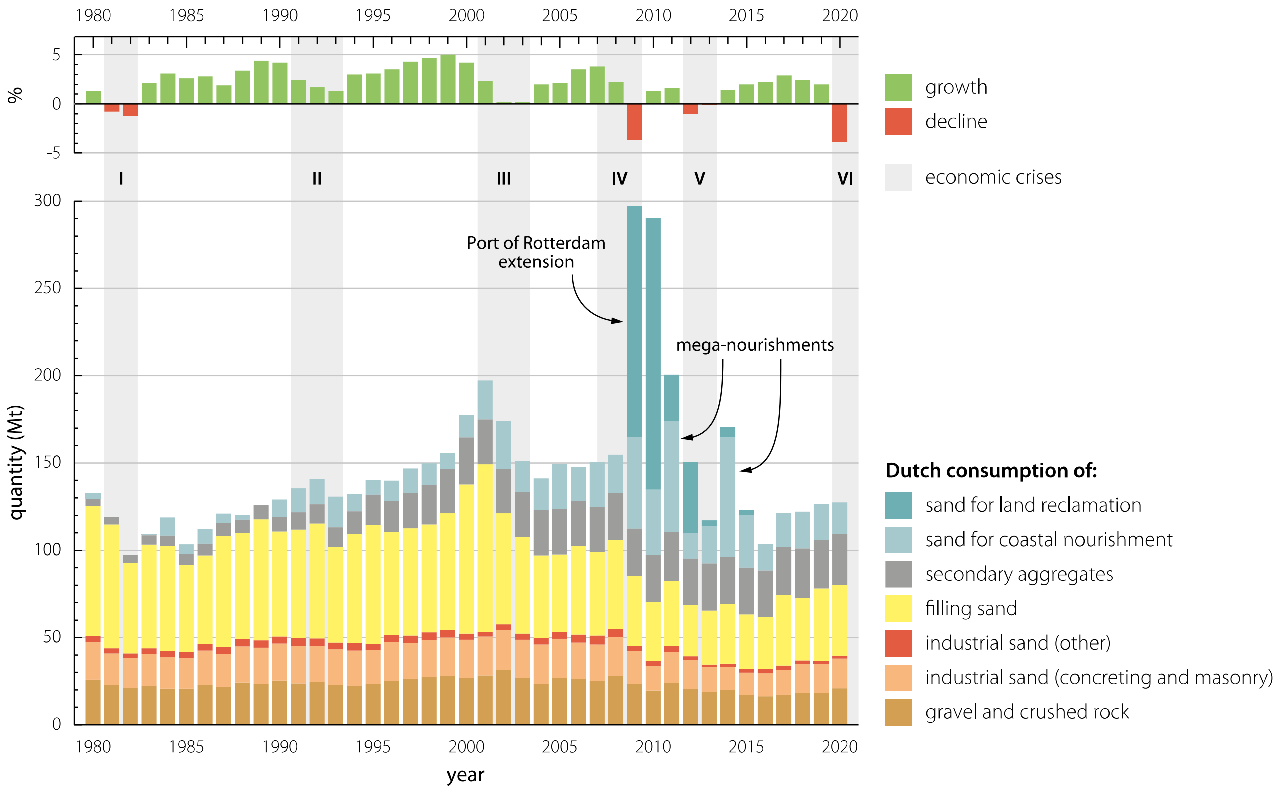


Figure 18.2. Lower panel: the consumption of aggregates in the Netherlands from 1980 to 2020. Upper panel: GDP-growth per annum, with an indication of economic crises: (I) global debt crisis, (II) European recession, (III) global recession, (IV) global financial crisis, (V) European sovereign debt crisis (VI) impacts of the Corona Pandemic. Production figures compiled from data provided by the Ministry of Infrastructure and the Environment (1980-2009), and MWH Global and H2H (2009-2020).

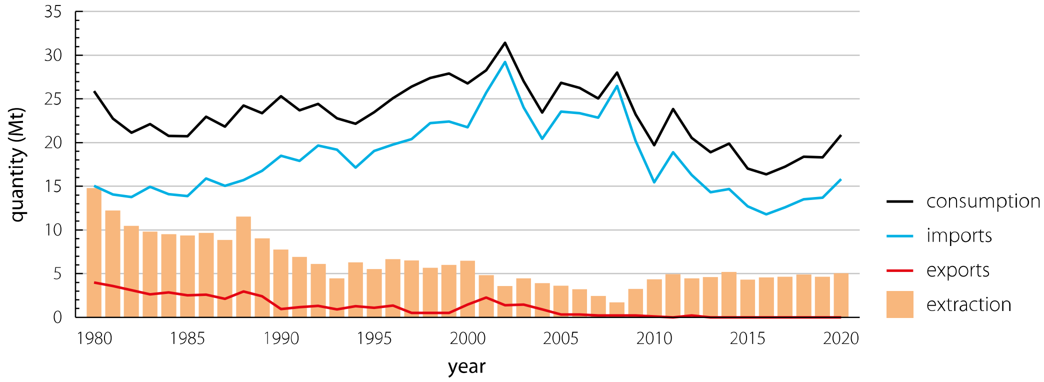


Figure 18.3. Dutch gravel and crushed rock supplies from 1980 to 2020. Sources: see Fig. 18.2.

Ureche-Rangau & Burietz, 2013). These events, however, coincided with three major national projects discussed below which demanded vast amounts of marine aggregates. As a result the consumption of sand for land reclamation and coastal nourishment peaked at his time, while that of all other aggregates declined and stabilized below the levels of 1990-2010. The effects of the Corona Pandemic crisis on the economy and minerals consumption have yet to become evident.

Another clear trend is the increasing share of secondary aggregates, the use of which was promoted by national policy during the last decades of the previous century and which has led to a stable market for their use (discussed in detail in the section on secondary aggregates). In principle, all recyclable aggregates are reused, amounting to a significant substitution of primary aggregates.

Gravel and crushed rock

Applications and demand

The Dutch building industry uses around 19 Mt/yr of gravel and crushed rock, mainly in the production of concrete and asphalt, but also for unbound applications (e.g. railway construction and maintenance, and hydraulic engineering). About one fourth of the demand is met with home-produced gravel, almost all of which is extracted in the province of Limburg in the southeast of the country (Fig. 18.1). The long-term trends in demand are similar to those discussed for aggregates in general (Fig. 18.3). However, production steadily declined from 2000 to about 2008 in response to a government policy to gradually decrease production to the approximate level of provincial self-supply, in response to environmental concerns and because of local resistance against extraction (Van der Meulen, 2005). Production subsequently stabilized at the current level. Meanwhile, gravel imports rose accordingly (Van der Meulen et al., 2003, 2005), stabilising at the current level of about 5 Mt/yr, mainly from Germany, Belgium and the British sector of the North Sea. About 6 Mt/yr of crushed rock aggregates are imported from Belgium, Germany, Scotland, France and Norway.

All current Dutch gravel extraction permits are tied to *Maaswerken*, a project that combines river widening and aggregates extraction (Van der Meulen et al., 2006). They will expire in the foreseeable future, which means that home production of gravel will come to an end unless new permits are granted.

Resources

The main Dutch gravel resources are located in the province of Limburg (Fig. 18.1), where they have been deposited by the river Meuse from the Early Pleistocene onwards. As a result of syn-sedimentary uplift, they have been preserved in terraces that cover the flanks of the river valley. In the provinces of Gelderland, Utrecht, North-Brabant and Overijssel, i.e. roughly in the southeastern half of the country, gravel occurs as admixtures and intercalations in coarse Pleistocene sands, where they constitute by-products of concreting and masonry sand production (<1 Mt/yr). There are some isolated, relatively minor surficial occurrences of gravel and gravely sand in the Dutch sector of the North Sea. The largest of these is located in the area of the Cleaver Bank (Fig. 18.4) and was formed as an end moraine during the last glaciation and subsequently marine-reworked. The estimated amount of gravel in place is a mere 30 Mt (Laban, 2002), resolved at the level of UNFC Prospective Projects class (UNECE, 2019).

Concreting and masonry sand (*beton- en metselzand*)

Applications and demand

Concreting and masonry sand refers to a range of industrially produced coarse sands. About 75% is used for concrete production and about 15% in masonry mortars. The remaining ~10% is used for a wide range of purposes such as the production of asphalt and bricks, and for unconsolidated applications such as drains and filters. Each of these

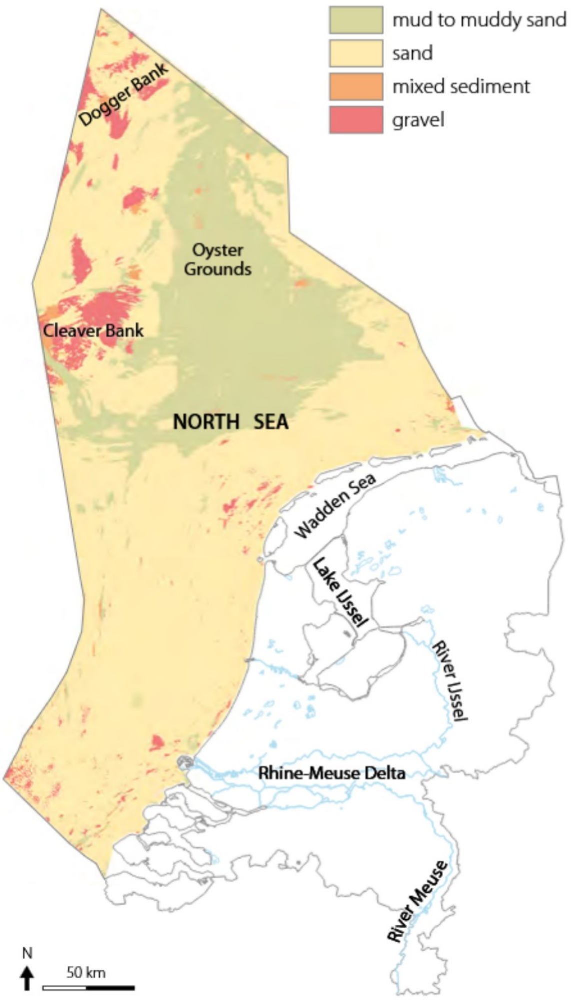


Figure 18.4. As the 3D lithological model used for Fig. 18.1 does not cover the Dutch offshore, a seabed sediment map for the Dutch sector of the North Sea Continental Shelf is provided as an indication of marine aggregate resources. Source: www.dinoloket.nl/en/subsurface-models/map (select seabed sediment).

applications has specific requirements for the grain-size distribution (Fig. 18.5) and, to some extent, for the grain shape of the aggregates. Producers have to sieve and blend natural aggregates in order to meet these requirements.

The demand for concreting and masonry sand shows more or less the same long-term trends as for aggregate in general: averaging at about 21 Mt/yr between 1980 and 2008, then dropping and stabilising at the current level of about 15 Mt/yr (Fig. 18.6). During the last 40 years sources of supply have shifted considerably. From the early 1980s until the late 1990s, a national policy was in place to approximately balance home production with demand by issuing sufficient permits to maintain the required supplies. However, due to the geological scarcity of sand suitable for concrete applications, the total production proved to be too little to meet the demand of Dutch concrete producers. Therefore, about 7 Mt/yr of coarse concreting and masonry sand were imported from Germany, while a similar amount of home-produced finer concreting and masonry sand was exported to Flanders (Belgium), which has limited coarse-sand resources.

Around 2000, the national government abandoned regulating the production of concreting and masonry sand (Van der Meulen, 2005). Home production decreased significantly and net imports rose to about 10 Mt/yr in 2003, remaining at such unprecedented high levels for 6 years. Only around 2015 has the balance between imports and exports been restored at about 5 Mt/yr, albeit under different economic circumstances and under a liberalized national permitting policy.

Resources

Concreting and masonry sand is mostly produced from Pleistocene fluvial deposits in the southern and eastern parts of the Netherlands (Kreftenheye, Urk, Beegden, Sterksel, Appelscha, Peize and Waalre formations; Busschers et al., 2025, this volume). These deposits protrude westward below the Rhine and Meuse riverplains and into the North Sea. However, since they are overlain by westward thickening, fine-grained Holocene flood and tidal basin deposits, and also display downstream fining, their exploitability and suitability for concreting applications in the coastal and North Sea areas is debatable (RWS,

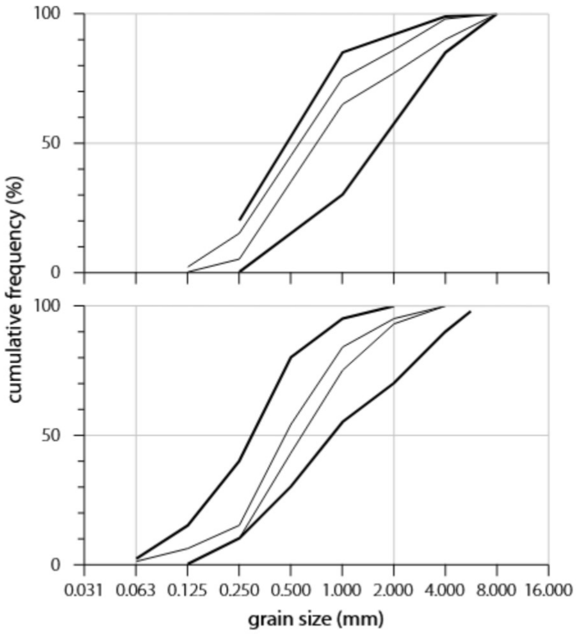


Figure 18.5. Grain-size distributions of the most important types of mortar sand (lower panel) and concrete sand (upper panel). Thick lines show the official minimum and maximum requirements (NEN, 1991, 1999); thin lines delimit the actual distributions on the market (RWS, 1998 and unpublished data).

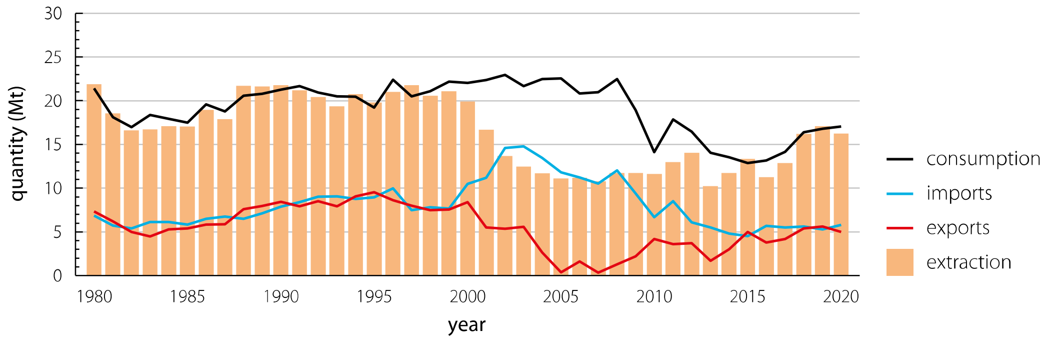


Figure 18.6. Dutch concreting and masonry sand supplies from 1980 to 2020. Sources: see Fig. 18.2.

2004). Coarse-sand extraction sites exist throughout the eastern and southern Netherlands, but since much of the sand is shipped to its destination, most of it is extracted in the vicinity of major rivers.

Sand for sand-lime bricks (*kalkzandsteenzand*)

Sand-lime bricks are produced from a mixture of sand (~90%), lime (~7%) and water, which is moulded under mechanical pressure and then hardened under steam pressure and heating. They are mainly used for inside building walls. Sand for sand-lime bricks has a median grain size between 150 and 400 μm. Ten to 30% in the grain-size distribution has to be finer than 125 μm and an equal share coarser than 500 μm. Natural sands which meet these requirements are quite common in the Netherlands. The production is about 1.5 Mt/yr (Fig. 18.7).

Filling sand (*ophoogzand*)

Applications and demand

The western and northern parts of the Netherlands have a largely muddy or peaty subsurface that is prone to compaction and subsidence. Building in these areas therefore requires large amounts of filling sand as a foundation (De Jong & De Mulder, 1998). The current yearly demand is about 25 x 10^6 m^3, all of which is extracted in the country (Fig. 18.8).

The share of sand from the Dutch sector of the North Sea rose from approximately 10% in 1980 to about 50% in the early 2000s (Stolk & Seeger, 1999; Fig. 18.6). This increase is due to a policy of phasing out the extraction from the densely populated coastal provinces of North Holland and South Holland, and more recently from the province of North Brabant (southern Netherlands). After 2009 the relative share of marine sand for offshore use increased significantly, especially in connection with the extension of the Port of Rotterdam and the mega-nourishments discussed below.

Resources

In contrast to the other aggregates discussed above, filling sand has virtually no grain-size constraints and includes all sands which are unsuitable (i.e. too fine-grained) to be used for higher-value applications. Fine sand is available all over the Netherlands. The Dutch Holocene comprises a wide range of fine-grained sand bodies, deposited in sedimentary environments ranging from fluviatile to shallow marine. Resources in the North Sea are vast (Fig. 18.4).

In Limburg, hoggin (*stol*) is used for about 7% of the provincial filling-material requirement. It is extracted from fine-grained soils which developed on local Miocene-Pliocene fluviatile pebbly sands. The pebbly sand-loam mixture is relatively cohesive and is unsuitable for concreting and masonry sand production, but apt for use as filling or road-foundation material.

Sand for coastal nourishment (*suppletiezand*)

The current Dutch coastal defence programme, initiated in 1990, involves monitoring the coastline and coastal processes, and instigating measures at places where the coast is being eroded (Brand et al., 2021). Sustained coastal erosion is countered by the application of sand on

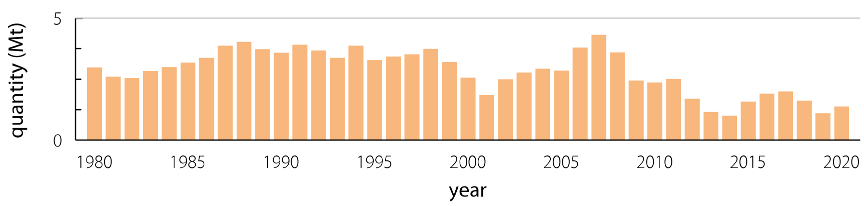


Figure 18.7. Production of sand for sand-lime bricks in the Netherlands from 1980 to 2020. Import and export figures are unavailable but are expected to be negligible. Sources: see Fig. 18.2.

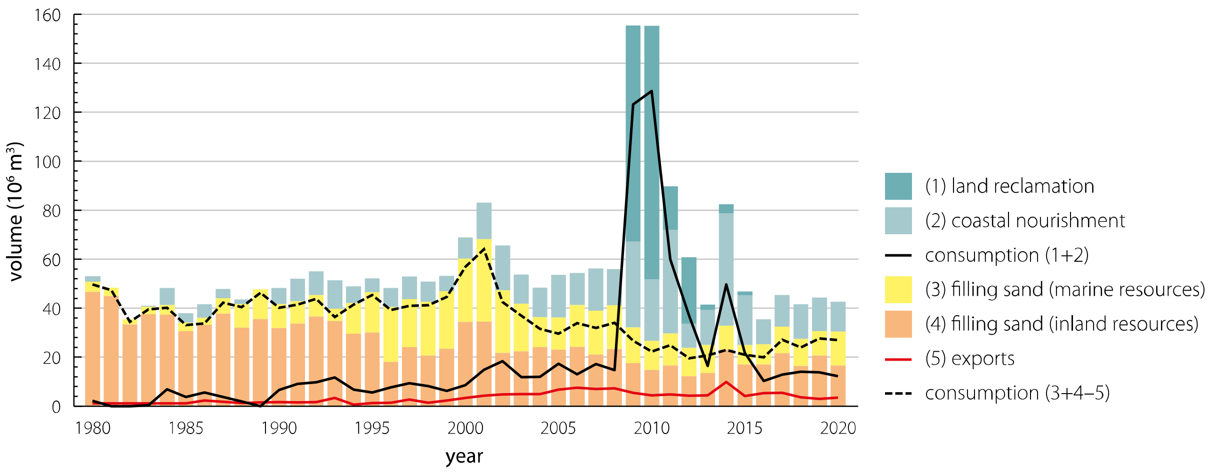


Figure 18.8. Dutch supplies of filling sand, sand for coastal nourishment and sand for land reclamation from 1980 to 2020. Amounts of these aggregates are usually given in volume rather than in weight units. Sources: see Fig. 18.2.

the beach or shoreface. The programme requires approximately 13 x 10^6 m³ of sand per year (Fig. 18.8), which is extracted from the inner shelf as near as possible to the nourishment site. On top of that, one-off large coastal reinforcement and land reclamation projects may double or triple the use. Over the past decade, the Dutch coastal nourishment program was supplemented with two large individual coastal protection projects. In 2011, an innovative nourishment scheme was implemented that involved emplacing 21.5 x 10^6 m³ of sand near The Hague (Stive et al., 2013). The resulting body of sand, the 'Sand Motor' (*Zandmotor*), reinforces a thin section of coastal dunes that was identified as a weaker zone in Dutch coastal defence policy. The sand is also intended to become eroded and dispersed along the coast via long-shore current sediment transport. Between 2013 and 2015, 30 million m³ of sand were emplaced to reinforce the Hondsbossche and Pettemer sea defence, a large seawall erected in 1880 that has been used to protect a section of coastline without significant coastal dunes (Oost et al., 2015).

Sand for land reclamation (*landaanwinningszand*)

Between 1980 and 2009, the sand used to reclaim land from the sea was included in the sand for coastal nourishment statistics. However, when the Port of Rotterdam established its most recent seaward extension, *Maasvlakte II*, the 200 · 10^6 m³ of sand it took to reclaim 20 km² of land in 2009 and 2010 (Fig. 18.8) was administered as a separate category. The port extension sits on the largest Dutch anthropogenic deposit created in a single project.

Secondary aggregates

Since the early 1990s, the substitution of primary by secondary aggregates has been stimulated by the Dutch national government through financial and regulatory instruments and, leading by example, by making use of secondary aggregates in national infrastructure projects. Since the mid-1990s, legislation and standards have been developed to enable the environmentally safe use of waste materials and industrial by-products in construction (e.g. VROM, 1995, 2007; Broers et al., 2002; Dijkstra et al., 2019). Reusing secondary aggregates reduces the consumption of the above primary aggregates in several applications, especially where filling is involved.

The share of secondary materials in the total provision has risen from ~7 Mt/yr (6%) in 1980 to ~32 Mt/yr (20%) in the early 2000s and stayed at approximately that level ever since (Fig. 18.2). Figure 18.9 is a breakdown of the secondary aggregate category in Figure 18.2 and considers the main types of secondary aggregates that are re-used in the Netherlands. Most of these materials, including granulated construction and demolition waste (CDW), steel slag and municipal solid waste incineration bottom ash (MWSI bottom ash), are currently used in unbound applications, replacing filling sand and coarse aggregate to an extent that should be accounted for in the total demand (see also Dijkstra et al., 2019). Typical applications include road foundations, landscaping, noise barriers, or ballast material in water works and coastal protection. Colliery spoil (not included in Fig. 18.9) is occasionally used for hydraulic engineering and as filling or paving material.

The strong rise in the use of secondary aggregates in the 1990s can mostly be attributed to CDW recycling. In 1985, the production of CDW was about 12 Mt/yr, of which 50% was landfilled and 50% was recycled (Hendriks & Pietersen, 2000; CLO, 2020). The steepest increase was coeval with the ban on landfilling of re-usable CDW in 1997 (VROM, 1997). The production of CDW stabilized in the years 2000-2014 at about 24 Mt/yr (CLO, 2020). Some other secondary aggregates in Figure 18.9 show a growth

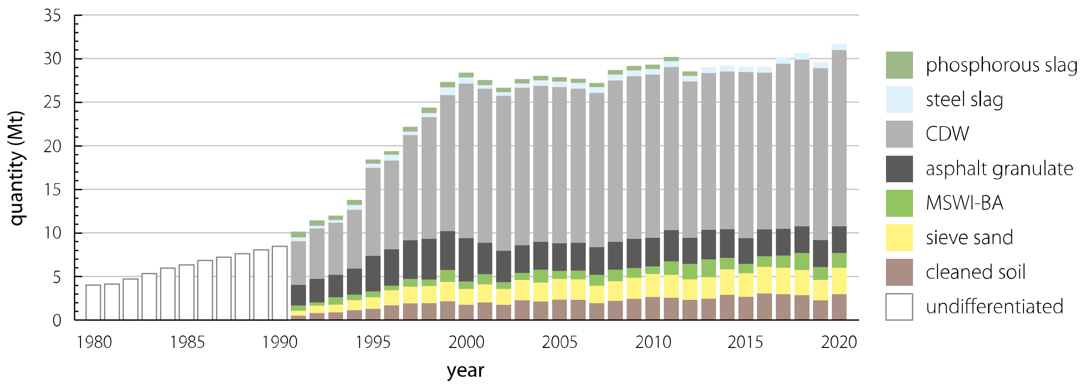


Figure 18.9. *Main categories of secondary aggregates and their usage in the period 1980-2016 in the Netherlands. CDW = granulated construction and demolition waste. MSWI-BA = Municipal Solid Waste Incineration Bottom Ash, which is the main ash fraction originating from the combustion of household waste; sieve sand is the fine fraction from granulated construction and demolition waste; cleaned soil is thermally or wet-treated contaminated soil. Sources: Hendriks et al. (1999), RWS (2005, 2022), Bijleveld et al. (2015), Van Lieshout & Nusselder (2016), I&W (2017), 't Hoen (2017), CLO (2020), Tata Steel (2020).*

as well. Most importantly, the use of MSWI bottom ash in infrastructural works doubled from 0.75 Mt in 1990-2000 to 1.5 Mt in 2010-2020 (RWS, 2005, 2022).

The use of secondary aggregates in bound applications such as concrete is relatively low. Replacement of concreting and masonry sand in bound applications is estimated to have been ~1 Mt/yr on a consumption of about 20 Mt/yr in the years 2001-2010 (about 5% replacement) and includes for instance sieve sand from construction and demolition waste and sand from asphalt granulate (MWH, 2012). Replacement of gravel and crushed stone by recycled concrete aggregate in new concrete amounted to a stable 0.5-0.7 Mt/yr in the years 2009-2016 (about 4% replacement, 't Hoen, 2017). In line with the Paris agreement (UN, 2016), the national government and the concrete sector expressed the ambition to achieve 100% circularity of the concrete production (*Betonakkoord*; Anonymous, 2018). Based on the ratio between the production volume of new concrete and the availability of recycled concrete aggregate, this could in theory result in a substitution of 15-20% of primary aggregate (Anonymous, 2018).

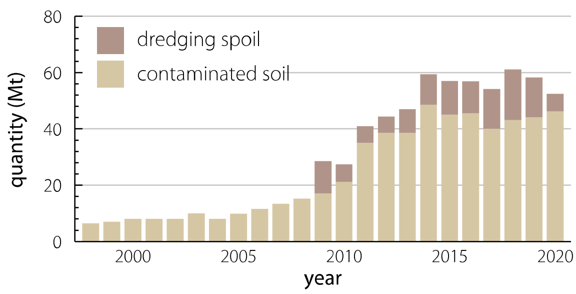


Figure 18.10. *Amounts of contaminated soil and freshwater dredging spoil reused in the Netherlands. Source: RWS (2022).*

Asphalt contains ~80-90 % m/m aggregate (sand, gravel, crushed rock; Bak et al., 2018). Asphalt granulate from infrastructural works is either recycled in unbound applications, replacing primary aggregate such as filling sand, or is recycled in new asphalt. MSWI fly ash is used as filler in asphalt, replacing sand. MSWI bottom ash has come to be treated and processed in such a way that its mineral fraction can substitute primary aggregate in concrete (e.g. Keulen, 2016).

Besides industrial wastes and by-products, increasing amounts of excavated contaminated soil and dredging spoil are partially replacing primary aggregates in unbound constructions (Fig. 18.10). Between 2010 and 2020, 91-95% of all excavated contaminated soil and 67-85% of freshwater dredging spoil was beneficially re-used in earthworks such as embankments and noise barriers (RWS, 2022), partially replacing filling sand. The remainder is too contaminated and is either treated, immobilized or landfilled. The (re-)use of freshwater dredging spoil peaked in 2018, when it was used in dyke maintenance (*Houtribdijk*, Lelystad) and in a large land reclamation project (*Marker Wadden*). However, it has sharply decreased following completion of these projects and also in response to the 'PFAS crisis', i.e. the widespread contamination of sediments with polyfluor-alkyl substances (PFAS) above the recognized safe limits (RWS, 2022).

Over the past decade, about 20% of the total re-use of contaminated soil and dredging spoil consists of backfilling sand and gravel extraction pits ('t Hoen, 2018). Although this practice can be viewed as the most literal replacement of primary aggregate by secondary materials, it cannot be attributed unambiguously to the substitution of primary aggregates in construction.

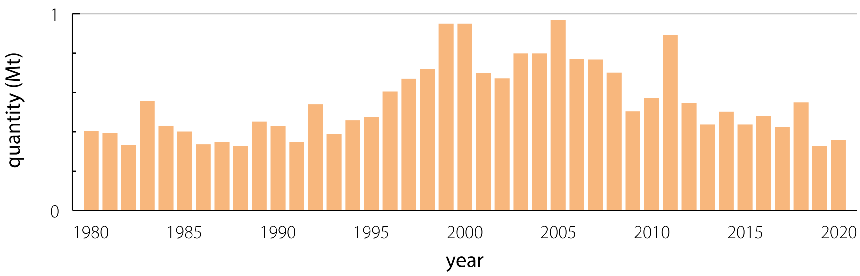


Figure 18.11. *The production of silica sand in the Netherlands from 1980 to 2020. Sources: see Fig. 18.2.*

Silica sand (*zilverzand*)

Applications and demand

Silica sand is a quartz resource employed in several industries (Van der Meulen et al., 2009). Various types of silica sand, with minimum SiO_2 percentages ranging from 97.0 to 99.8%, are used in the glass industry (~55%), the chemical industry (15%; the production of, e.g. water glass, zeolites and carborundum (SiC)), the ceramic industry (~20%) and foundries (~10%). Lower-grade silica sands are used when a white colour is desired for, e.g. masonry, the sand joints in pavements, or the production of sand-faced bricks. Table 18.1 shows the quality requirements for the main applications of silica sands in terms of quartz, iron, aluminium and titanium contents, and loss on ignition. Additional quality parameters, not shown in the table, include the grain-size distribution, and the chromium (Cr) and heavy-mineral contents.

Natural silica sands usually do not meet the industrial requirements and have to be upgraded. Impurities related to specific grain-size fractions such as clay are removed by washing or wet screening. Grain coatings of iron minerals such as limonite can be removed by attrition (scrubbing), or acid leaching (both cold and hot). Froth flotation and magnetic- or gravity separation methods are used to remove discrete contaminant minerals. The silica sands currently extracted in the Netherlands usually require only washing, or the combination of washing and attrition.

The production of silica sand was around 0.4 Mt/yr in the 1980s and has risen to around 0.8 Mt/yr in the early 2000s (Fig. 18.11). The rise was largely an increasing use of somewhat lesser-grade silica sands, which are more abundant. After that, the production of silica sand shows the economically driven trends shown in Figure 18.2 for aggregates. There are no accurate import and export figures. Exports to Germany are known to be significant and silica sand is imported from Belgium and Germany.

Resources

Currently exploited silica sands of the Miocene Groote Heide Formation (Munsterman et al., 2025, this volume) of South Limburg, near the town of Heerlen (Figs 18.12, 18.13), rank among the purest in Europe. The high quartz contents are the result of a combination of a quartz-rich source material, sorting in a coastal depositional environment and pedogenic processes (Van der Meulen et al., 2009). The silica sand is often intercalated with brown-coal layers, which may have acted as adsorption filters reducing the mineral content of percolating groundwater.

High-grade silica sand is used to produce silicon metal, which in its turn is listed as a critical raw material, i.e. a raw material of high economic importance with a high risk of supply disruption due to a dependency of imports from a very limited number of producing countries worldwide and lack of substitutes. The European Critical Raw Materials Act (EC, 2023) defines several types of actions

Table 18.1. *Matrix of five categories of silica sand (1-5) and their applications in the structural ceramic industry (A), foundries (B), low-grade glass (C), fine ceramics (D), high-grade glass I, water glass, zeolites (F) and carborundum (SiC) (G). The quality per category is given in terms of minimum quartz (SiO_2) and maximum iron (Fe_2O_3), aluminium (Al_2O_3) and titanium (TiO_2) contents, as well as the maximum loss on ignition (LOI; %m/m). Modified from Feenstra & Mulder (2003).*

		Applications							Chemical characterization				
		A	B	C	D	E	F	G	SiO_2	Fe_2O_3	Al_2O_3	TiO_2	LOI
Categories	1								99.80	0.01	0.05	0.02	0.05
	2								99.70	0.02	0.08	0.03	0.10
	3								99.50	0.03	0.14	0.04	0.25
	4								99.0	0.1	0.2	0.1	0.5
	5								97.0	0.5	0.5–0.10	0.3	1.0

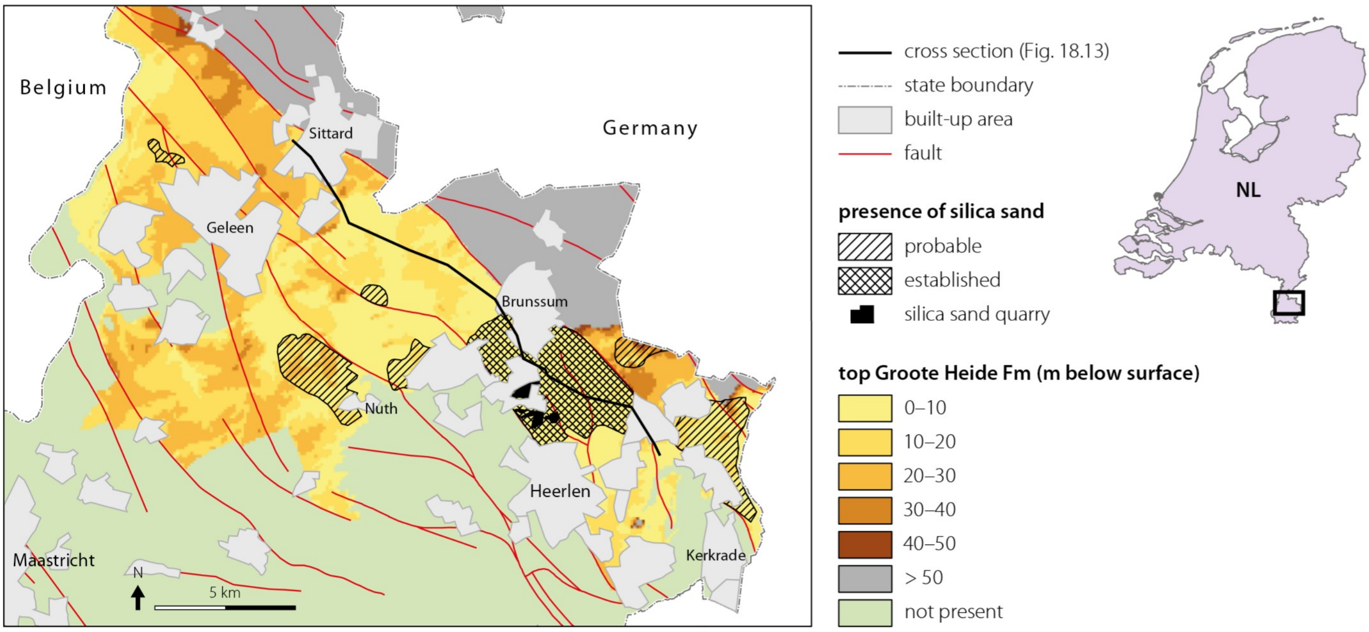


Figure 18.12. The distribution of silica sand in South Limburg. The top of the Groote Heide Formation is shown because silica sand in the area occurs in this stratigraphic unit (more detail in Fig. 18.13). Modified from Van der Meulen et al. (2009), reprinted with permission.

to secure supplies, one of which is to revive mining in Europe. This act will in its turn require the Dutch government to treat high-grade silica sand as a strategic resource and ensure some form of planning protection that is now not in place. Such policy would not only need to apply to the known, high-grade resources in the province of Limburg, but also to lower-grade sands that occur locally in the eastern and southern parts of the country (Van der Meulen et al., 2009).

Clay

Applications and demand

The structural ceramic industry uses an estimated amount of 1.5×10^6 m^3/yr of clay, mainly for the production of bricks and roof tiles (Fig. 18.14). Traditionally, bricks were the most important construction material in the Netherlands, but nowadays, they are mainly used for outer walls (Van der Meulen et al., 2007). Customer demands for certain colours or textures are important to the industry. These and other properties, such as behaviour during drying and firing, as well as the strength of the end product, are determined by the clay chemistry and mineralogy, and the sand and organic-matter contents (Van der Zwan, 1990; Van Wijck, 1997; Table 18.2). In order to obtain the desired clay mixtures, producers add sands or clays from other localities to their local stocks. Limited amounts of clay are imported for this purpose, mainly from Germany.

Clay (which in this case also includes loam) is also used for the building and maintenance of dykes, the covering of landfills, and landscaping. The material specifications for

Table 18.2. Approximate requirements for clay in the structural ceramic industry and for dyke maintenance (modified from Van der Zwan, 1990). Note that clay in the industrial definition may include fine-grained loam and silt, if they are sufficiently cohesive. Anonymous (2001) defined clay raw materials (in both applications) as having clay percentages between 17.5 and 35. Clays meeting this criterion are shown in Fig. 18.12.

Application	Share of grain-size fraction (% m/m)					C-org	$CaCO_3$
	Clay	< 10 µm	63–250 µm	> 250 µm	Sand	(% m/m)	(% m/m)
Roof tiles		50–57	< 20	< 40		< 3	< 25
Bricks		40–42	< 20	< 40		< 3	< 25
Extruded products		40–55	< 20	< 40		< 3	< 25
Dyke maintenance	18–40				< 40	< 3	

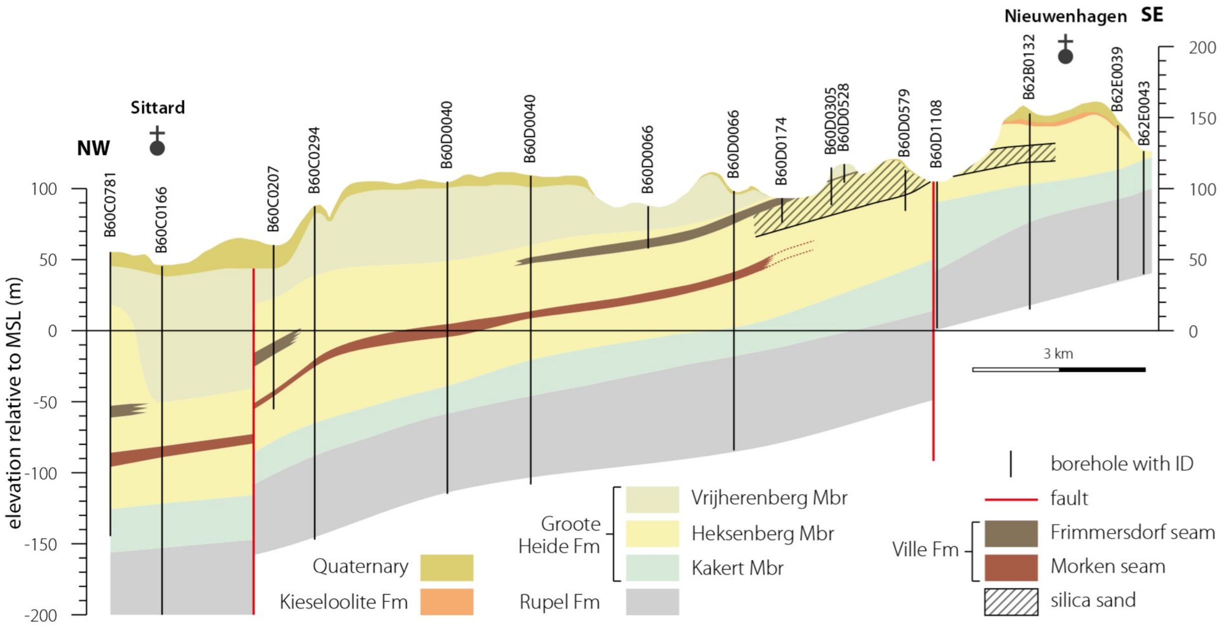


Figure 18.13. Profile through South Limburg (see Fig. 18.12 for profile line), showing the occurrence of silica sand in the Heksenberg Member of the Groote Heide Formation. Silica sand formation and the significance of the Frimmersdorf and Morken lignite seams are discussed in Van der Meulen et al. (2009), from which this figure is modified. Reprinted with permission.

such applications are related to the desired cohesiveness and impermeability. Up till the mid-1990s dyke maintenance required only relatively small amounts of clay, in the order of 0.5 to $1 \cdot 10^6$ m³/yr, but at that time, the demand rose spectacularly as a consequence of a major river-dyke upgrading programme, which was undertaken after two winters of exceptionally high waters and flood risk (Fig. 18.14). There is no differentiation in clay use statistics after 2002, but consumption peaks in that period are most probably in the 'other' category as well.

Resources

Quaternary overbank deposits of the rivers Meuse and Rhine and Holocene peri-marine clays in the coastal provinces provide the bulk of the Dutch clay resources (Fig. 18.15). Currently, the structural ceramic industry mainly uses the fluviatile clays, while the peri-marine clays are only used in the province of Groningen. Other exploited resources include Oligocene marine clays in the province of Gelderland, Quaternary brook deposits in the provinces of North Brabant, Gelderland and Overijssel, and Pleistocene eolian silt deposits in Limburg (loess).

Most of the ceramic clay extraction sites are located in the embanked floodplains of the central/eastern Rhine-Meuse Delta (RWS, 2001; Van der Meulen et al., 2007). Dutch rivers were progressively embanked from approximately 1000 AD onwards. Within the confinement of the dykes, the main river channel was initially free to migrate and able to deposit sand throughout the embanked floodplains (Middelkoop, 1997). From approximately 1850 AD

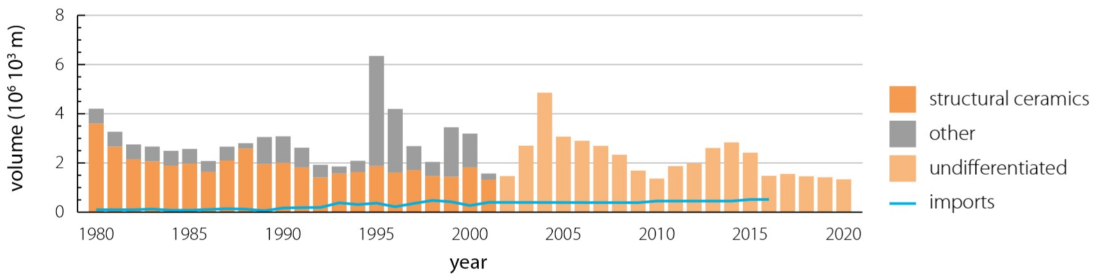


Figure 18.14. The extraction of clay for the structural ceramics industry and other applications (dyke building/maintenance, landscaping, lining of landfills) from 1980 to 2020. Reliable import figures for 2002-2020 are not available. Limited amounts of ceramic clay are imported, exports (not shown) are negligible. Amounts of clay are usually given in volume rather than in weight units. Sources: see Fig. 18.1.

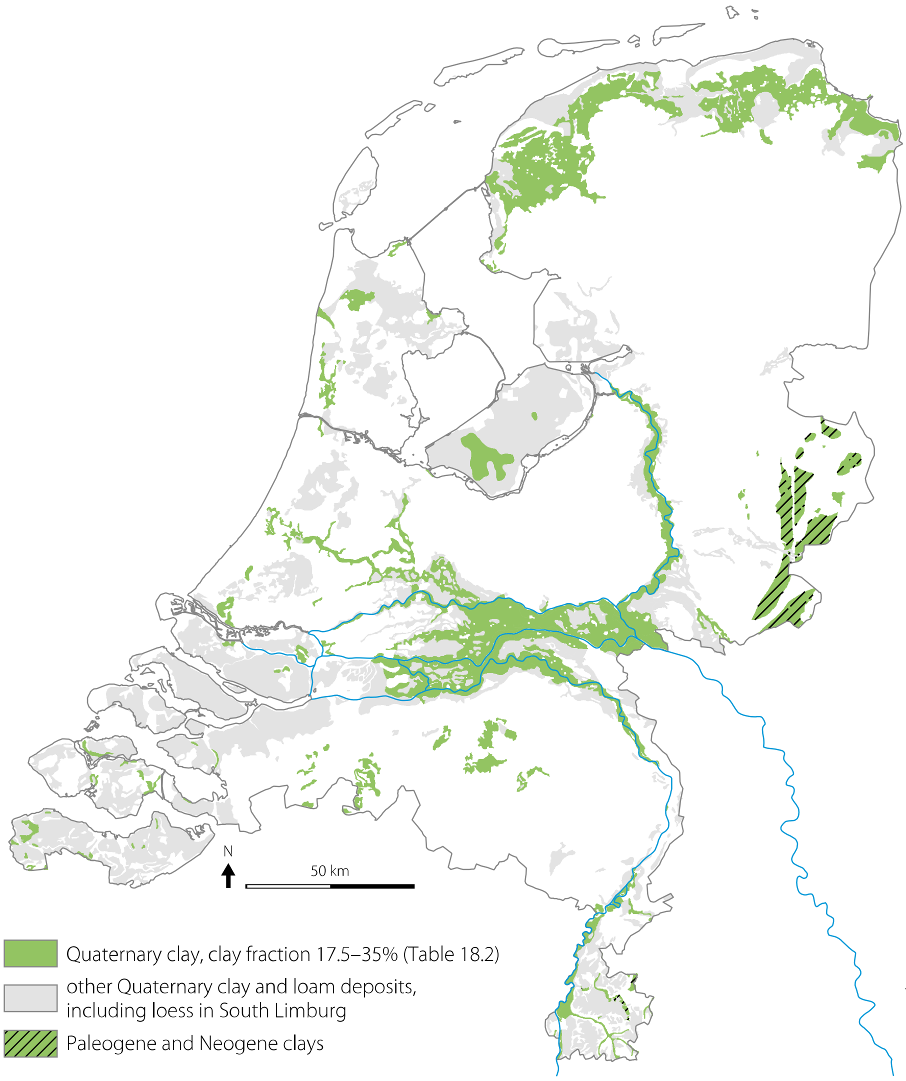


Figure 18.15. The distribution of superficial fine-grained deposits in the Netherlands.

onwards, however, the river channels were fixed by a combination of groyne construction, riverbed armouring and/or strengthening of natural levees. From that time, clay became the dominant overbank deposit in the embanked floodplains, while sand transport and sedimentation became limited to the river channel. These particular clay deposits have become the main resource for the structural ceramic industry and amount to about two-thirds in the total consumption. For dyke maintenance and the covering of landfills, locally extracted clay is used wherever possible.

Carbonates

Limestone and dolomite

Applications and demand

The only Dutch Portland cement production plant (ENCI), operational from 1926 until 2020, was located near the town of Maastricht in South Limburg. The plant operated a large quarry until 2018, where between 1.2-1.6 Mt/yrof chalk was extracted over the past decades (Fig. 18.16). The factory used various secondary materials such as blast furnace slag and coal fly ash for its pozzolanic properties, i.e. the ability to react with calcium hydroxide and form calcium silicates. After the permit to quarry chalk ended in 2018, the factory continued to produce cement until 2020 from clinker imported from Belgium.

About 0.3 Mt/yr of chalk, limestone and dolomite is quarried for the production of limestone powder in Limburg and eastern Gelderland (Fig. 18.16). Limestone powder is mainly used in agriculture (fertilizing, fodder), as a filler in ceramic products, paperware and asphalt, and for the desulphurisation of flue gases.

Chalk in Limburg has been used as dimension stone since the Roman era. Nowadays, only a minor amount of chalk is quarried for this purpose, mainly for reconstruction works. The Netherlands depends almost completely on imports of dimension stone, mainly from Belgium and Germany. Between 2000 and 2021, Dutch annual imports of dimension stone varied between 0.3 and 3.1 Mt (Statistics Netherlands).

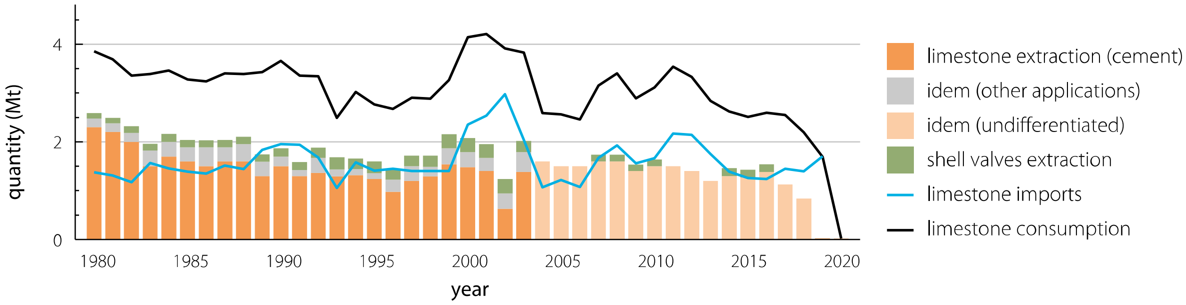


Figure 18.16. *Dutch carbonate supplies 1980 to 2020 (excluding dimension stone). Exports (not shown) are negligible. Shell extraction data are incomplete. Sources: see Fig. 18.1.*

Resources

Upper Cretaceous chalk deposits in Limburg form the most common pre-Cenozoic naturally exposed rocks in the Netherlands, and are the main carbonate resource (Fig. 18.17). The chalk was deposited as bioclastic carbonate muds, silts and sands in a shallow-marine basin that covered large portions of northwestern Europe during the Late Cretaceous and earliest Cenozoic (Zijlstra, 1994). The chalk has a very high $CaCO_3$ content (up to 99%); the only significant siliceous component being flint, which occurs in nodules or layers. The flint was used to make human tools as early as 6000 BP, and now is a by-product of limestone quarries, mainly used for road foundations, path pavements and hydraulic engineering.

Middle Triassic Muschelkalk carbonates quarried in Gelderland are an alternation of nodular limestone and dolomite, deposited in peri-marine environments. They have been quarried east of Winterswijk in the eastern Netherlands since 1933. The material is mainly used in road building and agriculture.

Shells

Mollusc shells are used in drains (~22%), path pavements (~20%), animal fodder (~16%), thermal and moisture insulation (~13%), and in several minor applications such as foundation material and the production of lime mortar (De Graaf et al., 2000). All applications except lime-mortar production make use of cockle shells (*Cerastoderma edule*), which endure intensive use and mechanical processing. When crushed, the combination of concentric growth increments and radial ribs results in approximately equidimensional fragments: a useful property for fodder production and path pavements.

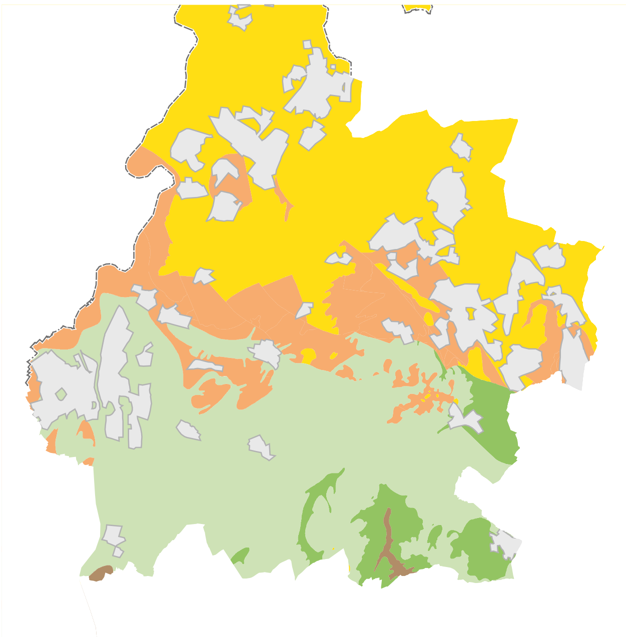
Shell extraction was monitored from 1980 to 2002, but more recent statistics are sparse and less reliable. The current demand for shells is estimated at 150 x 10^3 m^3/yr. In the 1990s, extraction rose from about 180 to 290 x 10^3 m^3/yr (Fig. 18.16). About 70% of this amount was extracted from Holocene deposits of the Waddenzee and its inlets. The remaining 30% is mainly extracted from the Pleistocene of the Westerschelde estuary and its prodelta. For reasons of sustainability, the annually permitted volumes in these areas are limited to the estimated average yearly growth increments of the exploitable shell stocks (cf. Beukema & Cadée, 1999). An estimated amount of about 10 x 10^3 m^3/yr of cockle shells is obtained from seafood producers.

Some historically exploited resources

Peat that has accumulated in Quaternary paralic, fluviatile and lacustrine environments and has been exploited from Roman times up to the mid-20th century (Van Bergen & Koster, 2025, this volume). Historically, dried peat has mainly been used as fuel. In Roman to medieval times paralic peat has been extracted and burned to produce salt from the ashes. The current demand for dried peat in the production of horticultural compost etc., is almost completely met by imports, mainly from Germany. Between 2000 and 2021, Dutch annual imports of 'turf and derived products' varied between 1.8 and 2.9 Mt (Statistics Netherlands).

Bog ore. In the central and southeastern parts of the country, iron has been extracted from bog ore, iron (hydr-) oxide concretions, mainly from Pleistocene ice-pushed ridges in Gelderland (see Griffioen et al., 2025, this volume), and from siderite nodules (e.g. from the upper Carboniferous of southernmost Limburg; Laban et al., 1988; Joosten, 2004). Artisanal iron production started in prehistoric times and reached a high in medieval times. Since 1926, the Netherlands has been producing iron and steel from imported iron ore in its steelworks at the Port of IJmuiden located east of Amsterdam. Between 2000 and 2021, Dutch annual net imports of 'iron ore, iron, semi-products and scrap iron' varied between 2.7 and 8.1 Mt (Statistics Netherlands).

Till. Pleistocene subglacial tills in the northern and eastern parts of the country (Busschers et al., 2025, this volume) have been used for dyke building, in particular



for the '*Afsluitdijk*', which separates Lake IJssel from the Wadden Sea (Fig. 18.4). Its construction, in 1927-1932, required 13.5 x 10^6 m^3 of till and 23 x 10^6 m^3 of sand.

Phosporite nodules. In eastern Gelderland and Overijssel, Oligocene phosphorite nodules occur in the shallow subsurface, either as a primary constituent of marine deposits, or reworked in Pleistocene moraines (Laban, 1988). These nodules were processed into fertilizer during the First and Second World Wars, when all imports were restricted. The current demand for phosphate in chemical fertilizers is about 50 kt/yr (Agricultural Economics Research Institute, Wageningen).

Diatomites are mainly used in various industrial filters, as grinding and polishing material, as a reactive silica source and for the production of paint, matches and dynamite (Vos & De Wolf, 1988). The only known Dutch exploitable resource, a Holocene lake deposit near Renkum, southern Gelderland, was virtually depleted in a 40-year period around the turn of the 19th century (Laban, 1987). Current import figures for diatomite are unavailable but are expected to be low.

Flint occurring as intercalations and nodules in the chalk of South Limburg was mined extensively during Neolithic times (7000-4000 BP). A total of about two thousand 12-m deep shafts were dug in an area of about 8 acres along the eastern slope of the Meuse valley near the current village of Ryckholt (Felder et al., 1998). These shafts were discovered by the Belgian archaeologist Marcel de Puydt in 1891 and the first one was cleared in 1914. Flint was used to make fire, and to produce axes, scrapers, spearheads, and other types of blades. From Roman times onwards, flint was a by-product of chalk mining and used as building stone.

Exploration and production

Exploration for aggregates

Exploration by Dutch sand and gravel extraction companies is aimed at estimating the tonnage of specific mixtures of sand and/or gravel that can be produced at a site. This requires a high-density drilling campaign (of up to one drilling per hectare) and grain-size analyses of samples per metre drilled. Within such a dense drilling grid, additional geophysical techniques are considered to have limited added value and are seldom used for commercial exploration. Another important exploration objective is to identify cohesive intercalations of clay or peat which may inhibit exploitation with dredging devices. The exploration depths vary between approximately 20 and 40 m, depending on the geological situation and the local policy concerning the depth of extraction pits.

The exploration results are interpreted in terms of the estimated costs of the removal of the overburden and the subsequent extraction and processing of the commodity. These costs, together with those for obtaining the concession area, the required permits, transportation etc., deter-