GC2030 | STRI

Golf Course 2030

Golf Course Aggregates

An Overview for a Sustainable Future

Contents.

The R&A facilitates and funds an international research programme, Golf Course 2030, over a three-year cycle. It focuses on key sustainability priorities including – sustainable agronomy; resource management; biodiversity; and climate – to create evidence-based best practices and solutions within the golf industry.

Project conducted by:

STRI

R&A

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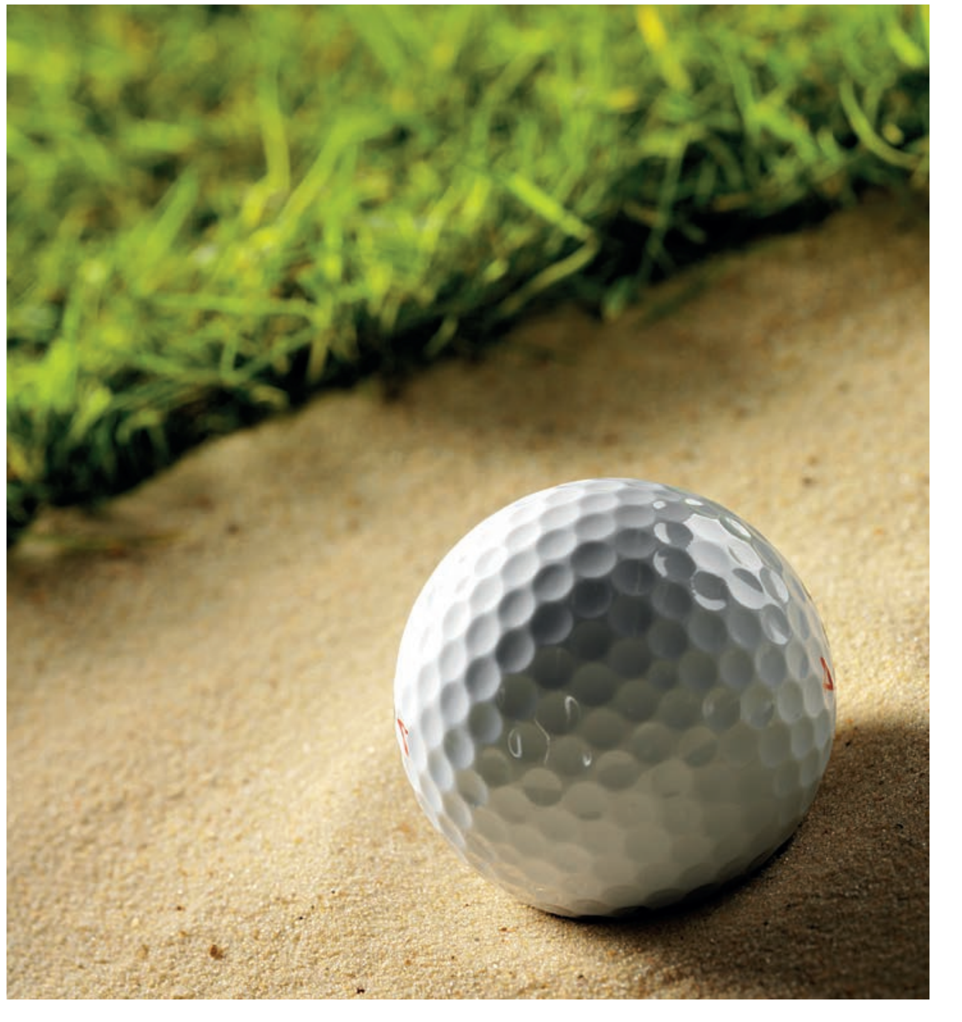
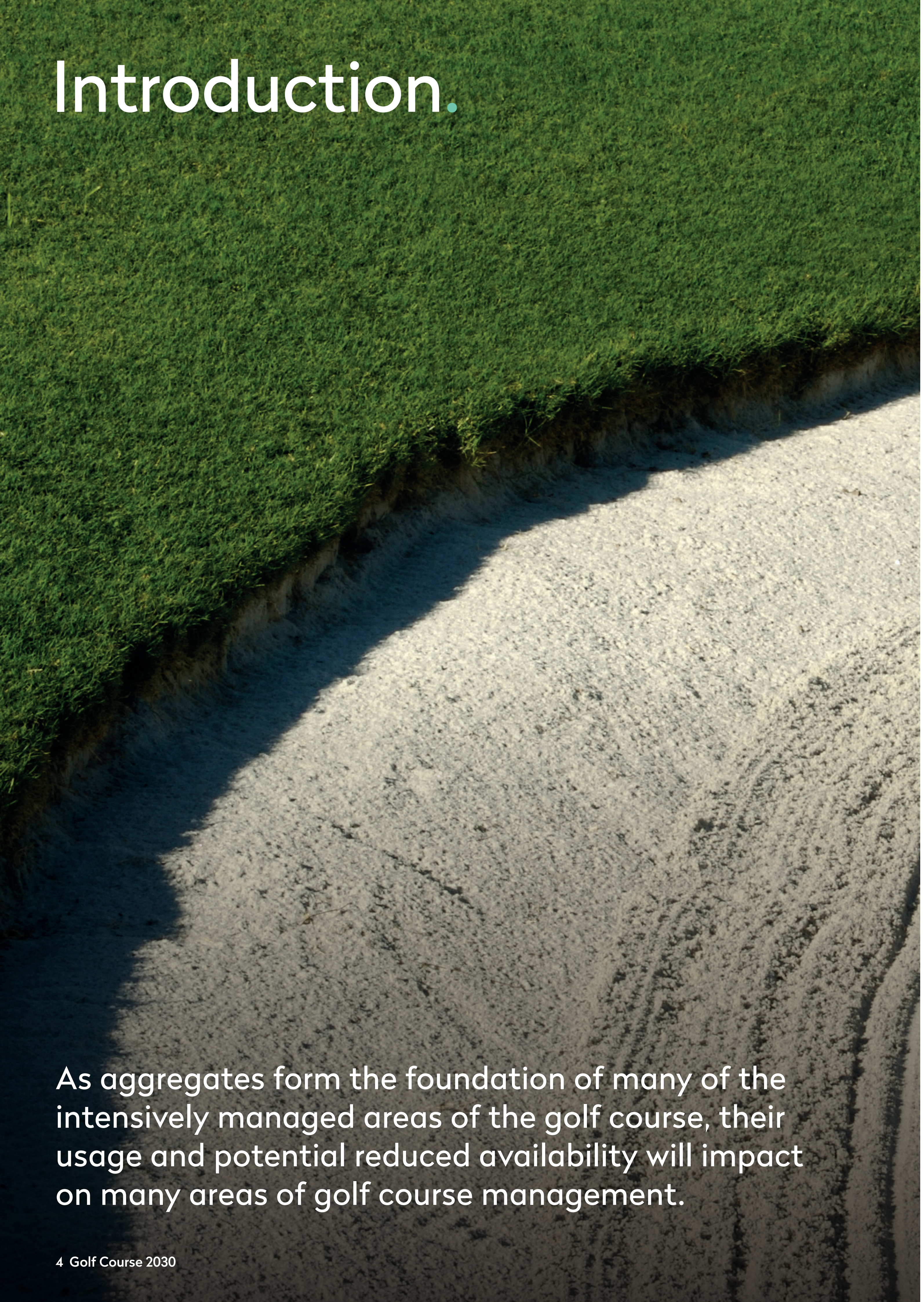




Introduction.

As aggregates form the foundation of many of the intensively managed areas of the golf course, their usage and potential reduced availability will impact on many areas of golf course management.

Over the years, a combination of practical experience and research work has developed requirements for the best type of aggregate materials to use.

Why are aggregates used?

Sands and gravels are widely used in golf course construction and management, including building golf greens and teeing grounds, for bunkers and as a component of top-dressing materials. These materials are used for the following reasons:

- They are hard wearing and long lasting.
- Their physical characteristics help provide good drainage that allows for year round play.
- Their use and quality control can be managed to meet the needs of the playing surface.
- They are compatible when used together in construction and drainage works.
- They can, when managed appropriately, provide a healthy growing medium to support grass growth.
- Sands in particular are heavily used as top dressing to dilute organic matter, level uneven surfaces and improve surface permeability.
- The playing surfaces they are used in will provide more consistent performance than many locally occurring materials.

Over the years, a combination of practical experience and research work has developed requirements for the best type of aggregate materials to use. A review of these technical requirements has been given in the appendix of this report. These technical requirements have focussed on the performance of the resultant playing surface but have assumed a plentiful and sustained supply of suitable materials, at a reasonable cost.

However, all non-recycled aggregates are from non-renewable sources that are extracted from the terrestrial or fluvial/coastal sources. These sources are by their nature finite and their availability has come under pressure and will continue to be further pressurised in the future.

As aggregates form the foundation of many of the intensively managed areas of the golf course, their usage and potential reduced availability will impact on many areas of golf course management. Sand is heavily used for both top dressing and in divot mixes. If sands of the appropriate grade become less available in some areas of Great Britain and Ireland, then there will be an impact on many aspects of turf maintenance, an perhaps most importantly on both Integrated Turf Management and water management. These are key topics explored in a number of Golf Course 2030 projects.

How much aggregate do golf courses typically use?

As part of this project, a survey of aggregate usage was undertaken, with 112 golf courses responded to the survey. These data were compared to any previous surveys available in the literature.

Typical quantities of sand used on golf courses

From survey work carried out as part of this project, the majority of golf courses asked use less than 200 tonnes of sand for top dressing with 46.8% of courses using between 100-200 tonnes sand. 10.8% of golf courses surveyed used more than 200 tonnes of sand for top dressing. This correlates well with another aggregate survey carried out as part of the GC2030 Resources National Action Plan (Miller 2019). In this work, 67% of the 258 responding clubs used between 50-150 tonnes of sand for top dressing with 18% using more than 150 tonnes. There was a trend of increased sand use for top dressing with 44% of clubs indicating they were using significantly more sand now than 5 years ago.

In the greens survey carried out by Baker et al (1997), average rates of top dressing on greens were given per m². If one assumes that typical green area is between 1-1.5 ha on a golf course, equivalent average top dressing rates ranged from 45-123 tonnes.

Typical quantities of sand used in bunkers

From survey work carried as part of this GC2030 aggregates project, of the 112 golf courses that replied to the survey 62% said they use between 20-30 tonnes sand for bunker work, whilst 30% of courses use between 30-60 tonnes with the remainder using > 60 tonnes. This correlates with data from the survey carried out as part of the GC2030 Resources National Action Plan (Miller 2019). This survey found that 76% of golf clubs asked use less than 40 tonnes of bunker sand per year.

Typical quantities of drainage aggregates use on golf courses

As part of the survey of aggregate usage carried out as part of this GC2030 aggregates project, 44% of clubs surveyed said they use 0-20 tonnes of gravel, 39% use 20-50 tonnes, 12% use 50-100 tonnes and 5% used greater than 100 tonnes. This is supported by the survey carried out as part of the GC2030 Resources National Action Plan (Miller 2019). In this survey, more than 85% of golf clubs use less than 40 tonnes of gravel per year.

Other uses of aggregate on the golf course

There are other uses for aggregates on the golf course, including in as rootzone, in divot mix and for pedestrian/buggy paths. Of the clubs surveyed, 85% used 60 tonnes or less of rootzone/divot mix, with 51% using between 10-30 tonnes.

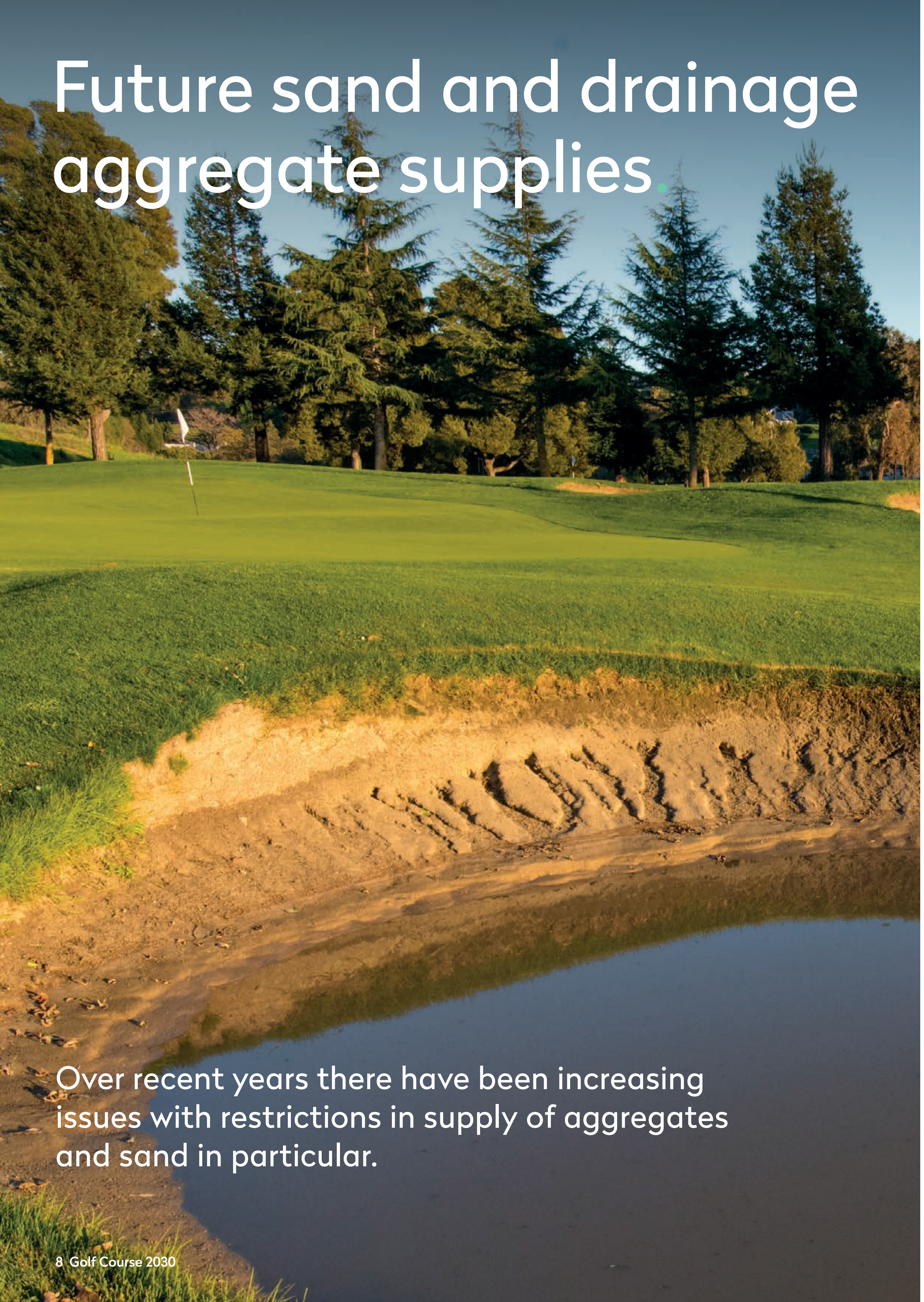
As path aggregates, 80% of clubs used between 20-30 tonnes of aggregates for on pedestrian or buggy paths.

Are golf courses taking or considering taking action in response to aggregate supply pressures?

In the survey, 30% of clubs said they were taking action and 28% were considering taking action to mitigate pressures from aggregate supply. This means that over half of clubs surveyed were aware of the issues and it had or was forming part of their strategic thinking.

Over half of golf clubs surveyed were aware of aggregate supply pressures and this is part of their strategic thinking.

Future sand and drainage aggregate supplies.



Over recent years there have been increasing issues with restrictions in supply of aggregates and sand in particular.

Sands and drainage aggregates are a key component of golf course construction and maintenance.

Many sands used are high silica content materials which are located in specific geological deposits for example in Bedfordshire, Kent and Surrey from the Lower Cretaceous, fluvio-glacial deposits from the Pleistocene period in Cheshire and other major sources in the Trent Valley, the Central Lowlands of Scotland and the Wicklow-Wexford area of Ireland. There are other localised sources and lower silica content materials that are already being used and which could potentially be exploited further.

Over recent years there have been increasing issues with restrictions in supply of aggregates and sand in particular. As will be discussed later, there are a number of alternative sources or materials that can be used for drainage works. However, medium and medium-coarse sand sized materials are becoming less available and this situation is likely to become worse.

The status quo is not a sustainable option. We need to build resilience into golf courses, golf businesses and turf maintenance programmes.

The main drivers for current and future supply challenges are summarised below:

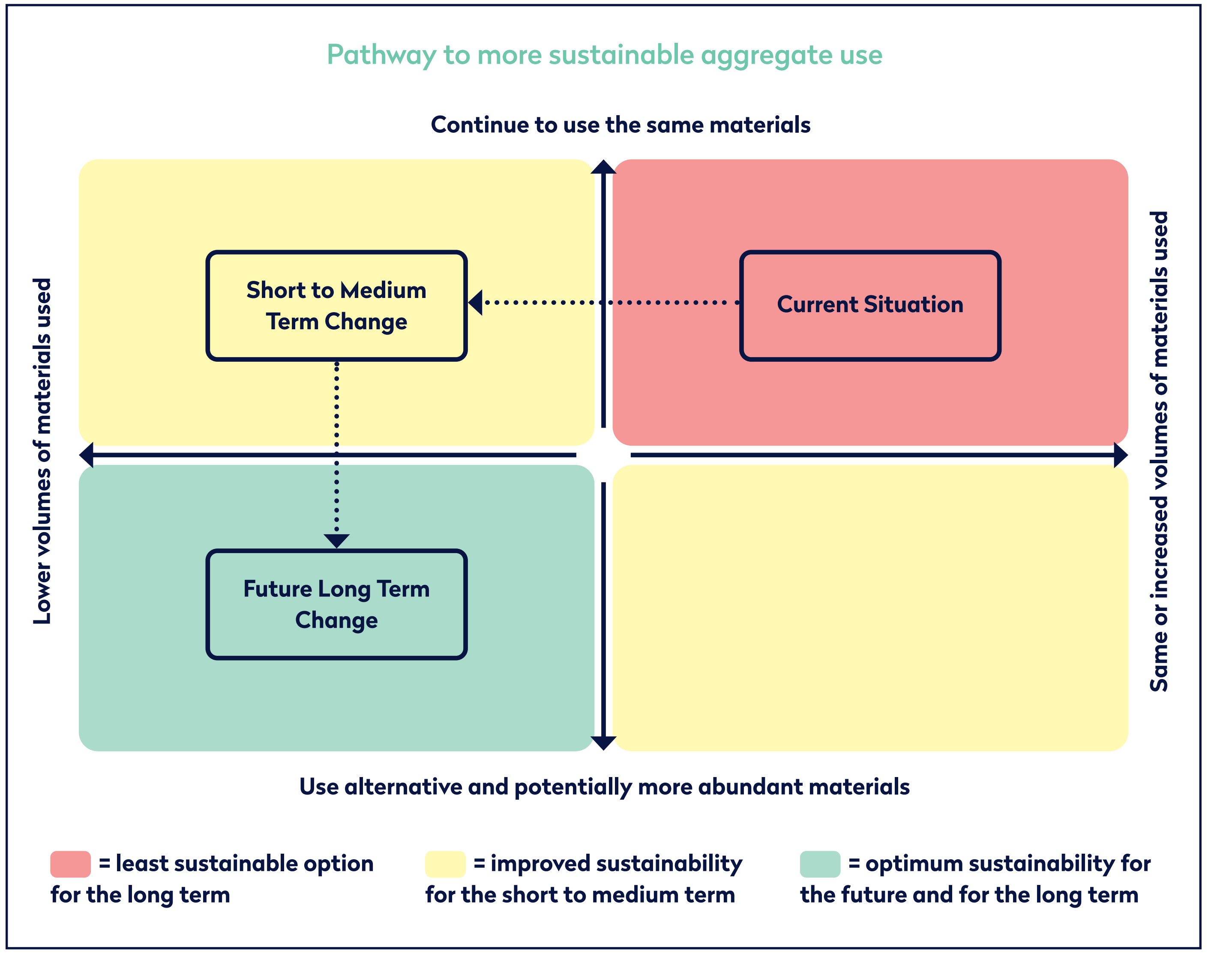
- Increasing pressure from the construction industry, especially large infrastructure projects like HS2. Quarries are only financially viable because of the volumes of materials needed by the construction industry, and therefore available resources are often diverted to this industry rather than for golf course use.
- There are ever greater constraints on quarries being able to expand into new areas of their sites to extract fresh reserves of aggregates or to open up new facilities. These are often associated with planning constraints due to environmental, access or community concerns.
- Costs for maintaining quarries (inflation pressures, infrastructure maintenance, energy and fuel, wage costs) and for transporting extracted aggregates.
- Resource exploitation resulting in fewer reserves that are more expensive to extract.

What has become clear when engaging with the aggregate supply industry, these pressures are not homogeneous over the whole of Great Britain and Ireland. Some areas are not greatly impacted, whilst others are experiencing significant issues. This is due to the levels of reserves in particular areas coupled with local demand.

It is also important to understand that these pressures operate at a number of temporal scales (short, medium or long term) and may be either temporary or permanent. For example, a short to medium term temporary effect would include large construction projects using vast quantities of aggregates, but once those projects finish, as long as there are viable aggregate reserves left, more materials may be available again for golf course use. An example of a long-term and permanent change would be the depletion of aggregate reserves in a quarry and it not being granted planning permission to expand its site to access new reserves.

One thing is for certain, ignoring the challenges and trying to continue on in the "status quo" is not a sustainable option. It does not build resilience into golf courses, golf businesses and turf maintenance programmes. One of the key responses to sand usage is how we can address the issues for which we are top dressing sand whilst reducing the quantity of material needed and potentially changing to different grades, especially on playing surfaces where the grade sand may be less of an issue (for example fairways.

Below is a figure that helps visualise the potential pathway from where many courses are now to perhaps where they should be in the future.



The table below is a risk assessment that outlines the severity of the potential impact of restricted supplies of existing aggregate materials. It also outlines key alternative approaches and further actions that are needed.

Risk Assessment of Aggregate Supply for Golf Courses

Colour coding describes risk of negative impacts for the functioning and management of the area, where: red = high risk yellow = moderate risk green = low risk

RISK ASSESSMENT

	Greens Topdressing	Greens Construction	Bunker Sand	Drainage Aggregates
Supply	red	red	yellow	green
Alternatives	• Alternatives undeveloped (such as recycled sands) • Use finer grade sands • Core recyclers when aerating to put back more effectively materials removed when hollow coring	• Alternatives undeveloped • Use finer grade sands • Construct with natural or amended natural soils in "push up" type designs • Construct with finer sands to make deeper profiles (such as Dutch Golf Green model)	• Use of bunker liners to prevent contamination of sand • Use sand cleaners to prolong life existing sands • Consider sand free designs such as grass bunkers • Use finer materials with greater depth of install	• Utilise the range of alternative materials to gravels such as: • Crushed rock • Recycled aggregates • Manufactured aggregates such as Lytag • Geocellular or recycled plastic drain tiles • Use of geotextiles with sub-optimal materials
Actions	• Reduce OM production of surfaces • Reduce volumes used in conjunction with adapted OM management • Consider sourcing of indigenous / finer grade sands • Consider quality of playing surfaces and demands (i.e. winter greens)	• New golf courses or course recon-structions need to consider the design specifications – should consider soil based greens or deeper designs based on finer sands • Architects and courses to consider concept of dual seasonal greens where one can be out of action for renovation	• Architects to look at sand free alternative hazards and minimise the use of bunkers to key green defences • Courses to consider alternative sand types and bunker renovation to prevent contamination • Develop sand rejuvenation approach	• Greenkeepers should familiarize themselves with drainage material alternatives as they may provide cost savings or help fulfil several roles such as water storage and re-use

In the following sections, the implications for changes in the availability of sands for top dressing/construction, bunker sands and drainage aggregates are outlined.

Implications for changes in the availability of different sand types

The most likely changes in sand supply are understood to be a reduction in the amount of medium and medium-coarse sands. Under these circumstances the following issues need to be considered:

- When the supply of medium and medium-coarse sands is restricted, the cost of these sand types will increase due to market forces. This will affect golf course budgets for both construction and maintenance, requiring additional resource or limiting the amount of work that is possible.
- There are, and will continue to be, significant geographical effects on availability. This is because the larger deposits of highly suitable materials tend to be located in certain geographical areas, for example in Bedfordshire, Kent and Surrey from the Lower Cretaceous, fluvio-glacial deposits from the Pleistocene period in Cheshire and other major sources in the Trent Valley, the Central Lowlands of Scotland and the Wicklow-Wexford area of Ireland.
- The demand for aggregates from the supply chain is not homogeneous across Great Britain and Ireland meaning that some areas will see more severe pressures than others.
- If material availability from local quarries declines, courses will be forced to obtain supplies from more distant quarries will increase transport and environmental costs.
- Unless changes are made to the composition of the entire rootzone profile, the alternative use of finer sands, i.e. medium-fine to medium materials with a high percentage of particles below 0.5 mm, for top dressing will lead to lower hydraulic conductivity, lower air-filled pore space and greater water retention.
- To compensate for the changes in physical properties associated with finer sands, the amount of organic or inorganic amendment materials in both rootzone materials and top dressing would have to change. For example, an 80:20 sand:peat mix may be acceptable with a medium-coarse sand, but this may have to be adjusted to either a 85:15 or 90:10 mix with a finer sand. This could have implications in terms of nutrient retention, necessitating changes to nutrient input especially in the first few years before there is a natural build-up of organic matter in the upper layers. A finer sand with less organic amendment may also give a firmer/harder playing surface in the initial years of use.
- If finer sands or materials with a less uniform particle size distribution are used, this has implications for compaction levels in the rootzone layer. Adjustments to aeration programmes and cultural practices will be needed.
- If use of finer sands results in greater retention of moisture in the surface layer, this may reduce the rate of breakdown of organic matter. This has potential implications for surface firmness,

disease incidence, and the need to adjust aeration and top dressing practices.

- One possible response to any forced use of finer sands is increased depth of the construction profile as this affects water retention (Brown & Thomas, 1980; Hunt & Baker, 1986; Baker & Binns, 2001b, Hejduk et al. 2010). For greens or teeing grounds with a gravel drainage layer the depth of the rootzone layer may have to increase to say 350 mm, rather than the 300 mm depth that is used for rootzones based on medium and medium-coarse rootzones. This has cost implications and more research will be needed to determine the most appropriate mix with amendments, depending exactly on the type of sands likely to be available in the future.

- An alternative approach that may also need to be considered (especially for drier areas of eastern England and eastern Scotland) is placement of a greater depth of finer sand over the native soil with no drainage layer. This approach has been widely used in Holland with typical depths of 150-250 mm of sand:organic rootzone over a pure sand base of typically 250-300 mm (Collinge, 1997). Particle size analysis from 30 such greens showed a typical D50 value of 0.25 mm to 0.35 mm (Baker et al.,2006) and based on these analyses, recommended gradings for the sand included 95-100% passing 1.0 mm, 75-95% passing 0.5 mm, 25-60% passing 0.25 mm and 6-15% passing 0.15 mm (Baker, 2006).

- If finer sands are used in the rootzone layer this has implications for the potential migration of particles into any underlying drainage layer. A bridging factor can be used to assess the risk of particle migration. Finer sands will inevitably require finer gravels for the drainage layer, or alternatively use of a blinding layer.

- Links courses are less likely to be affected by sand supply issues, as the indications are that it is supply of coarser sands that are most likely to be affected. However, it may take more work to locate finer sand supplies and/or it may mean that more processing is needed by blending sands together to produce suitable materials.

- The more processing materials need and the further they need to be transported increases their embodied energy, which will impact on their sustainability of use.

Implications for changes in the availability of different sand types for bunkers

The assumption is again made that the availability of coarser sands will be reduced and under these circumstances the following issues need to be considered:

- Costs of medium and medium-coarse sands are likely to rise and accordingly alternatives will need to be considered.

- Finer sands will be more water retentive and this will affect the drainage requirements within bunkers and possibly the optimum depth of sand.

- In dry weather, windblow of finer sands is likely to be greater than for the existing medium and medium-coarse sands. This will influence the frequency with which fresh sand has to be added and on exposed sites there should review the design, orientation and depth of bunkers to minimise windblow problems.

- The situation on links courses is likely to be less affected by changes in supply as medium-fine sands are likely to remain available, although local supply issues may become more frequent.

Implications for changes in the availability of different gravel types

Some of the main issues that need to be considered are as follows:

- A wide range of gravels are used in other industries, such as construction. It is therefore likely that suitable grades of gravel could still be obtained, but issues are more likely to revolve around gravel type, cleanliness of the gravel, stability issues, quality control and the additional costs incurred through a more complicated production process.

- Potential natural sources of gravel from excavation of suitable deposits are likely to be reduced, forcing a greater reliance on crushed rock materials. This may lead to greater use of crushed limestones, raising possible stability issues and the need to eliminate dust remaining from the crushing process.

- Some dust may be acceptable for some of the construction industries, but criteria are often stricter for golf course construction and drainage. This may be a particular issue with finer gravels, e.g. 3-8 mm grades, derived from crushed rock.

- Clean, stable gravels are needed for intermediate/blinding layers and these may be harder to obtain unless finer crushed gravels are available that are well washed to remove fines.

- In the past, use of limestone gravels has been avoided where possible because of the risks of particle breakdown. Some long-term research or monitoring is needed to access the stability of gravels that have been derived from crushed limestone.

Alternative sources and changing management practices.

With restriction in supply becoming more severe in some areas of Great Britain and Ireland, there is a real imperative to look at both alternative materials and approaches.

With the availability of suitable sand and gravel materials in the Great Britain and Ireland, being readily available until recently, there has been little need to consider alternative maintenance, construction and drainage materials. However, with restriction in supply becoming more severe in some areas of Great Britain and Ireland, means that there is a real imperative to look at both alternative materials /approaches and also how management practices can be changed to reduce the need for aggregates.

Alternatives for approaches under situations of restricted aggregate availability

The key aggregate affected by restricted availability is sand. There are a number of options that might be considered when the preferred medium to medium-coarse sands become less available.

Use of alternative sand materials, which up to this point have been relatively under developed. This would include the use of the following materials:

- The use of sand derived from crushed glass (Owen et al. 2005 a,b) as a component of rootzone and possibly bunker sand mixes.
- The use of recycled sand from other industries (such as construction industry or coastal dredging when clearing harbours and shipping channels).
- The use of crushed sandstone to produce sand or the fine granular arisings (washed) from stone crushing.
- Use of different grades of sand (finer materials) during construction or top dressing. For construction purposes, the use of finer sands has been widely used on links greens and those used in the Dutch Golf Green approach. Under these design models, typically greater installation depths of sand are needed to maintain rootzone physical properties.
- Constructions should consider the use of native soils or even amending the soils with quantities of finer sands to improve their physical properties. This could utilise the push-up green design, but with more modern drainage techniques, such as capillary drainage to help pull water from the finer and more water retentive construction materials.
- For topdressing, the use of core recyclers should be considered when removing hollow cores so that any sand from areas like sand-based greens and tees can be used to partially back fill the holes, thereby reducing the need for additional top dressing sand.
- Consider the use of sand free bunkers or lined bunkers to minimise the need for sand or the need to refresh the existing sand. Also, if suitable equipment and process could be developed, it should be feasible to remove the sand from bunkers and "rejuvenate" it by removing contaminants reducing the need to add more fresh sand.
- Any approach that reduces the amount of sand needed on the golf course will reduce the reliance on large quantities of sand based materials for maintenance purposes.

The future of golf course maintenance will require a twin pronged approach; looking at sand alternatives, and redressing the rate of thatch build up.

Drainage aggregates pose less of a challenge compared to sand. This is because as well and natural gravels, the use of crushed stone of recycled drainage aggregate are both available to meet demands. There are also manufactured materials that can be used such as Lytag and Leca. Finally, there have been advances in the use of geocellular materials, which already have a proven track record in water management from SuDS (Spring, 2020). The geocellular materials typically cost more, but are made from recycled materials and can provide a host of functions that would aid integrated water management.

Although the use of geotextiles has been advocated for the intermediate layer (Callahan et al., 1997), their use has been generally avoided because of long-term concerns and practical experience of contamination of the geotextile layer, and subsequent problems with loss of drainage performance. If suitable gravels become less easy to obtain this type of approach might have to be considered, but long-term research work would be essential beforehand to ensure that modern types of geotextile material can eliminate problems that have been evident in the past.

Changing management practices to reduce sand requirements on golf courses

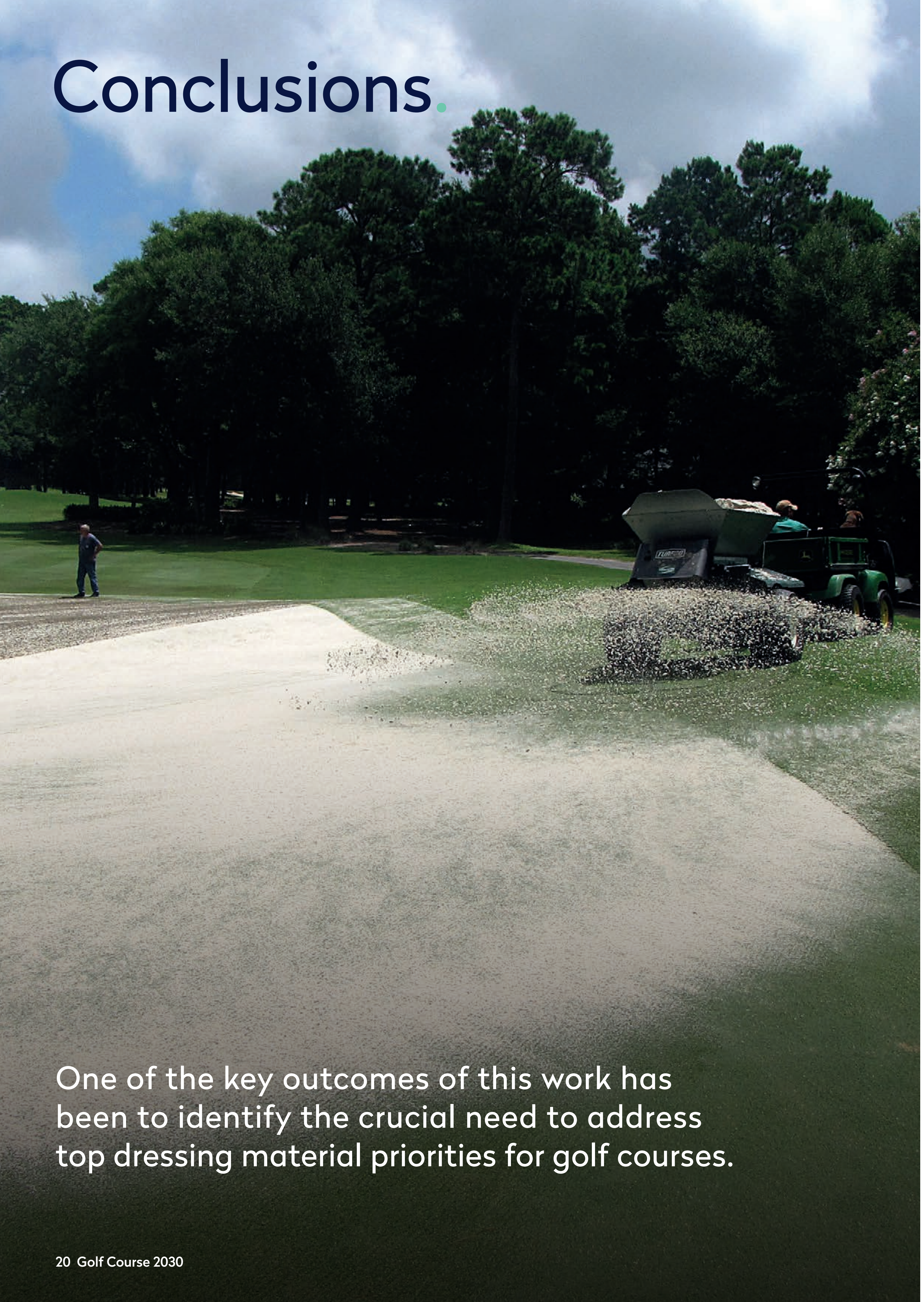
Another approach that should be considered is how golf courses, especially greens are managed.

The use of top dressing to dilute organic matter helps tackle the manifestation of the accumulation of excess organic matter, but it is not tackling the root cause for the imbalance in the soil system which is resulting in that accumulation. This means it is necessary to take a long hard look at why excess organic matter is accumulation (such as over watering, poor soil health and compaction, inappropriate grass species or excessive nutrient inputs). These underlying issues need to be addressed to reduce the baseline rate of organic matter accumulation, which in turn means that less sand needs to be used as a "sticky plaster" to put on the wound that is thatch build up.

Any future optimisation will require the twin pronged approach of not only looking at sand alternatives, but also looking at redressing the natural rates of thatch build up. This is the only way to find true sustainability when it comes to sands and their use for top dressing.

The reduced availability of sand will be one of the drivers for agronomic changes to how golf courses are maintained.

Conclusions.



One of the key outcomes of this work has been to identify the crucial need to address top dressing material priorities for golf courses.

Golf courses are very reliant on good quality sands and drainage aggregates for both the initial construction work and subsequent maintenance.

Use of lower grade sand sources, in particular, will have a significant effect on the quality of putting surfaces and teeing grounds. Restricted availability of aggregates will directly impact golf course management, albeit the effects may be subject to regional variation.

Many of the existing guidelines or specifications call for uniform medium or medium-coarse sands. Their availability is starting to become restricted and will continue decrease in the next 10-30 years and which will compromise the quality of golf courses. Greater competition for a limited natural resource will result in an increase in the cost of materials. Furthermore, there will be significant geographical effects, as the better materials are restricted to certain geological deposits in limited regions of the United Kingdom and Ireland. This will have other knock-on consequences, as greater transport distances will result in not only greater financial costs, but also greater environmental impacts.

The situation with gravels is likely to be less serious as crushed rock sources are likely to remain available. However, the availability of river washed, rounded gravels are likely to decrease and crushed rock materials would need thorough washing to achieve the standard currently available for golf courses. This will increase the need for quality control monitoring and, most likely, cost.

There is quite a lot of existing data on the use of finer sands, but further research work particularly to look at optimum construction depths may be needed. Similarly, there are some alternative construction procedures that could be considered, but again a firm research foundation is needed to avoid unnecessary mistakes and to optimise construction methods with resources that are likely to be available by 2030.

The reduced availability of aggregates, in particular sand, will be one of the drivers for agronomic changes to how golf courses are maintained. In other words, practical management changes will be needed to address the key agronomic challenges that sand is being used to mitigate, such as organic matter control and maintaining adequate surface drainage.

The use of non-renewable or recycled/recyclable materials negatively impacts on sustainability objective when it comes to the design and maintenance of high quality golf surfaces. Minimising the use of non-renewable resources should be a sustainability priority for all courses. It will also help lead to financial sustainability in the long run as the price of these resources increases.

Aggregates play a crucial role in water management. This is why an integrated approach is needed to target the “easy wins” on courses, whilst helping to tackle long-term and more challenging issues such as water storage and reuse.

One of the key outcomes of this work has been to identify the crucial need to address top dressing material priorities. With sands of suitable grade becoming much rarer in some areas, the need to look at long-term preventative solutions is vital. This is why further research work is planned to look at how sand quantities can be reduced by promoting soil health to reduce the build up of thatch, whilst excessive organic matter can be targeted with focussed maintenance whilst reducing the reliance on heavy sand top dressing.

R&A

Appendix.

Technical review of aggregates used on golf courses, including rootzones, top dressing, bunker sands and drainage materials.

Historical background

Much of the early development of golf took place on naturally sandy soils, notably on the coastal links courses, but also on inland heathland courses. The sandy characteristics of these soils provided relatively free draining fairways and greens and the low nutritional status helped to sustain the finer grasses that were better suited for golf.

Increasing popularity of golf led to the construction of many more golf courses near to towns and cities, with extensive early development taking place in the late 1800s and through the 1920-39 inter-war years. Many of these locations were on heavier, clay-rich soils and this had significant effects on drainage and associated issues such as earthworm casting and weed contamination. Furthermore, increasing usage levels brought about greater soil compaction. This has likely to have been a catalyst for the more widespread use of sand materials, but until the 1950s and 1960s relatively little systematic research work had been carried out to define the best materials for use.

Research studies

Much of the earlier research was from the United States. Garman (1952), for example, examined the effects of various grades of sand in rootzone mixes amended with peat and vermiculite. Kunze et al. (1957) examined the effects of compaction on golf green mixtures containing various amounts of sand, soil and peat on drainage, air-filled pore space and water retention. Ferguson et al. (1960) proposed laboratory testing methods for evaluating putting green mixtures and these were a forerunner of the methodology widely used today. Much of this earlier work was primarily laboratory based, but extensive field trials were set up in 1961 at Penn State University that included soil, coarse sand, concrete sand and mortar sand, along with several organic and inorganic amendment materials (Waddington et al., 1974).

In the United Kingdom, a number of laboratory studies have looked at the effect of different sands on physical properties. Adams et al. (1971) gave results for the effects of different sand fractions on hydraulic conductivity, air-filled porosity and water retention. Baker (1983) looked in more detail at the effects of sand particle size, the uniformity of the size distribution and the effects of shape (angularity and sphericity) in sand:soil mixes. Zhang & Baker (1999) examined the role of sand type in mixes with sandy loam soil, peat and fensoil. This included 28 different sands with a mid-particle diameter (D_{50})[1] ranging from 0.17 mm to 0.83 mm. Drainage rates, air-filled porosity and capillary porosity were influenced primarily by sand size, while total porosity, bulk density and shear strength were influenced primarily by uniformity. Smaller effects were evident from angularity and sphericity, but it was suggested that unless there were extremes in grain shape, sand selection could usually be based on sand size and uniformity characteristics.

A number of field trials have also been carried out in the United Kingdom to examine the effect of different sands for the construction of golf greens. Daniells (1977) studied the effects of various rootzones containing different proportions of sand, soil and peat, either as a 100 mm depth over sandy loam topsoil or 250 mm depth over gravel. Only one sand type was included in the study and this had a very wide spread of particles including 14% ‹0.125 mm diameter and 18% ›1 mm diameter. A more specific trial relating to the performance of different sand types was carried out by Baker (1991) and Baker & Richards (1991, 1993). This included four different sands in mixes with a sandy loam soil, ranging from equal parts of sand and soil to pure sand rootzones. The four sand types were: uniform medium-fine sand (D_{50} = 0.2 mm), uniform medium sand (D_{50} = 0.35 mm), medium-coarse sand (D_{50} = 0.55 mm) and a fourth sand with a wide range of particles (8% ‹0.125 mm and 18% ›1 mm). Sand type, as well as mixing ratio of sand to soil had major effects on the physical properties of the rootzone, on changes in sward composition and on playing quality. Specific effects on infiltration rate, air-filled pore space and moisture content are discussed later in this document (Section 2.3).

R&A funded research (Baker et al., 1999) looked in more detail at the effects of sand type, amendment materials (sandy loam topsoil, peat[2] and fensoil) and three mixing ratios (90:10, 80:20, 70:30 sand:amendment). The range of sand types was smaller than the earlier STRI studies (i.e. good quality medium and medium-coarse sands only) and accordingly sand type had less effect than the amendment materials. However, there were effects of sand type on hydraulic conductivity, air-filled pore space and capillary pore space in laboratory mixes and on infiltration rate and water retention in field conditions. Effects of sand type on grass cover and species composition were only evident on a limited number of assessment dates and the effects on playing quality (ball roll, hardness and stopping distance after ball impact) were generally smaller than the effects associated with amendment type and mixing ratio. Both sands used in this study would be regarded as good quality materials and it is likely that poorer sand types would have had greater effects.

Other UK research work on sand-dominated greens has mainly considered management implications, for example related to fertiliser nutrition (Woolhouse 1981, Lawson 1987, Canaway et al. 1987, Colclough & Canaway 1989) or interactions of fertiliser and irrigation (Lodge et al.1991, Lodge & Baker 1991).

Aggregates play a crucial role in water management. This is why an integrated approach is needed to target the "easy wins" on courses, whilst helping to tackle long-term and more challenging issues such as water storage and reuse.

One of the key outcomes of this work has been to identify the crucial need to address top dressing material priorities. With sands of suitable grade becoming much rarer in some areas, the need to look at

[1] D_{50} and D_{20} values used in this document are both indices of particle size. The D_{50} value is the particle size diameter below which 50% of the mass of the material by weight is smaller. Similarly, the D_{20} value has 20% of the mass below this size.

[2] Peat is a non-renewable resource and its excavation leads to environmental degradation and is considered to be an unsustainable practice. The use of peat is becoming more restricted through legislation and there are good non-peat alternatives such as compost. The use of peat alternatives is becoming evermore common in sports turf contexts.

long-term preventative solutions is vital. This is why further research work is planned to look at how sand quantities can be reduced by promoting soil health to reduce the build up of thatch, whilst excessive organic matter can be targeted with focussed maintenance whilst reducing the reliance on heavy sand top dressing.

Effect of sand type on the physical properties of golf green materials

From the literature reviewed above, two specific studies have been selected that illustrate the effects of different sand types on physical properties. These studies provide information on changes from the preferred medium and coarse sands to either finer materials or sands with a greater range of particle sizes (such sands are likely to have greater particle inter-packing, as a result of compaction from players and maintenance equipment).

Table 1 is from Zhang & Baker (1999) and uses the data from a mix of 75% sand and 25% peat. Mixes with the medium and medium-coarse sand have good drainage and an effective balance of air-filled and capillary pore space. The very fine sand (D20 = 0.1 mm) has significantly lower drainage rate and air-filled porosity and is therefore unlikely to be suitable for a good quality golf green rootzone.

Table 1. **Effect of sand size on physical properties of golf green mixes formed from 75% and 25% peat (Zhang & Baker, 1999)**

	D20 (mm)	0.1	0.2	0.3	0.4
Property	Dominant sand sizes	Very fine-fine sand	Fine sand	Medium sand	Medium-coarse sand
Hydraulic conductivity (mm/h)		120	260	370	560
Capillary porosity at -4 kPa (%)		36	32	27	22
Air-filled porosity at -4kPa (%)		12	17	22	27

Table 2 is taken from a four-year field trial and includes the effects of four different sand types on mixes of 80:20 sand peat and pure sand rootzones (Baker & Richards, 1991). Values such as infiltration rate declined over the course of the trial, but again the performance of the medium and medium-coarse sand was much better than either the medium-fine sand or the sand with a wide spread of particles.

Table 2. **Effect of sand type on selected physical properties averaged over a four-year period under simulated golf green wear (Baker& Richards 1991)**

	Dominant size range (mm)				
Property	Medium-fine 0.125-0.5	Medium 0.25-0.5	Medium-coarse 0.25-1.0	Wide range 8% <0.125 18% >1.0	Were there statistically significant differences among sand types for these properties?
Infiltration rate (mm/h)					
80:20 sand soil mix	40	45	115	35	All four measurement dates
Pure sand rootzone	140	230	470	100	All four measurement dates
Air-filled pore space at -4 kPa after four years					
80:20 sand soil mix	17	19	25	19	Significant at both sampling depths
Pure sand rootzone	21	25	31	22	Significant at both sampling depths (10-90 mm and 100-180 mm)
Rootzone moisture content (0-30 mm)					
80:20 sand soil mix	32	27	24	32	Significant 5 out of 6 measurement dates
Pure sand rootzone	30	26	17	33	All six measurement dates

Specifications

There are a number of specifications that have been published that are relevant to sand supply in the United Kingdom and Ireland. Some are specific to the properties of the actual sand materials, but others refer to the final composition of the rootzone mix, but this inevitably has a major impact on the selection of sands to be used, as sand normally forms the largest component of the rootzone.

1. USGA recommendations

This was first published in 1960 and has since undergone a number of revisions, most recently in 2018 (USGA 2018). This is probably the most widely used specification in the United Kingdom and Ireland, indeed worldwide. The particle size requirements relate to the final rootzone mix, rather than being a specific grading for the sand component. Rootzone mixes also need to meet various performance characteristics for saturated hydraulic conductivity and porosity components.

The particle size composition of the mix is given in Table 3. Two particularly relevant features are: (1) a requirement of a minimum of 60% of particles in the range 0.25-1.0 mm, i.e. medium and coarse sands; and (2) not more than 20% fine sand particles in the range 0.15 – 0.25 mm. This low content of fine sand may be the most difficult requirement to satisfy if there is a trend to finer sand production by 2030.

2. Sand grading (Baker 1990, 2006)

After a considerable amount of work with the sports turf industries and research trials at the STRI, a book was published to provide guidance for "Sands for sports turf construction and maintenance". This provided grading curves for several situations for which sand is required, including for both golf courses and winter games pitches. The gradings given are specific to the sand component and were used to give sports turf managers guidance to the best materials to use and to provide information to the sand industries of what was required to help improve sand production and processing.

The guidance for sands was given in terms of a preferred size range and an alternative acceptable range, which may have to be considered in situations where good quality sands are not available, or costs of transport become excessive. There was a minor revision to the grading requirements in 2006 and this is given in Table 4 and as a grading curve in Figure 1.

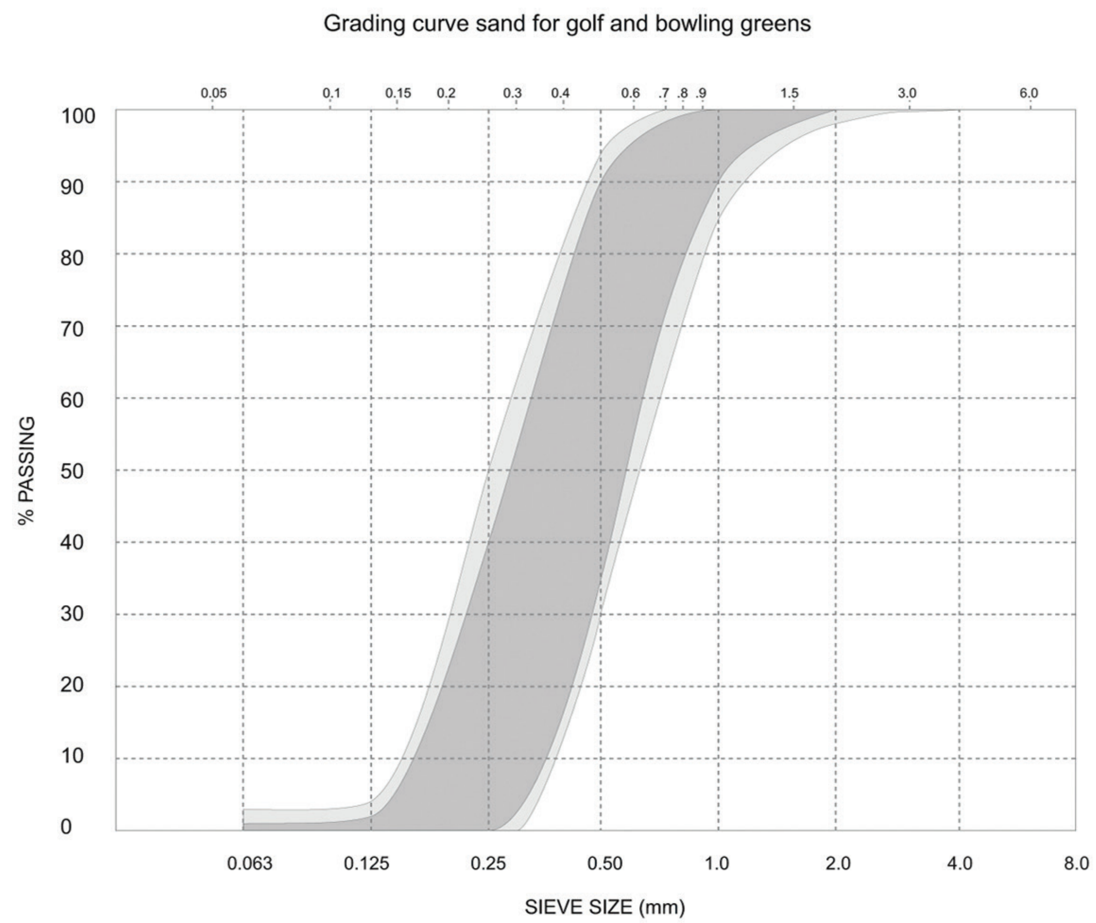
Table 3. Particle size distribution of USGA rootzone mix

Category	Particle diameter (mm)	Recommendation (by weight)
Fine gravel Very coarse sand	2.0-3.4 1.0-2.0	Not more than 10% including maximum of 3% fine gravel (preferably none)
Coarse sand Medium sand	0.5-1.0 0.25-0.5	Minimum of 60% of the particles must fall in this range
Fine sand	0.15-0.25	Not more than 20%
Very fine sand	0.05-0.15	Not more than 5%
Silt	0.002-0.05	Not more than 5%
Clay	‹0.002	Not more than 3%
Total fines	‹0.15 mm	Not more than 10%

Table 4. Recommendation for sands for golf greens (Baker 2006)

	Percent passing (by weight)	
Sieve size (mm)	Recommended range	Acceptable range
8	100	100
4	100	100
2	100	98-100
1	90-100	85-100
0.5	35-90	30-95
0.25	0-40	0-50
0.125	0-2	0-4
0.063	0-1	0-3

Figure 1. Grading curve for sands used on golf greens (Baker 2006)



The most noticeable difference from the USGA recommendations was tolerance of a slightly higher component of fine sand, with up to 40% passing 0.25 mm, provided the amount of very fine sand, silt and clay was low.

The document also recommended that lime content for inland courses should ideally be zero, and certainly no more than 0.5%.

Requirements for particle shape were not given, although rounded to sub-angular materials were preferred, i.e. avoiding significant components of highly rounded or angular grains.

3. Jim Arthur specification (1992a)

This was given primarily for mixes of humus rich, alluvial fensoil and sand. The document is however flawed, as the recommended sand component is for a minimum of 80% in the range 0.125-0.5 mm and up to 5% very fine sand (0.063-0.125 mm), but the specification for the resulting mix allows no more than 3% below 0.25 mm. The characteristics given for the rootzone mix are given in Table 5.

Table 5. **Recommendation for rootzone mix for golf greens (Arthur 1992a)**

Sieve size (mm)	Percent passing
8	100
4	100
2	98-100
1	95-100
0.5	50-100
0.25	0-3
0.063	0-0

4. STRI Golf green construction guidelines (2005)

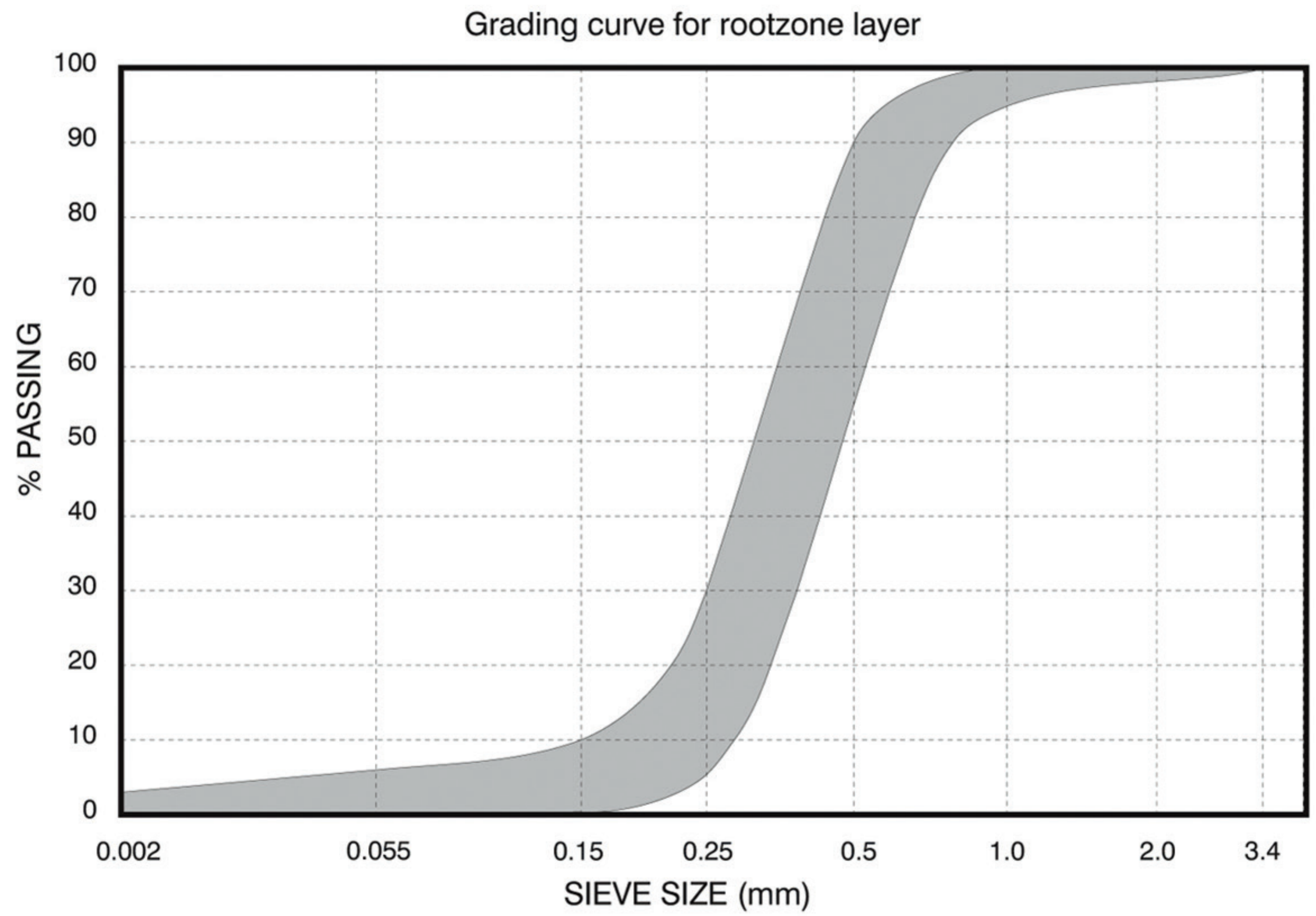
The USGA recommendations are widely and successfully used around the world, but as such they are designed to cover a very wide range of climate conditions. In particular, the performance limits have been developed to include areas with very high intensity rainfall, e.g. humid tropics, and this is not necessarily appropriate for temperate, maritime climates where rainfall amounts are often high, but spread over a longer time period. STRI considered it possible to use the basis of the USGA recommendations, but to make it more specific to the climate conditions in the United Kingdom. The document also set particle size requirements specifically as grading curves, rather than tables of requirements given by the USGA.

Grading requirements for the rootzone mix are given in Table 6 and as a grading curve in Figure 2. It was also noted that lime-free sands were preferred, i.e. with a lime content no greater than 0.5%, and that grain shape should be predominantly sub-angular to sub-rounded. Coarse sands with very rounded, spherical grains should be avoided because of potential problems of surface stability.

Table 6. **Recommendation for rootzone mix for golf greens (STRI 2005)**

Sieve size (mm)	Percent passing
4	100
2	98-100
1	95-100
0.5	55-90
0.25	5-30
0.15	0-10
0.05	0-6
0.063	0-3

Figure 2. **Grading curve for rootzone mixes for golf greens (STRI 2005). If the material fits within the shaded zone it is acceptable for use.**



This grading curve allows potentially slightly more fine sand than the USGA recommendations, but again is essentially based on medium to medium-coarse fractions, with a maximum of 30% of the rootzone mix containing material less than 0.25 mm diameter.

A significant issue for all of these specifications is that it would be impossible to meet their grading if, in the future, medium or medium-coarse sands are not available. As these sand grades are also used in the construction industry there is already pressure on the availability of these materials, which will become more significant as the decades roll by.

5. Links courses

The greens on links courses are typically based on finer sands than used for the construction of most inland courses. Baker et al. (1997) reported an average mid-particle diameter (D50) of 0.21-0.23 mm for twelve links golf greens compared to 0.25-0.33 mm for 37 greens from other course types constructed with sand:soil or sand:organic matter mixes.

Baker (1990, 2006) indicated a grading for suitable medium-fine sands for links courses (Table 7) and a similar grading is given by Arthur (1992b).

As these materials fall primarily in the medium-fine sand categories. It is less likely that there will be future supply problems for this grade than for the type of sands used to parkland-type courses, on heavier soils, where coarser sands are preferred.

Table 7. Particle size recommendations for greens on links golf courses

Sieve size (mm)	Percent passing		
	Baker (1990, 2006)		Arthur (1992b)
	Preferred range	Acceptable range	
2.0	100	98-100	99-100
1.0	95-100	90-100	95-100
0.5	75-100	55-100	50-100
0.25	15-55	10-65	0-60
0.125	0-2	0-5	0-5
0.063	0-1	0-2	0-2

Bunker sands.

Sand selection

Bunkers on the original links courses would have been based on the local sand materials. Indeed, this still can be the case, although strict rules relating to sand extraction in environmentally sensitive areas usually mean that compatible medium-fine sands have to be imported. Particle size distribution of typical links courses tends to be in the range 0.125-0.355 mm diameter (Marshall & Lindsay, 1990).

For inland/parkland courses it is inevitable that bunker sand materials have to be imported and again this has been subject to research and the development of guidelines.

Research

In the USA, Brown & Thomas (1986) indicated that:

- Materials that are too coarse may result in excessive sand blasting and this can damage mowers being used on the adjacent turf area;
- Sands containing too much silt and clay may be subject to crusting and require higher maintenance to provide satisfactory playing conditions;
- Round sands are hard to keep in place on bunker faces and may lead to excessive burying of the ball on impact.

They examined 42 different bunker sands and identified typical sand particle ranges that were reported as satisfactory (Table 8), with the main range being 0.1-1.0 mm. They also looked at ball penetration into the sand using a modified penetrometer test and indicated that sands with a value >0.24 MPa[3] performed well, sands with a value below 0.18 MPa were poor with sands between 0.18-0.24 MPa classified as fair. Angular sands were generally more resistant to excessive ball plugging and also reported to be more stable on bunker faces.

Baker et al. (1990) examined the performance of 23 sands in relation to ball impact using a simulated

Table 8. Typical particle size ranges and assessment criteria used in bunkers and considered to be satisfactory (Brown & Thomas, 1986)

Size (mm)	Percent	Criteria for sand evaluation	Good	Fair
0.05-0.1	<5	Silt and clay	<3%	Not given
0.1-1.0	78-100	Ball penetration	>0.24	0.18-0.24
1.0-2.0	<15	Crusting/set up	None	Slight
>2	<2	Shape	Angular	Sub-angular

[3] MPa is megapascal and is a unit of pressure, used in this case to measure the pressure required to insert a probe into a bunker sand. The more pressure needing to be applied the more compact the sand, which gives an indication of the sands stability and plugging characteristics.

8 iron shot, penetration resistance and the angle of repose of the sand, which influences potential sand retention against a bunker face. Grain size and the uniformity of the sand distribution were the main sand properties influencing plugging depth, although moisture content and preparation by raking also influenced the results. Penetration resistance was used as a measure of the stability of the sand and was most closely influenced by the uniformity of the sand and the proportion of spherical grains. The angle of repose of air-dry sand was most closely related to the angularity of the grains, but particle size would also influence water retention and the stability of the sand against a bunker face.

Owen et al. (2005) compared the performance of very angular sands derived from recycled glass against more rounded conventional sands. The angular sands had higher penetration resistance, lower depth of golf ball penetration on impact and lower hardness following consolidation than conventional sands. The grade of sand also made a difference to some parameters: water retention was inevitably greater for finer sands and golf ball penetration was less on finer sands.

Guidelines/specifications

A lot of the earlier guidelines were very general. USGA (1977) recommended that 100% of the sand should fall in the range 0.25 mm to 1.0 mm. O'Brien (1985) further suggested that at least 75% of the sand particles should fall into the range of 0.25 mm to 0.5 mm.

Baker (1990, 2006) indicated the following grading for sands for bunkers on inland courses (Table 9). The guidelines also recommended a lime content less than 0.5% and that there should be no more than 60% of particles in the rounded and well-rounded shape categories. A further warning was included that very uniform sands, particularly those with a high proportion of rounded grains, may be fluffy and prone to instability. Under these circumstances, sands with a D90/D10 gradation index of 2.5 or more are preferable.

Table 9. Recommendation for sands for bunkers (Baker 2006)

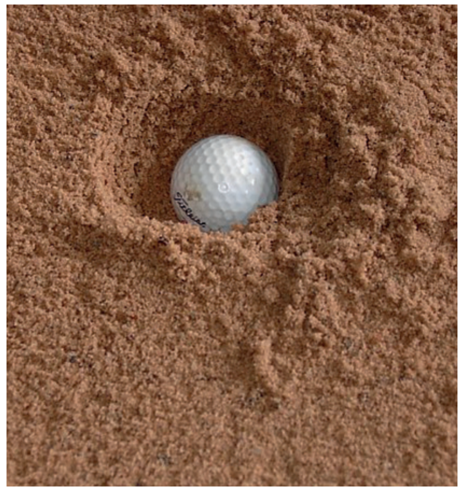
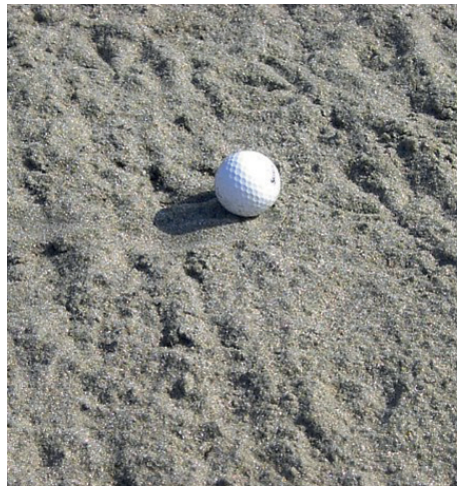
Sieve size (mm)	Percent passing (by weight)	
	Recommended range	Acceptable range
8	100	100
4	100	99-100
2	100	98-100
1	90-100	85-100
0.5	35-90	25-95
0.25	0-40	0-50
0.125	0-2	0-5
0.063	0-1	0-2

The most recent USGA guidance (Whitlark, 2020) considers nine different performance requirements for bunker sands as follows:

- Particle size
- Particle shape
- Uniformity coefficient
- Infiltration rate
- Penetrometer test
- Angle of repose
- Crusting potential and set-up
- Acid reaction
- Colour

No single set of parameters or requirements is given because of the potential effects of a wide range of course types and climate zones, but issues that should be considered for sand selection are discussed in detail in the text.

Aesthetic considerations, particularly the colour of the sand may also influence the selection of materials, with typically lighter coloured materials being preferred to give a better contrast against the surrounding turf areas.


Aggregates for base layers and drain trenches.

Grading requirements

A variety of coarser aggregate materials are used on golf courses, most notably in drain trenches and any drainage layers under golf greens or teeing grounds.

Most of the guidance for these materials has been practically based, rather than derived from research studies. Issues relating to the intermediate/binding layer in golf green construction need to be considered as selection is also related to the sand type used for the overlying rootzone layer.

Specifications

A number of guidelines or specifications have been published, both by the USGA and from work carried out in the United Kingdom.

USGA guidelines for the gravel depend on whether an intermediate layer is used or not. If an intermediate layer is used the recommendation is for a gravel primarily between 2 mm and 12 mm, but dominated by at least 65% in the range 6 mm to 9 mm. Under these circumstances an intermediate layer with at least 90% between 1 mm and 4 mm would be used (full details are given in Table 10).

Table 10. **USGA Guidelines for gravel selection when an intermediate layer is used**

Layer	Characteristics
Gravel drainage layer	Not more than 10% of particles greater than 12 mm At least 65% of particles between 6 mm and 9 mm Not more than 10% of the particles less than 2 mm
Intermediate layer	At least 90% of particles between 1 mm and 4 mm

Where an intermediate layer is not used, the guidelines have to take account of:

- A bridging factor to prevent the risk of particle migration
- A permeability factor
- The uniformity of the gravel

In general, most of the material would be in the range of 3-10 mm, but the only specific grading criteria are:

- No particles greater than 12 mm
- Not more than 10% less than 2 mm
- Not more than 5% less than 1 mm

For the United Kingdom, STRI guidelines (2005) are given as a series of grading curves (Table 11 and Figures 3 to 5). The grading curve for the gravel layer is also appropriate for drain trenches.

Table 11. **Recommendation for drainage aggregates *(STRI 2005)***

Sieve size (mm)	Percent passing		
	Drainage layer (no intermediate layer)	Drainage layer (with intermediate layer)	Intermediate layer
16	100	100	-
12.5	98-100	60-100	-
8	90-100	15-100	100
4	0-60	0-30	90-100
2	0-6	0-5	10-85
1	0-3	0-2	0-25
0.5	0-2	0-1	0-10
0.25	-	-	0-3
0.125	-	-	0-1

Figure 3. **Grading curve for materials used in drainage layers if an intermediate layer is used. If the materials fits within the shaded zone it is acceptable for use.**

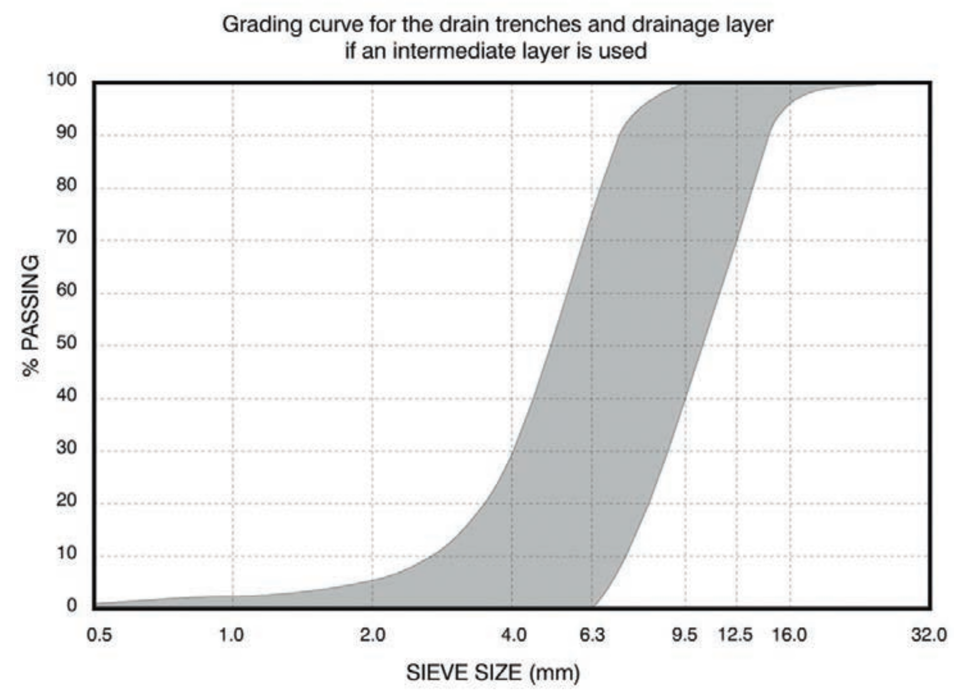


Figure 5: Grading curve for materials to be used as an intermediate layer. If the materials fits within the shaded zone it is acceptable for use.

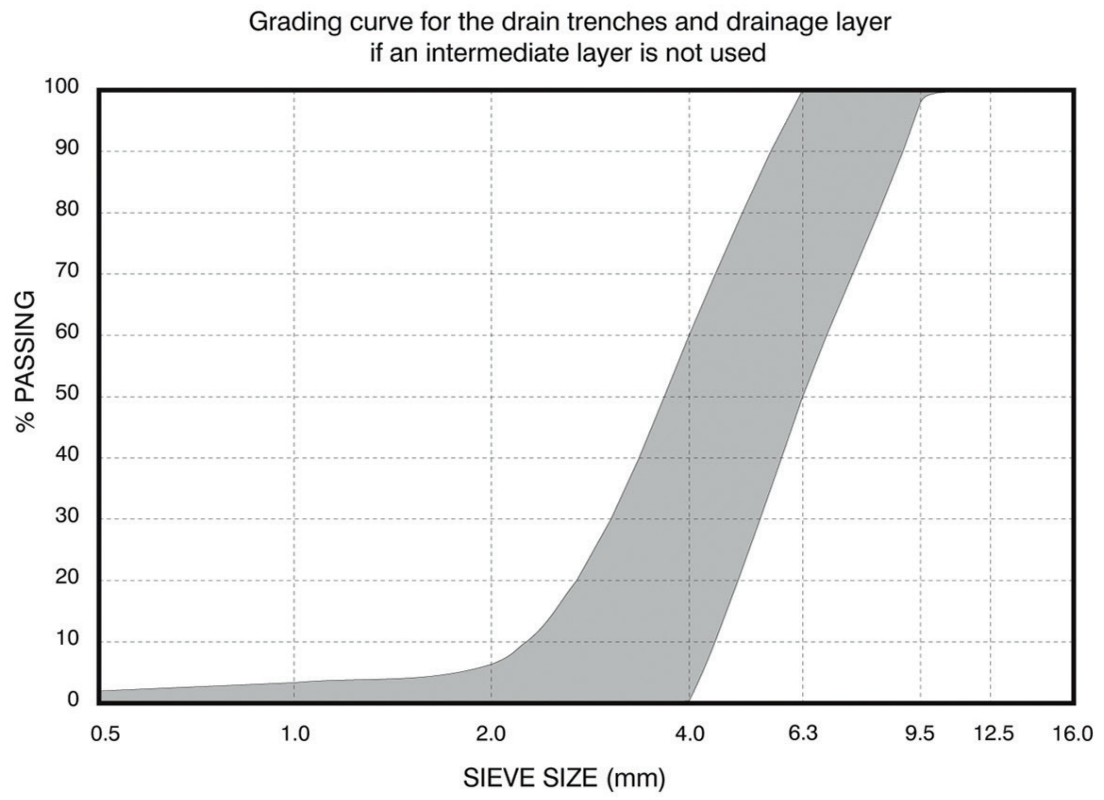
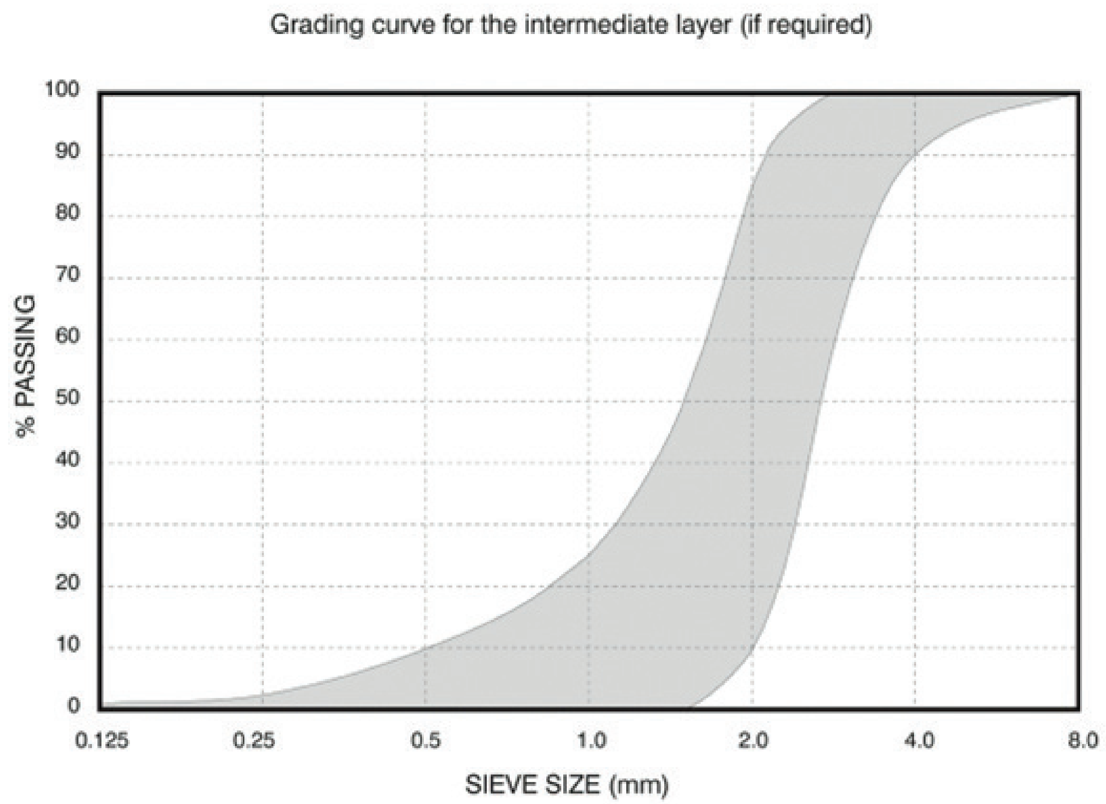


Figure 4: Grading curve for materials used in drainage layers if an intermediate layer is not used. If the materials fits within the shaded zone it is acceptable for use.



Gravel source, weathering stability and mechanical stability

It is important that any gravels that are used are stable and will, therefore, not break down over time. Some of the softer limestones will gradually dissolve, particularly if the water percolating through the rootzone is slightly acidic. Mechanical stability is also important and sulphate soundness and abrasion tests may need to be carried out if there are concerns about the durability of the gravel source.

Specific issues with the bridging factors for sands and gravels

If medium and medium-coarse rootzone sands become harder to obtain this may also influence gravel selection. Unless an intermediate/blinding layer is used, the composition of the rootzone mix will affect the gravel type that is used for the underlying drainage layer. Specifically, USGA guidelines include a bridging factor to ensure that the rootzone material does not migrate downwards into the gravel layer. This bridging factor indicates that the D15 of the gravel shall be less than or equal to 8 times the D85 of the rootzone. Under these circumstances, and also based on a series of uniformity factors for the gravel, the implications of different rootzones on acceptable gravels can be calculated (Table 12). If there was a shortage of medium-coarse rootzone sands this would decrease the options for selection of a suitable gravel type, or alternatively it would force the use of an intermediate/blinding layer, which has implications for construction time and costs.

Table 12: Effect of sand size of the rootzone mix on bridging factors and gravel selection (based on USGA criteria when intermediate layer is not used)

Rootzone sand calculation criteria	D_{85} rootzone (mm)	Maximum D_{15} of gravel (mm)	Maximum D_{90} of gravel (mm)	General description of coarsest possible gravel type
		Note a	Note b	Note c
Medium-fine	0.45	3.6	10.8	3-8 mm grade
Medium	0.55	4.4	13.2	4-10 mm grade
Medium-coarse (normal example)	0.65	5.2	15.6	5-12 mm grade
Medium-coarse (coarser example)	0.75	6.0	18.0	6-12 mm grade

Note a Bridging factor = D15 Gravel no more than 8 x D85 rootzone
Note b Uniformity factor =D90 gravel no greater than 3 x D15 gravel
Note c Uniformity factor = No particles greater than 12 mm

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R&A

The R&A group of companies was formed in 2004 to take on The Royal and Ancient Golf Club of St Andrews' responsibilities for governing the Rules of Golf, staging The Open, golf's original championship, and developing the sport. The World Golf Museum in St Andrews is part of The R&A group.

Together The R&A and the USGA govern the sport of golf worldwide, operating in separate jurisdictions with a commitment to a single code for the Rules of Golf, Rules of Amateur Status and Equipment Standards. The R&A, through R&A Rules Ltd, governs the sport worldwide, outside of the United States and Mexico, on behalf of over 41 million golfers in 144 countries and with the consent of 159 organisations from amateur and professional golf.

The R&A has responsibility for running a series of world class amateur events and international matches in women's and girls' as well as men's and boys' golf. The R&A stages the AIG Women's Open and works with the DP World Tour to stage the Senior Open presented by Rolex.

The R&A is committed to investing £200 million over ten years in developing golf and supports the growth of the sport internationally, including the development and management of sustainable golf facilities. For more information, visit www.randa.org.

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