A-LEVEL
ENVIRONMENTAL SCIENCE
7447

Specification
For teaching from September 2017 onwards
For A-level exams in 2019 onwards

Version 1.0 9 January 2017

Contents

Are you using the latest version of this specification?

- You will always find the most up-to-date version of this specification on our website at aqa.org.uk/7447
- We will write to you if there are significant changes to the specification.

1 Introduction

1.1 Why choose AQA for A-level Environmental Science

Students who enjoy a multi-disciplinary approach to learning and have a keen interest in the sustainability of our planet will find this new specification engaging and thought provoking.

We've kept much of the popular content that we know you like and key topics include the bio-physical environment, energy resources, pollution, circular economy and sustainability. With opportunities to include real life case studies in your teaching, this contemporary qualification has never been more relevant.

The new assessment structure is clear and straightforward and we've used a mixture of question styles, so that students have the best opportunity to demonstrate their knowledge and understanding.

We've ensured that the AS and A-level are fully co-teachable. The AS exams include similar questions to those in the A-level, with less difficulty, allowing for future growth.

This is a great accompaniment to A-levels in geography, biology, physics and maths and develops key skills including communication, teamwork and critical thinking.

You can find out about all our Environmental Science qualifications at aqa.org.uk/environmentalscience

1.2 Support and resources to help you teach

We've worked with experienced teachers to provide you with a range of resources that will help you confidently plan, teach and prepare for exams.

1.2.1 Teaching resources

Visit aqa.org.uk/7447 to see all our teaching resources. They include:

- flexible schemes of work to help you plan for course delivery in your own way
- specimen assessment materials that will give your students a clear idea as to what is expected in the exams
- training courses to help you deliver AQA Environmental Science qualifications
- subject expertise courses for all teachers, from newly qualified teachers who are just getting started to experienced teachers looking for fresh inspiration.

1.2.2 Preparing for exams

Visit aqa.org.uk/7447 for everything you need to prepare for our exams, including:

- past papers, mark schemes and examiners' reports
- specimen papers and mark schemes for new courses
- Exampro: a searchable bank of past AQA exam questions
- example student answers with examiner commentaries.

1.2.3 Analyse your students' results with Enhanced Results Analysis (ERA)

Find out which questions were the most challenging, how the results compare to previous years and where your students need to improve. ERA, our free online results analysis tool, will help you see where to focus your teaching. Register at aqa.org.uk/era

For information about results, including maintaining standards over time, grade boundaries and our post-results services, visit aqa.org.uk/results

1.2.4 Keep your skills up-to-date with professional development

Wherever you are in your career, there's always something new to learn. As well as subject specific training, we offer a range of courses to help boost your skills.

- Improve your teaching skills in areas including differentiation, teaching literacy and meeting Ofsted requirements.
- Prepare for a new role with our leadership and management courses.

You can attend a course at venues around the country, in your school or online – whatever suits your needs and availability. Find out more at coursesandevents.aqa.org.uk

1.2.5 Help and support

Visit our website for information, guidance, support and resources at aqa.org.uk/7447

If you'd like us to share news and information about this qualification, sign up for emails and updates at aqa.org.uk/from-2017

Alternatively, you can call or email our subject team direct.

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2 Specification at a glance

This qualification is linear. Linear means that students will sit all their exams and submit all their non-exam assessment at the end of the course.

2.1 Subject content

Working scientifically: opportunities for skills development and independent thinking

At the end of each subject content section, there are details of opportunities for students to develop scientific skills within the context of that topic.

These include:

- skills related to the methodologies and sampling techniques that students must gain through first-hand experience
- skills related to research methods that can be gained through class-based and/or practical activities.

2.2 Assessments

Paper 1
What's assessed • The physical environment • Energy resources • Pollution • Research methods Students will be expected to draw on knowledge and understanding of the entire course of study to show a deeper understanding of the interconnections between topics.
How it's assessed • Written exam: 3 hours • 120 marks • 50% of A-level
Questions A combination of multiple choice, short answer and extended writing questions.

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Paper 2
What's assessed • The living environment • Biological resources • Sustainability • Research methods Students will be expected to draw on knowledge and understanding of the entire course of study to show a deeper understanding of the interconnections between topics.
How it's assessed • Written exam: 3 hours • 120 marks • 50% of A-level
Questions A combination of multiple choice, short answer and extended writing questions.

3 Subject content

The key scientific principles of the subject should be developed throughout the course, using examples to illustrate these whenever appropriate.

Environmental science is a holistic subject with many interconnected systems and processes. A change to one process can affect many other processes over different spatial and temporal scales.

Consideration of environmental issues and the conclusions reached should be based on reliable evidence-based information and quantitative data.

Students must develop an understanding of how human society relies upon natural systems for resources and life support systems.

An understanding of these systems should be used to propose changes in society that would produce sustainable lifestyles.

The requirements set out in scientific principles (page 99) must be integrated into theoretical and practical contexts where appropriate.

3.1 The living environment

The emphasis should be placed on the interaction of living organisms with each other and their abiotic environment, and how an understanding of this can inform decisions that lead to sustainable human activities. Students must apply their understanding of these interactions in a wide range of contexts throughout this area.

3.1.1 Conditions for life on Earth

3.1.1.1 How the main conditions, which allowed early life to develop and survive on plant Earth, came about

Students should understand how the conditions of planet Earth allowed early life to develop and survive.

Content	Additional information
Atmosphere	The mass of Earth and force of gravity retained an atmosphere. The atmosphere provided gaseous resources: carbon dioxide, methane, nitrogen. Atmospheric pressure and temperature maintained liquid water.
Insolation	A suitable temperature range was controlled by incoming insolation and its behaviour in the atmosphere. This was controlled by the surface albedo, absorption of infrared energy and the presence of the atmosphere.

Content	Additional information
Position in the solar system	Suitable temperatures were maintained by the distance from the Sun.
Orbital behaviour	The rotation and tilt of the Earth on its axis and its orbit around the Sun, controlled daily and seasonal variations in insolation and temperatures.
Magnetosphere	The magnetosphere provides protection from radiation: the Earth's molten core produced a magnetic field (magnetosphere) that deflects solar radiation.

3.1.1.2 How the presence of life on Earth has brought about environmental change

3.1.1.2.1 How biota have helped to maintain stability

Content	Additional information
Oxygen production	Oxygen was first produced by photosynthetic bacteria, then by algae and plants.
Ozone layer	Ozone was produced by chemical reactions involving oxygen and ultraviolet light in the stratosphere.
Carbon sequestration	Atmospheric carbon dioxide concentrations were reduced by photoautotrophs.
Biogeochemical cycles	The processes of biogeochemical cycles are linked by living organisms, preventing the build-up of waste products or shortages of resources.

3.1.1.2.2 How historical conditions for life were monitored in the past and how these methods have been developed over time

Students should understand how changes in monitoring methods have allowed more accurate estimation of past conditions on Earth.

Content	Additional information
Limitations of early methods.	• Lack of ancient historical data. • Limited reliability of proxy data for ancient conditions. • Limited coordination between researchers. • Lack of sophisticated equipment for accurate measurements. • Inability to measure many factors. • Lack of data collection in many areas. • Reliance on proxy data, eg dendrochronology, pollen analysis.
Improved methods.	• Collection of long-term data sets. • The use of electronic monitoring equipment. • Gas analysis of ice cores. • Isotope analysis of ice cores. • Improved carriers for monitoring equipment, eg helium balloons, aircraft, satellites. (See Research methods (page 83))

3.1.2 Conservation of biodiversity

3.1.2.1 The importance of the conservation of biodiversity

3.1.2.1.1 Resources and how sustainable habitat management strategies can be used to secure future supplies

Content	Additional information
Wood	Timber for structural uses.
Fibres	Plant and animal fibres.
Oils	Uses of vegetable oils.
Fuels	Biofuels.
New foods	Many plant species have the potential for commercial cultivation.

3.1.2.1.2 Knowledge and how decisions over habitat conservation can be made to protect those species that have not yet been investigated

Content	Additional information
Biomimetics	Students should understand that features of living organisms can be copied in the development of new structures and materials, eg: • vehicle design • architecture • structures • adhesion • materials • ultrasound diagnosis.
New medicines	New medicines can be developed from the chemicals produced by plants and animals.
Physiological research	Animal species may be more useful or practical than humans for physiological research.
Wildlife species as pest control agents	Many wildlife species can be used to control agricultural pests. They may be predators, herbivores, parasites orpathogens.
Genetic resources	New genes to improve crop genetic characteristics may be found in the wild relatives of the cultivated crops. The importance of Centres of Diversity/Vavilov centres for crop wild relatives (CWRs).

3.1.2.1.3 Ecosystem services and their interaction with each other

Content	Additional information
Atmospheric composition	The role of living organisms in the regulation of the composition of the atmosphere: O_2, CO_2, water vapour.
Biogeochemical cycles	The importance of iving organisms in biogeochemical cycles.
Interspecies relationships	Living organisms often provide services that aid the survival of other species, eg pollination, seed dispersal and habitat provision.
Soil maintenance	Living organisims are important in soil formation and erosion control, eg plants, detritivores, decomposers.

3.1.2.2 How humans influence biodiversity, with examples in a range of different context

Content	Additional information
Direct exploitation	Populations of many species have been reduced by over-exploitation for resources or deliberate eradication, eg: • food • fashion • entertainment • furniture and ornaments • traditional medicines • other products.
Deliberate eradication	Eradication of predators and competitors.
Changes in abiotic factors	Human activities may change the abiotic features of a habitat, making it more or less suitable for the survival of wildlife. • The changes may be caused by an action, or by inactivity, eg stopping plagioclimax management. • Water availability, eg by drainage or flooding. • Light levels, eg by forest clearance. • Oxygen availability, eg by pollution of water with organic matter. • Nutrient levels, eg fertiliser runoff from farmland. • pH, eg acid mine drainage. • Temperature, eg thermal pollution from power stations.
Changes in biotic factors	Changing the population size of one species often has an impact on the population size of other species. • Introduced species. • Loss of inter-species relationships.
Habitat destruction	Many human activities remove the natural communities of species: • deforestation • expansion of farmland • urbanisation • mineral extraction • flooding by reservoirs.

3.1.2.3 Methods of conserving biodiversity

3.1.2.3.1 Setting conservation priorities

Content	Additional information
	Students should understand that the conservation of biodiversity requires setting priorities about which species and communities are to be conserved.
International Union for Conservation of Nature (IUCN) criteria	The roles of the IUCN: • coordinating global data on biodiversity conservation • increasing understanding of the importance of biodiversity • deploying nature-based solutions to global challenges in climate, food and sustainable development. Students should have knowledge of the criteria used by the IUCN to identify the species that should be prioritized for conservation. These are developed further elsewhere in the specification: • red list categories for threatened species • classification of habitats, threats and required actions • evolutionary uniqueness • endemic species • keystone species • flagship species • threats to survival • population dispersal.
Evolutionary uniqueness	EDGE species (Evolutionary Distinct and Globally Endangered) are threatened by extinction and diverged from other taxa long ago so they have greater genetic differences.
Endemic species	Species found within a single area, especially if the population is small.
Keystone species	Species whose survival is important for the survival of many other species.

3.1.2.3.2 Legislation/protocols

Content	Additional information
	How legislation and protocols protect species and habitats by establishing restrictions and management agreements.

Content	Additional information
Protection of habitats and species	The key features of the Wildlife and Countryside Act (1981). Students should understand the different ways in which designated areas protect species and habitats by restricting activities and establishing management plans. Designated protected areas in the UK, eg: • Sites of Special Scientific Interest (SSSI) • National Nature Reserve (NNR) • Special Area of Conservation (SAC) • Special Protection Area (SPA) • Natura 2000 sites • Ramsar sites • Marine Nature Reserve (MNR) • Local Nature Reserve (LNR) • Marine Protected Area (MPA) • Marine Conservation Zone (MCZ).
Trade Controls	How the Convention on International Trade in Endangered Species (CITES) protects selected species: • Appendix I. • Appendix II.
Regulation of sustainable exploitation	Organisations that aim to exploit living resources sustainably: • International Whaling Commission (IWC) • European Union Common Fisheries Policy (EU CFP) • International Tropical Timber Organisation (ITTO).

3.1.2.3.3 Captive breeding and release programmes (CBR)

Content	Additional information
Ex-situ conservation is needed when conservation of species in their natural habitat is impossible or insufficient to protect the species.	• Criteria for the selection of species for captive breeding programmes. • Difficulties in keeping a captive population. Reasons why keeping species in captivity may be difficult.

Content	Additional information
Methods of increasing breeding success	• Provision of essential conditions for breeding. • Group dynamics. • Difficulties in providing required abiotic conditions. • Artificial insemination. • Embryo transfer.
Soft and hard release programmes	The selection of suitable release sites: Soft release. Hard release. Post-release monitoring.

3.1.2.3.4 Habitat conservation

Content	Additional information
In-situ conservation protects communities of species not just individual selected species.	
Habitat creation	New habitats may be created as a consequence of other human activities. New habitats may be created when wildlife conservation is the main aim. • New conservation habitats: wetlands, woodlands. • Habitat restoration – rewilding. Structural features of habitats may affect the success of conservation programmes: • habitat area • habitat shape • age structure • ease of colonization/need for introduction • biological corridors.
Management and conservation of habitats	Students should use a range of ecosystems and habitat areas to analyse their similarities and differences, especially the controlling ecological features and how this can inform conservation strategies. The importance of conservation should be related to the threats from human activities.

Content	Additional information
Temperate broadleaf woodland Features: • regular water supply • summers not very hot • winters not very cold • seasonality.	
Importance: • high biodiversity • resources • climate control • soil erosion control • recreation.	
Threats: • deforestation for other land uses • fragmentation of remaining woodland • management change.	
Conservation efforts: • designated protected areas • legal protection of ancient woodland in the UK • conservation management.	
Tropical rainforest Features: • warm/hot • high rainfall • high light levels • inter-species relationships • low seasonality.	
Importance: • high biodiversity • resources • carbon sequestration • hydrological cycle • soil erosion control.	

Content	Additional information
Threats: • fuelwood collection • timber for construction and furniture • agricultural expansion • mineral extraction • reservoirs • global climate change • exploitation of individual species.	
Conservation efforts: • establishment of protected areas • debt for Nature Swaps • sustainable exploitation.	
Tropical coral reefs Features: • cnidarians • nutrition systems • high light levels • warm, stable temperatures • low turbidity • constant salinity.	
Importance: • fisheries • erosion protection • medicinal discoveries • climate control • tourism.	
Threats: • physical damage caused by human activites • souvenir collection • sedimentation • climate change • pollution • fishing • introduced species.	
Conservation efforts: • control of damaging activities • establishment of protected areas.	

Content	Additional information
Deep-water coral reefs. Features: • cold and dark • slow coral growth.	
Importance: • research • fisheries.	
Threats: • trawling • oil and gas exploration • ocean acidification.	
Conservation efforts: • establishment of protected areas • control of damaging activities.	
Oceanic islands Features: • isolation • few or no indigenous mammal predators • endemic species.	
Importance: endemic species.	
Threats: • species exploitation • introduced species • habitat change/destruction • sea level rise.	
Conservation efforts: • eradication of introduced species • control of developments and visitors.	
Mangroves Features: • tropical climates • halophytic trees • low oxygen availability.	

Content	Additional information
Importance: • coastal erosion protection • fisheries • timber supplies • trap suspended solids.	
Threats: • clearance for urban development/ aquaculture • coral reef destruction • pollution • global climate change.	
Conservation efforts: • reforestation • control of damaging activities • establishment of protected areas.	
Antarctica Features: • very low temperatures • low precipitation • high albedo • high levels of marine nutrients • large variations in ice cover • extreme seasonal changes.	
Importance: • water store • ice albedo • carbon sequestration • resources • research.	
Threats: • global climate change • ozone depletion • tourism • overfishing • future mineral exploitation • scientific research.	

Content	Additional information
Conservation efforts: • The Antarctic Treaty (1959) • fisheries control • waste management • tourism control.	

3.1.2.3.5 The importance of ecological monitoring in conservation planning

Content	Additional information
It is important to identify the species present and features of their populations in planning conservation strategies.	Population dynamics: • size • distribution • survival rate • age structure. (See Research methods (page 83))

3.1.2.3.6 The development of new technologies for ecological monitoring

Students should understand how new technologies improve the validity of ecological research by allowing the collection of more representative data and new information.

Content	Additional information
New technologies used in ecological research	• Satellite/radio tracking. • DNA databases, eDNA. • Image recognition, including software • Acoustic monitoring, sonograms. (See Research methods (page 83))

3.1.3 Life processes in the biosphere and conservation planning

3.1.3.1 How adaptation to the environment affects species' habitat requirements and influences conservation decision-making

Students should be able to use examples of habitat management which benefit species that are adapted to particular abiotic and biotic factors. The deliberate provision of these conditions may increase species' survival.

Content	Additional information
Abiotic factors: • light • water • nutrients • pH • abiotic habitat provision.	
Biotic factors: • food • control of predation • pollination • seed dispersal • biotic habitat provision • other inter-species relationships.	

3.1.3.2 Terminology to describe the roles of living organisms in their habitats and their interactions with the physical environment

Students should be able to use appropriate terminology to describe the roles of living organisms in their habitats and their interactions with the physical environment.

Content	Additional information
Ecological terminology	• Species. • Taxon. • Ecological niche. • Population. • Community of species. • Ecosystem. • Biome.

3.1.3.3 The control of ecological succession in conserving plagioclimax habitats

Students should understand that many wildlife communities have developed in plagioclimax habitats maintained by long-term human activities. They should understand the processes in ecological succession that can inform conservation strategies.

Content	Additional information
Ecological succession	• Colonisation and pioneer species. • Seres. • The modification of abiotic conditions by new colonisers. • Climax communities. • Deflected succession. • Secondary succession. • Plagioclimax communities.
Methods of maintaining plagioclimax communities: • grazing • mowing • burning • coppicing • pollarding.	

3.1.3.4 How population control and the management of desired and undesired species affects the conservation of biodiversity

Students should understand the concept of carrying capacity and the influence of density and density-independent factors on regulating populations.

Content	Additional information
Management of desirable species: • release programmes • habitat management.	
Control of undesirable species: culling/ eradication.	
r- and k- selection strategies and how they affect the ease with which species can be over-exploited.	

3.1.4 Opportunities for skills development and independent thinking

Mathematical skill number	Opportunities for skills development and independent thinking
MS 0.2	Students could use an appropriate number of decimal places in calculations, eg calculating mean population density from multiple sample sites in a habitat.
MS 0.3	Students could calculate and compare percentage loss, eg of rain forests over a given time period of declining populations of endangered species.

Mathematical skill number	Opportunities for skills development and independent thinking
MS 0.5	Students should demonstrate their ability to interpret population growth curves.
MS 1.1	Students could report calculations to an appropriate number of significant figures given raw data quoted to varying numbers of significant figures, eg in calculating indices of biodiversity.
MS 1.2	Students could calculate mean population density from multiple quadrats.
MS 1.5	Students could compare and analyse data collected by random sampling and systematic, eg use Simpson's index of diversity to compare the biodiversity of habitats with different management regimes.
MS 1.9	Students could use Spearman's Rank Correlation Coefficient to analyse changes in abiotic and biotic factors with distance into a habitat, eg woodland.
MS 1.10	Students should demonstrate their understanding of standard deviation as a useful measure of dispersion for a given set of data, eg for comparison with other data sets with different means such as populations of endangered species under different management regimes.
MS 1.11	Students could calculate percentage error where there are uncertainties in measurement, eg estimating total population using sub-samples in a preliminary study.
MS 2.1	Students could use $= \; < \; \ll \; \gg \; >$ when estimating maximum sustainable yield.
MS 2.3	Students could use Simpson's index of diversity to assess the impact of a new habitat management regime.
MS 3.1	Students could construct a kite diagram of the change in population density of species along a transect.
MS 3.3	Students could plot changes in species abundance with changes in abiotic factors eg temperature, water, pH.
MS 3.7	Students could measure the gradient of a point on a curve, eg rate of population growth.
MS 4.1	Students could calculate the circumference and area of nature reserves to assess the impact of the edge effect on wildlife conservation programmes.

Working scientifically

Students could plan activities to investigate environmental issues which they could carry out eg:

- population surveys in a habitat to be visited
- measurement of abiotic factors in a habitat to be visited.

Students could plan activities to investigate environmental issues in broader environmental contexts where first-hand experience would not be possible eg:

- monitoring the impact of invasive species on indigenous species
- monitoring the impact of the local extinction of forest elephants on plant species with animal-dispersed seeds
- monitoring changes in population size, age structure and diversity after an area gains protected status, eg new MCZs
- monitoring the survival and dispersal of animals in captive breeding programmes after release
- estimating increases in biomass of tropical forests in response to increases in CO_2 levels
- monitoring changes in water turbidity on coral reefs caused by land use changes, eg deforestation
- monitoring changes in penguin populations in Antarctica using satellite imagery
- monitoring the impact of fishing controls by the EU CFP on fish populations
- monitoring colonisation and changes in community composition in a recently created habitat.

Practical skill number	Opportunities for skills development and independent thinking
PS 1.1	Students could assess the knowledge required to solve an environmental problem, eg: • population size • population density • biomass • distribution • movements.
PS 1.2	Students could analyse existing knowledge and data eg: • changes in species abundances • changes in age structure • current biomass.
PS 1.3	Students could evaluate and explain the contribution that the results of the planned study would make to solving the problem eg: • how changes in abiotic factors may cause changes in woodland floor plant survival • how a change in population of trees may be caused by the loss of forest elephants • how a change in age structure in an MCZ may indicate the effectiveness of protection.
PS 1.4	Students could plan studies to gain representative, reliable data, using the selected methodologies and sampling techniques below.
PS 2.1	Students could evaluate the methods of previous studies and analyse the reliability of the data produced.
PS 2.2	Students could analyse their method and the results produced to identify limitations in the method and any inaccuracies in results eg: • limitations of population estimates from population sub-samples and the Lincoln Index • inaccuracies caused by the use of data that fluctuate unpredictably, eg abiotic factors related to weather.

Practical skill number	Opportunities for skills development and independent thinking
PS 2.3	Students could identify the other variables that could also affect their results eg: in a study of the effect of light levels on ground flora: soil pH, temperature, humidity, wind velocity. In a study of increased forest biomass caused by rising CO_2 levels: changes in water availability, temperature and forest management.
PS 2.4	Students could use a variety of methods to present data: • construct a table of raw data eg abundances of species found in each quadrat • construct a table of changing abiotic factors along a transect across a habitat.
PS 3.1	Students could construct line graphs to show changes in data over time or correlations between variables.
PS 3.2	Students could use data on species richness and abundance to calculate Simpson's Index of diversity.
PS 3.3	Students could compare estimates of population size for the same habitat produced by different groups to consider possible causes of the variation.
PS 4.1	The practical skills of using equipment within scientific environmental studies are expanded in the selected methodologies and sampling techniques below.

Opportunities to investigate the required methodologies of which students must have first hand experience. Further details can be found in Appendix A: Working scientifically (page 95)

Methodology skill number	Opportunities for skills development and independent thinking
Me 1	Students could plan the collection of samples using random sampling. Eg: Ground flora in woodland or grasslands.
Me 2	Students could plan the collection of samples using systematic sampling eg: • abiotic factors along a transect • species abundance or distribution along a transect • data from moth or bat surveys at regular intervals, eg weekly.
Me 3	Students could carry out a preliminary study and analyse the results to assess the smallest number of samples that produce reliable results eg: Using increasing numbers of quadrats to estimate the total population. Eg estimating total population using mean values from 5, 10, 25, 50, 100 etc quadrats. The reduction in fluctuations in overall mean values will enable students to select an appropriate sample number for further studies.

Methodology skill number	Opportunities for skills development and independent thinking
Me 4	Students could carry out a preliminary study and analyse the results to assess the smallest sample size that produces reliable results. eg: estimating lichen percentage cover on bark using increasing sizes of sample area. The minimum size is that where using larger areas does not cause the value to change significantly and reliability to increase.
Me 5	Students could identify appropriate timings for surveys to be carried out eg: • moth surveys carried out overnight with standardized conditions of temperature, precipitation, wind velocity • population surveys related to breeding cycles • plant surveys related to periods of emergence/flowering.
Me 6	Students could carry out statistical tests to assess the significance of the data eg: Spearman's Rank Correlation Coefficient for abundance of a species and an abiotic factor along a transect.

Opportunities to investigate the required sampling techniques of which students must have first hand experience. Further details can be found in Appendix A: Working scientifically (page 95)

Sampling technique skill number	Opportunities for skills development and independent thinking
ST 1	Students could analyse the effect of wind velocity or temperature on the activity of bats or moths to consider the possible impacts of climate change.
ST 2	Students could compare plant biodiversity in grasslands with different mowing regimes.
ST 5	Students could use a Tüllgren funnel to compare the invertebrates in the leaf litter of two different woodlands.
ST 6	Students could use kick sampling to compare invertebrate diversity in different streams or areas of the same stream with different substrates.

3.2 The physical environment

The emphasis should be placed on understanding how anthropogenic activities are inter-connected with physical processes, to formulate management strategies and plan sustainable activities.

Supplies of renewable physical resources may be maintained by the control of activities that may cause over-exploitation and by protecting the processes that aid their production.

Supplies of non-renewable physical resources may be extended by controlling exploitation and developing improved technologies to harness them.

3.2.1 The atmosphere

3.2.1.1 How atmospheric energy processes involving ultra violet (UV), infrared (IR) and visible light in the stratosphere and troposphere affect life-support systems

Content	Additional information
Origins and roles of UV and IR in the atmosphere.	• Insolation. • Emissions from the earth. • Thermal stratification. • Chemical processes.
How different wavelengths of electromagnetic light behave in the atmosphere: • transmission • absorption • conversion to heat • conversion to chemical energy • reflection.	

3.2.1.2 Global climate change: how interconnected natural systems cause environmental change

Students should select, analyse and evaluate the data available on natural and anthropogenic climate change.

Content	Additional information
Greenhouse gases	The anthropogenic sources of greenhouse gases, residence times and relative effects: CO_2, CH_4, NO_x, tropospheric ozone, CFCs.
Changes in oceans	Changes in thermohaline circulation in the North Atlantic. Changes in ocean, wind and current patterns: El Niño. Sea level rise.
Changes in the cryosphere	Reduced snow cover – amount and duration. Glaciers: changes in extent and speed of movement. Land ice caps and ice sheets: changes in thickness and movements. Ice shelves: changes in the break-up of ice shelves and the impact on land ice movements. Sea ice: changes in thickness and area of sea ice cover.

Content	Additional information
Changes in climate processes	Precipitation changes: • amount, duration, timing and location • changes in proportions of rain and snow. Wind pattern changes: direction, velocity.
Difficulties monitoring and predicting climate change	Students should understand the limitations in the available data when attempting to predict future natural and anthropogenic climate change. They should be able to evaluate the reliability of existing information and discuss the methods that are used to fill gaps in current knowledge including remote sensing. Students should be able to discuss the importance of accurate, representative data in climate modelling. Uncertainty of ecological impacts of climate change: • changes in species survival caused by changes in abiotic factors • changes in species survival caused by changes in biotic factors • changes in species distribution • population fragmentation. Why there is uncertainty over the use of some data in drawing conclusions. • Lack of historical data: atmospheric composition, temperature, weather patterns. • Limited reliability of proxy data. • Lack of understanding of natural processes that control weather, ocean currents and their interconnections. • How understanding is improved by climate modelling. • Natural changes and fluctuations that mask changes caused by anthropogenic actions. • Time delay between cause and effect.

Content	Additional information
Feedback mechanisms and tipping points	Impact of negative feedback mechanisms caused by: • increased low-level cloud • increased photosynthesis. Impact of positive feedback mechanisms: • melting permafrost • ocean acidification • reduced albedo • melting methane hydrate • increased forest and peat fires • increased cirrus clouds • more rapid decomposition of dead organic matter in soil. The role of tipping points in climate change.
Carbon footprints and sustainable development	Students should compare the per capita carbon emissions and carbon footprints for different countries to evaluate different strategies to achieve sustainable development. How the control of greenhouse gases may help achieve sustainable lifestyles.

3.2.1.3 Ozone depletion

Students should consider the success of tackling ozone depletion and compare this with other environmental issues.

Content	Additional information
The study of ozone depletion should be used as an example of an environmental issue where all the stages of scientific investigation are present.	• Identification of an environmental issue. • Formulation of a hypothesis. • Collection, analysis and evaluation of data. • Proposal for solutions. • Enactment of solutions.

Content	Additional information
Rowland-Molina hypothesis	The properties of chlorofluorocarbons (CFCs) that lead to stratospheric ozone depletion. • Persistence of CFCs. • Dissociation by UV. • Reactions of chlorine with ozone. Effects of ozone depletion. Why increased UV(B) reaching the Earth's surface may cause problems: • human health • damage to plants • damage to marine organisms.
Collection, analysis and interpretation of data, an evaluation of data collection methods available and the reliability of data produced	The collection of data on ozone depletion: • ground-based data collection • aerial/satellite surveys • variability of results: spatial, temporal, altitude.
Why ozone depletion has been greatest over Antarctica	Unusual atmospheric conditions over Antarctica: • very low temperatures • ice crystals • stratospheric clouds • polar vortex winds.
The restoration of the ozone layer	Main features of the Montreal Protocol (on Substances that Deplete the Ozone Layer) (1987): • use of alternative processes • use of alternative materials • collection and disposal of CFCs and other ozone-depleting substances (ODSs).
Evaluation of the effectiveness of the methods used to restore the ozone layer compared with the effectiveness of tackling other atmospheric pollution problems	An analysis of the evidence for changes in area of ozone depletion, ozone concentrations and UV levels. A comparison with the effectiveness of tackling climate change.

3.2.1.4 Opportunities for skills development and independent thinking

Mathematical skill number	Opportunities for skills development and independent thinking
MS 0.2	Students could use standard form when dealing with carbon reservoir masses and transfer rates.
MS 1.3	Students could plot atmospheric carbon dioxide levels, atmospheric temperature and solar output over time represented on a graph.

Mathematical skill number	Opportunities for skills development and independent thinking
MS 1.4	Students could consider probability when assessing the various possible causes of climate change.
MS 1.10	Students could use standard deviation values to assess the significance of fluctuations in ozone levels over Antarctica.
MS 1.11	Students could calculate the percentage difference between estimated values and real outcomes from computer models of global climate change.
MS 2.2	Students could use and manipulate an equation to estimate carbon sequestration rates.
MS 3.1	Students could construct a flow diagram of carbon reservoirs and transfer processes in the carbon cycle.
MS 3.4	Students could use data on different scenarios of carbon emissions to predict a graph of atmospheric CO_2 concentration.

Working scientifically

Students could plan activities in a range of environmental contexts related to the atmosphere, including ones where first-hand experience of practical activities may not be possible.

Practical skill number	Opportunities for skills development and independent thinking
PS 1.2	Students could analyse the reliability of past data collected on ozone depletion.
PS 1.4	Students could plan how to collect representative data on changes in flow in the North Atlantic Conveyor. Students could plan how to collect data on UV levels in Antarctica to monitor the recovery of stratospheric ozone.
PS 2.1	Students could assess the reliability of using proxy data to monitor climate change.
PS 2.2	Students could assess uncertainties over predictions of sea ice loss, changes in atmospheric temperature and sea level rise.
PS 3.1	Students could construct graphs on changes in factors related to climate change: land ice volume, sea ice area, atmospheric CO_2 concentration.
PS 3.3	Students could assess degrees of uncertainty of data collected on climate change and predictions of changes that will occur in the future.

Opportunities to investigate the required methodologies of which students must have first hand experience. Further details can be found in Appendix A: Working scientifically (page 95)

Methodology skill number	Opportunities for skills development and independent thinking
Me 2	Students could plan the location of temperature sampling sites and timing to produce reliable data on climate change.

Methodology skill number	Opportunities for skills development and independent thinking
Me 6	Students could assess the variability of data on climate change and ozone depletion and the methods that can be used to assess statistical significance of differences.

3.2.2 The hydrosphere

3.2.2.1 The impact of unsustainable exploitation

Content	Additional information
Students should understand that the natural hydrological cycle is in a state of dynamic equilibrium. Human activities that alter the rates of processes in the hydrological cycle can lead to changes in residence times and quantities in the reservoirs of the cycle. Students should be able to use the technical terminology related to the hydrological cycle to discuss anthropogenic changes and strategies that may allow sustainable exploitation. Students should be able to explain how human activities change processes in the hydrological cycle. Students should be able to explain the consequences of changes in the hydrological cycle.	

3.2.2.2 Analysis and evaluation of strategies for sustainable management

Content	Additional information
Students should use examples of water resources that have been exploited unsustainably.	

3.2.2.3 Ocean currents: the importance of thermohaline circulation in distributing heat and regulating climate

Content	Additional information
Students should discuss the impacts of changes in thermohaline circulation on the climate of countries around the North Atlantic, including the UK.	

3.2.2.4 Increasing sustainability by treating contaminated water

Content	Additional information
The methods used to remove the following contaminants: • litter • suspended solids • some metals and odours • organic pollutants • salt • pathogens.	

3.2.2.5 Increasing sustainability by economical use and the exploitation of new sources

Content	Additional information
Management of water resources: • metering • low water-use appliances • greywater use • exploitation of new sources • rainwater catchment • new reservoirs/estuary barrages • unexploited aquifers • inter-basin transfers.	

3.2.2.6 Opportunities for skills development and independent thinking

Mathematical skill number	Opportunities for skills development and independent thinking
MS 0.1	Students could convert data and change the units used in transfer rates, volumes and residence times in the hydrological cycle.
MS 0.4	Students could estimate results to sense check that the calculated values are appopriate, such as when calculating residence times in different water reservoirs.
MS 1.2	Students could calculate the mean rate of water transfer between two water reservoirs.
MS 1.3	Students could interpret data relating to aquifer flow rates.
MS 1.6	Students could use data on changing transfer rates to calculate changes in the mean water content in an aquifer.
MS 1.7	Students could analyse a scatter graph of per capita water use against mean GDP to suggest reasons for different rates of water use.
MS 1.8	Students could compare storage volumes of natural water reservoirs and transfer rates.

Mathematical skill number	Opportunities for skills development and independent thinking
MS 3.1	Students could construct a flow diagram using data on processes and reservoir storage.
MS 3.6	Students could calculate the rate of infiltration through rocks with different permeabilities.

Working scientifically

Students could plan activities in a range of environmental contexts related to the hydrosphere, including ones where first hand experience of practical activities may not be possible.

Practical skill number	Opportunities for skills development and independent thinking
PS 1.2	Students could analyse data on deforestation and precipitation levels.
PS 1.4	Students could plan monitoring programmes for the salinization of aquifers.
PS 2.1	Students could analyse results of previous studies on catchment area changes and difficulties in producing representative data.

Methodology skill number	Opportunities for skills development and independent thinking
Me 5	Students could plan the timing of studies of fluctuating river and aquifer levels to produce reliable long-term trends.

3.2.3 Mineral resources

3.2.3.1 Minerals extracted from the lithosphere

Content	Additional information
The mineral resources extracted from the lithosphere are non-renewable as they are reformed too slowly to be replaced within timescales that would allow human use. Long-term use relies on an understanding of the scientific methods that will increase supplies, extend use and find alternatives for those in restricted supplies.	Students should understand the importance of resources extracted from the lithosphere on society. • Metals and metal ores. • Industrial minerals. • Construction materials.

3.2.3.2 Geological processes that produced localised concentrations of recoverable mineral deposits

Content	Additional information
Geological processes	• Hydrothermal deposition. • Metamorphic processes. • Proterozoic marine sediments. • Physical sediments. • Biological sediments.

3.2.3.3 Reserves and resource

Content	Additional information
The reserves include the amount of material that can be exploited using existing technology under current economic conditions. The resource includes all the material that could be exploited technically and economically now or in the future.	
Lasky's principle	As the linear purity of a deposit decreases, there is a logarithmic increase in the amount of the material that is included. The ability to exploit low-grade deposits results in a large increase in the reserves.

3.2.3.4 How a range of exploratory techniques work

Students should understand the methods that are used to discover the localised concentrations of deposits produced by geological processes.

Content	Additional information
Exploratory techniques	• Satellite imagery. • Seismic surveys. • Gravimetry. • Magnetometry. • Resistivity. • Trial drilling.

3.2.3.5 Factors affecting mine viability

Content	Additional information
For a mining operation to be viable, a wide range of geological and economic criteria must be met.	• Ore purity and cut-off ore grade. • Chemical form. • Associated geology: overburden, hydrology. • Economics: cut-off ore grade and mining costs.

3.2.3.6 Control of the environmental impacts of mineral exploitation

Content	Additional information
All mining activities impact on the environment, but good site management and post-mining restoration can minimise problems.	• Turbid drainage water. • Spoil. • Leachate neutralisation. • Site management. • Site restoration.

3.2.3.7 Strategies to secure future mineral supplies

Content	Additional information
As high-grade deposits become depleted, it is important to develop new technologies to find and extract new deposits, including low-grade and less accessible deposits. Manufactured products should be designed to minimise the amount of material needed and extend the lifetime of material use.	• Improvements in exploratory techniques including remote sensing. • Bioleaching with acidophilic bacteria. • Phytomining. • Cradle to Cradle design.

Table 1: Recycling

Content	Additional information
The advantages of recycling.	• Conservation of mineral resources. • Reduced energy use (of mineral extraction). • Reduced mineral extraction/processing impacts. • Reduced waste disposal impacts.
Difficulties with recycling schemes:	• Identification of materials. • Separation of mixed materials. • Reduction in quality. • Increased transport costs/impacts. • Collection difficulties. • Lack of consumer cooperation.

3.2.3.8 Opportunities for skills development and independent thinking

Mathematical skill number	Opportunities for skills development and independent thinking
MS 0.5	Students could estimate the impact of a change in cut-off ore grade on the abundance of mineral reserves using the exponential trend of Lasky's principle.
MS 1.1	Students could demonstrate understanding that calculated results can only be reported to the limits of the least accurate measurement, eg in estimating lifetimes of mineral reserves.
MS 1.7	Students could identify trends in mineral use from scatter diagrams of per capita use and mean GDP.
MS 1.8	Students could estimate the lifespan of reserves of a metal using data on per capita use, population size and current reserves.
MS 1.11	Students could identify the uncertainties of predictions in mineral reserves using trends in population, per capita use and improvements in extraction technology.

Working scientifically

Practical skill number	Opportunities for skills development and independent thinking
PS 1.2	Students could analyse trial core survey data to assess mine viability.
PS 3.2	Analyse metal ion concentration data in a mining area to identify the sources of contamination.
	Students could plan activities in a range of environmental contexts related to the lithosphere, including ones where first-hand experience of practical activities may not be possible.

Methodology skill number	Opportunities for skills development and independent thinking
Me 3	Students could plan a grid survey for trial drilling to assess the optimum distance between drilling sites.

3.2.4 Biogeochemical cycles

3.2.4.1 The importance of biogeochemical cycles for living organisms

Content	Additional information
Many elements have low availability to living organisms. Biogeochemical cycles involve inter-linked processes that allow materials to be recycled and repeatedly re-used.	

3.2.4.2 The carbon cycle including human influences

Content	Additional information
The processes in the carbon cycle that are affected by human activities	• Photosynthesis. • Aerobic respiration. • Anaerobic respiration. • Combustion. • CO_2 dissolving in the sea/exsolving from the sea. • Biomass movements. • Changes in carbon reservoirs. • Increased atmospheric concentration of CO_2. • Less soil dead organic matter. • Increased concentrations of dissolved CO_2, carbonic acid, hydrogen carbonate ions. • Increased atmospheric concentration of methane. • Reduced amount of carbon in plant biomass. • Reduced amount of carbon in fossil fuels.
Sustainable management of the carbon cycle: methods of counteracting human activities that alter the natural equilibria of the carbon cycle	• Alternatives to fossil fuel use. • Carbon sequestration. • Carbon Capture and Storage (CCS). • Matching afforestation to deforestation. • Increasing soil organic matter. • Conservation of peat bogs.

3.2.4.3 The nitrogen cycle including human influences

Content	Additional information
The processes in the nitrogen cycle that are affected by human activities	• The Haber Process fixing nitrogen in ammonia, mainly to produce agricultural fertilisers. • Land drainage increases nitrogen fixation and reduces denitrification. • The growth of legume crops increases nitrogen fixation in plant proteins. • Sewage disposal increases nitrate movements to rivers and the sea, together with phosphates, causes eutrophication. • Combustion processes cause nitrogen and oxygen to react, producing oxides of nitrogen. • Decomposition and ammonification affected by organic waste disposal policies.

Content	Additional information
Consequences of changes in nitrogen reservoirs: • eutrophication • global climate change • NO_x toxicity • photochemical smogs.	
Sustainable management of the nitrogen cycle and methods of counteracting human activities that alter the natural equilibria of the nitrogen cycle	Methods of counteracting anthropogenic nitrogen movements: • reduced combustion processes • use of natural nitrogen fixation processes instead of the Haber process • management of biological wastes • methods of reducing soil nitrate leaching.

3.2.4.4 The phosphorus cycle including human influences

Content	Additional information
The processes in the phosphorus cycle that are affected by human activities	Phosphorus compounds are mobilised in more soluble forms for use in agricultural fertilisers. Eutrophication is caused by nutrient enrichment of water bodies, combined with the effect of nitrates.
Sustainable management of the phosphorus cycle and methods of counteracting human activities that alter the natural equilibria of the phosphorus cycle	The lack of abundant reservoirs of phosphates in the atmosphere or hydrosphere is often the limiting factor on biological productivity: • the use of biological wastes as fertilisers • breeding of crops that absorb phosphates more efficiently • providing suitable conditions for soil mycorrhizal fungi increases phosphate uptake combustion processes.

3.2.4.5 Opportunities for skills development and independent thinking

Mathematical skill number	Opportunities for skills development and independent thinking
MS 0.1	Students could convert values and units used in transfer rates, reservoir mass and residence time in the nitrogen cycle.
MS 0.2	Students could convert numbers in standard and ordinary form when using masses in biogeochemical cycles.
MS 2.2	Students could use and manipulate equations of nutrient transfer rates.

Mathematical skill number	Opportunities for skills development and independent thinking
MS 3.1	Students could use data on reservoirs and transfer processes to construct a flow diagram of the nitrogen or phosphorus cycle.

3.2.5 Soils

3.2.5.1 How human activities affect soil fertility

Content	Additional information
Activities that control soil conditions and affect fertility: • aeration of soil by ploughing and drainage • addition of soil nutrients • irrigation • soil compaction, increasing bulk density • pH control.	

3.2.5.2 Causes of soil degradation and erosion

Content	Additional information
Types of soil erosion: • rain splash • wind blow • surface runoff.	
Natural features that reduce erosion: • vegetation • soil organic matter • high infiltration rate.	
The Universal Soil Loss Equation (USLE) can be used to estimate erosion rates.	

Content	Additional information
Human activities that cause soil erosion and degradation: • ploughing vulnerable soils • vegetation removal • overgrazing • reducing soil organic matter • reducing soil biota • cultivating steep slopes • soil compaction by machinery or trampling.	
The environmental impacts of soil erosion: • reduced productivity • sedimentation in rivers and reservoirs • downstream flooding • coastal sedimentation • increased atmospheric particulates • desertification • landslides.	

3.2.5.3 Soil management strategies to increase sustainability

Content	Additional information
Methods that can be used to reduce soil erosion: • long-term crops • contour ploughing • tied ridging • terracing • windbreaks • multicropping • strip cropping • mulching • increasing soil organic matter.	

3.2.5.4 Opportunities for skills development and independent thinking

Mathematical skill number	Opportunities for skills development and independent thinking
MS 0.3	Students could use data on mass and mass change during heating to estimate the percentage water and organic matter composition of soil.
MS 1.1	Students could demonstrate appropriate numbers of significant figures in calculations of soil water and organic matter content.

Mathematical skill number	Opportunities for skills development and independent thinking
MS 2.4	Students could use the Universal Soil Loss Equation to assess the effectiveness of soil conservation programmes.
MS 3.2	Students could demonstrate their ability to use data presented in a number of formats and be able to use these data, eg soil erosion rates presented in graphs, tables and formulae.

Working scientifically

Students could plan activities to investigate environmental issues which they could carry out eg:

- the impact of soil texture on soil water content
- the impact of soil water content on organic matter levels
- the effect of slope on rain splash soil erosion
- the effect of vegetation cover on rain splash erosion
- the impact of soil compaction on soil water levels.

Students could plan activities in a range of broader environmental contexts related to soils, including ones where first hand experience of practical activities may not be possible eg: the effect of soil erosion on downstream ecosystems.

Practical skill number	Opportunities for skills development and independent thinking
PS 1.1	Students could plan a strategy to monitor and reduce soil erosion, within the context of global food supply problems.
PS 4.1	The practical skills of using equipment within scientific studies are expanded, as appropriate, in detail in the selected methodologies and sampling techniques below.

Opportunities to investigate the required methodologies of which students must have first hand experience. Further details can be found in Appendix A: Working scientifically (page 95)

Methodology skill number	Opportunities for skills development and independent thinking
Me 2	Students could mark out a transect across a field to investigate changes in edaphic factors down a slope or away from a hedge/field margin.
Me 3	Students could calculate mean values of selected factor, eg water content, to find the number of samples required to calculate a reliable mean.

Opportunities to investigate the required sampling techniques of which students must have first hand experience. Further details can be found in Appendix A: Working scientifically (page 95)

Sampling technique skill number	Opportunities for skills development and independent thinking
ST 1	Students could investigate the effect of a hedgerow on the downwind wind velocity, in the context of soil erosion.

Sampling technique skill number	Opportunities for skills development and independent thinking
ST 3	Students could compare the water and organic matter contents of soil from fields with different long-term management systems. Students could use sedimentation or soil sieves to compare the textures of soils from areas with different bedrocks.

3.3 Energy resources

The importance of energy resources in both past and future developments in society should be analysed. The impact of future energy supply problems should be evaluated.

Students should understand how improvements in technology can provide increasing amounts of energy from sustainable sources.

Quantitative data should be used to compare and evaluate new and existing technologies.

3.3.1 The importance of energy supplies in the development of society

Content	Additional information
Agriculture	How increased mechanization has increased productivity.
Fishing	How energy has increased catches and made processing easier.
Industry	How energy allows the extraction and processing of materials. The role of energy in service industries.
Water supplies	How energy is used to treat water for use and clean waste water from industrial or domestic use.
Transport	The use of energy in transport systems.
Domestic life	The role of energy in improved material living standards.

3.3.2 The impact of the features of energy resources on their use

Students should understand that each energy resource has its own features which make it applicable to particular uses. Technologies in current use often developed to match them to the available energy resources. New energy technologies may need additional technologies to be fully usable, eg storage.

Content	Additional information
Features of energy resources	• Abundance. • Energy density. • Locational constraints. • Intermittency. • Need for energy conversions to produce point-of-use energy. Quantitative data should be used to compare different energy resources and evaluate the potential for energy resources in the future.

3.3.3 The sustainability of current energy resource exploitation

Content	Additional information
Impact of resource exploitation before the use of the energy: • fuel extraction: coal mines, oil extraction • fuel processing: coal, crude oil • equipment manufacture: all energy resources • site development/operation: all energy resources • transport: combustible fuels • embodied energy in equipment: all energy resources.	
Impact as a consequence of use.	Pollution: • atmospheric pollution caused by fossil fuels • oil pollution • radioactive waste • noise pollution: wind power • thermal pollution: steam trubine power stations.
Habitat damag.e	• Fuel extraction. • Power station and equipment location. • Ecological impacts of tidal power schemes. • Ecological impacts of HEP schemes. • Pipelines and cables.
Depletion of reserves.	Non-renewable energy resources.

3.3.4 Strategies to secure future energy supplies

Students should analyse and evaluate key issues and quantitative data to evaluate the potential future contribution of each energy resource.

3.3.4.1 Evaluation of improved extraction/harnessing/processing technologies related to a range of energy technologies

Students should understand how specific technologies increase the usability of each energy resource.

Content	Additional information
Fossil fuels	• Secondary/tertiary recovery of oil, directional drilling. • Oil shales/Tar sands. • Carbon Capture and Storage (CCS). • Hydraulic fracturing. • Coal gasification. • Coal liquifaction. • Methane hydrates from marine sediments.
Nuclear power: fission and fusion.	Fission: • improved uranium extraction techniques • plutonium reactors • thorium reactors.
Fusion as a research technology: • toroidal reactors • laser fusion.	
Renewable energy technologies.	Solar power: • photothermal solar power • heat pumps • photovoltaic solar power • multi-junction photovoltaic cells • anti-reflective surfaces • Concentrating Solar Power (CSP).
HEP: • low head turbines • helical turbines.	
Wind power: • new Horizontal Axis Wind Turbines (HAWT) • new Vertical Axis Wind Turbines (VAWT) • wind-assisted ships.	
Wave power: new developments in wave power technology.	

Content	Additional information
Biofuels: • biofuel crops • hydrogen from algae • biofuels from microorganisms.	
Geothermal power: • low temperature fluids • district heating systems.	
Tidal power: • tidal barrages • tidal lagoons • in-stream turbines.	
Fluctuations in energy supply and demand, and new energy storage systems.	Students should evaluate the importance of energy storage in the use of the available energy resources and energy forms. The development of new energy storage methods will allow more effective peak-shaving to match fluctuating supplies to fluctuating demand.
Causes of fluctuations in energy supply.	The use of intermittent energy resources.
Causes of fluctuations in energy demand.	• Weather-related fluctuations. • Seasonal fluctuations. • Weekday/weekend fluctuations. • 24 hr work fluctuations. • Short-term fluctuations: mealtimes/TV ‘pickup’.
Developments in energy storage technologies.	• Peak shaving using Pumped-Storage HEP. • Rechargeable batteries. • Fuel cells. • Compressed gas. • Thermal storage. • Vehicle to grid systems (V2G). • Power to grid systems (P2G). • The ‘hydrogen economy’.

3.3.4.2 New energy conservation technologies

Content	Additional information
Improvements in the efficiency of energy use enable the same activities to be carried out with less energy.	

3.3.4.2.1 Transport energy conservation

Content	Additional information
Vehicle design for use	• Aerodynamics/hydrodynamics. • Low mass. • Tyre/wheel design. • Kinetic Energy Recovery System (KERS)/ regenerative braking. • Use of low embodied energy materials. • Bulk transport systems.
Transport infrastructure and management systems	• Integrated transport systems road/rail/cycle. • Active Traffic Management (ATM)/'Smart motorways'.
Vehicle design for end of life	• Use of recyclable materials. • Easier component identification. • Easy dismantling/material separation.

3.3.4.2.2 Building energy conservation

Content	Additional information
Building design	• Orientation/features for passive solar gains. • Low surface area: volume ratio. • High thermal mass materials.
Use of materials/construction methods with low embodied energy	• Low embodied energy materials, eg rammed earth, limecrete, straw. • Earth-sheltered buildings.
Use of materials with low thermal conductivity/transmittance	• Double/triple glazing. • Low emissivity glass. • Vacuum/inert gas double/triple glazing. • Wall/floor/roof insulation.
Energy management technologies	• Occupancy sensors. • Improved insulation. • Automatic/solar ventilation. • Heat exchangers.
Low energy appliances	• Lighting: CFL, LED. • 'Low-energy' white goods.

3.3.4.2.3 Industrial energy conservation

Content	Additional information
Heat management	• Bulk storage of hot fluids. • Use of heat exchangers. • Combined Heat and Power (CHP) systems.
Electricity infrastructure management	• High voltage grid. • Peak shaving/pumped storage HEP. • The use of ICT to co-ordinate data on electricity supply and demand and plan supply changes. • Locational factors affecting the development of new generating infrastructure.

3.3.5 Opportunities for skills development and independent thinking

Mathematical skill number	Opportunities for skills development and independent thinking
MS 0.1	Students could convert between joules, watts, kWh and MWh when carrying out calculations.
MS 0.2	Students could carry out calculations using numbers in standard and ordinary form, eg when comparing production of different energy resources.
MS 0.3	Students could calculate surface area to volume ratios and relate this to heat loss.
MS 0.5	Students could use V^3 in wind power calculations.
MS 1.2	Students could find the mean of a range of data, eg mean power output of a wind farm.
MS 1.3	Students could represent a range of data in a table with clear headings, units and consistent decimal places, eg to compare the energy density, production cost, carbon intensity and mean load factor for a range of energy resources.
MS 1.3	Students could interpret data from a variety of graphs, eg change in electricity cost from renewable energy sources, industrial output and level of financial incentives/tax over a number of years.
MS 1.7	Students could construct a scatter graph of per capita energy use and mean GDP.
MS 1.8	Students could calculate national energy use from population and individual use data.
MS2.2	Students could use and manipulate equations, eg energy conversion efficiences.
MS 2.3	Students could use data on wind velocities in the formula used to calculate kinetic energy avaliable to an aerogenerator.

Mathematical skill number	Opportunities for skills development and independent thinking
MS 2.4	Students could calculate the power outputs of HEP stations with different flow rates and head of water.
MS 3.1	Students could construct a Sankey diagram to represent energy resources, uses and efficiency for a country. Students could construct a radar diagram to show variations in wind direction.
MS 3.4	Students could predict/sketch the shape of a graph with a linear relationship, eg the relationship between isolation and solar panel output.
MS 3.7	Students could use a tangent to measure the gradient of a point on a curve, eg rate of heat loss through double glazing with varying gaps.
MS 4.1	Students could calcuate the surface area and volume of cylinders or spheres, eg to estimate rates of heat loss in energy conservation programmes.

Working scientifically

Students could plan activities to investigate environmental issues related to energy which they could carry out eg:

- the effect of climatic variability on the use of solar or wind power
- the cost-effectiveness of increasing thicknesses of thermal insulation
- students could compare the energy input and light output of a range of light bulb types to investigate efficiency and cost-effectiveness.

Students could plan activities in a range of broader environmental contexts related to energy, including ones where first-hand experience of practical activities may not be possible eg: students could plan a study to investigate the cost-effectiveness of different double glazing systems.

Practical skill number	Opportunities for skills development and independent thinking
PS 1.2	Students could analyse historical and current data to suggest how building energy efficiency could be improved most effectively.
PS 3.1	Students could plot and interpret graphs on the energy intensity of domestic products to assess improvements in energy efficiency.
PS 4.1	The practical skills of using equipment within scientific studies are expanded, as appropriate, in detail in the selected methodologies and sampling techniques below.

Opportunities to investigate the required methodologies of which students must have first hand experience. Further details can be found in Appendix A: Working scientifically (page 95)

Methodology skill number	Opportunities for skills development and independent thinking
Me 2	Students could use a grid of sample sites and collect data on wind velocities to select the optimum location for a wind turbine.

Methodology skill number	Opportunities for skills development and independent thinking
Me 5	Students could measure insolation levels at a standard time of day to assess the impact of variability on the practicality of solar power.
Me 6	Students could use secondary data on wave heights collected over time and the t-test to select the best site for harnessing wave power. Data variability could be assessed using standard deviation.

Opportunities to investigate the required sampling techniques of which students must have first hand experience. Further details can be found in Appendix A: Working scientifically

Sampling technique skill number	Opportunities for skills development and independent thinking
ST 1	Students could measure changes in temperature in thermal stores with different heat capacities. Students could measure variations in wind velocities in selected locations or over time. Students could use a light meter and parabolic reflector to investigate the effect of cloud cover on light intensity and the limitations of CSP in cloudy conditions.

3.4 Pollution

Students should understand how the properties of materials and energy forms interact to result in environmental change. They should apply this knowledge to suggest solutions to minimise current pollution problems and prevent future problems. Students should apply their understanding through a range of different historic and contemporary pollution events.

3.4.1 The properties of pollutants

Students should consider how the properties of pollutants affect behavior in the environment, their harmful impacts and the strategies that can be used to minimise problems.

Content	Additional information
Pollutant properties	• State of matter: solid/liquid/gas. • Energy form. • Density. • Persistence/degradability. • Toxicity. • Reactivity. • Adsorption. • Solubility in lipids/water. • Bioaccumulation. • Bomagnification. • Synergism. • Mutagenic action. • Carcinogenic action. • Teratogenic action.

3.4.2 How environmental features affect the severity of pollution

Students should use examples to explain how environmental features affect the behavior of pollutants and the severity of pollution caused.

3.4.2.1 Factors that affect dispersal

Students should understand the effect of point and diffuse sources on the dispersal and concentration of pollutants.

Content	Additional information
Air currents: • velocity • direction.	
Water currents: • velocity • direction.	

3.4.2.2 Environmental factors that affect rates of degradation

Students should understand how environmental features can affect the chemical changes to pollutants, including the changes that convert primary pollutants to secondary pollutants.

Content	Additional information
Temperature	The rate of decomposition of sewage.
Light	The role of light in: • photochemical smogs • degradation of pesticides.

Content	Additional information
Oxygen	Aerobic decay of organic wastes.
pH	Neutralisation of acids by basic/alkaline rocks.
The presence of other chemicals	The role of oxidation by ozone in producing secondary pollutants.
Temperature inversions	The role of temperature inversions in the dispersal of atmospheric pollutants.
The presence of adsorbent materials	The adsorption of toxic metal ions on clay particles.

3.4.3 Strategies to control pollutants based on their properties and features of the environment

3.4.3.1 Principles of control

Content	Additional information
Critical Pathway Analysis: to predict pollutant mobility and inform monitoring programmes	Application to monitoring discharges of pollutants such as radioactive materials, heavy metals and persistent organic pollutants eg chlorinated organic compounds.
Critical Group Monitoring: to identify members of the public most at risk	Application to monitoring the health risks caused by pollutants such as radioactive discharges and heavy metals.
Emission location	Increased concentrations in valleys, enclosed water bodies.
Emission timing	Restriction of activities during temperature inversions.

3.4.3.2 Selection of control technologies: to reduce production, reduce release and mitigate damage caused

Students should consider the following pollutants to identify their properties to analyse their environmental impacts and to plan control strategies

Students should understand the properties of pollutants and environmental features so they can analyse and evaluate the changes in human activities and strategies that can be used to minimize pollution.

3.4.3.2.1 Smoke/PM10 (Particulate matter less than 10 microns in diameter)

Content	Additional information
Sources	Incomplete combustion of coal, diesel, wood, crop waste.

Content	Additional information
Impacts	• Respiratory disease. • Increased albedo of atmosphere. • Smoke smogs during temperature inversions.
Controls	• Legislation: Clean Air Act (1956). • Coal treatment: heating to remove tar. • Electrostatic precipitators. • Cyclone separators. • Bag filters.

3.4.3.2.2 Acid precipitation

Content	Additional information
Primary and secondary pollutants: • SO_x: sulfurous and sulfuric acids • NO_x: nitric acid • ozone involved in production of secondary pollutants.	
Sources	• Combustion of fossil fuels. • Smelting of sulphide ores.
Impacts	• Non-living objects: damage to limestone buildings, metal structures. • Living organisms. • Direct effects of acids. • Damage to proteins. • Damage to exoskeletons. • Respiratory effects in humans.
Controls	SO_x: • fuel desulfurization • Flue Gas Desulfurization (FGD) wet FGD and dry FGD. NO_x: • catalytic converters • urea sprays. Ozone: control of NO_x reduces ozone formation.

3.4.3.2.3 Oxides of nitrogen (NO_x)

Content	Additional information
Sources	• Reaction of nitrogen and oxygen in hot combustion processes. • NO_x release due to fertiliser use.
Effects	• Photochemical smogs. • Global climate change.
Controls	• Catalytic converters. • Urea sprays. • Control of fertilizer use.

3.4.3.2.4 Hydrocarbons

Content	Additional information
Sources	• Unburnt hydrocarbon fuels. • Gaseous emissions from fossil fuel exploitation. • Solvents. • Aerosol propellants.
Effects	• Greenhouse gases. • Photochemical smogs.
Controls	• Catalytic converters. • Improved combustion efficiency. • Vapour collection and incineration. • Activated carbon filters.

3.4.3.2.5 Carbon monoxide

Content	Additional information
Source	Incomplete combustion of hydrocarbons.
Effect	If inhaled reduced carriage of oxygen by haemoglobin.
Controls	• Catalytic converters. • Improved combustion efficiency.

3.4.3.2.6 Thermal pollution

Content	Additional information
Scientific principles	The relationship between temperature and maximum dissolved oxygen level.

Content	Additional information
Source	Hot water from steam turbine power station condensers.
Effect	Deoxygenation of water.
Control	Temperature reduction using cooling towers.

3.4.3.2.7 Oil pollution

Content	Additional information
Sources	• Waste lubricating oil. • Ship tank washing. • Ship tanker accidents. • Other ship accidents. • Oil refinery spills. • Pipeline leaks. • Leakage during drilling.
Effects	• Toxicity. • Asphyxiation. • Loss of insulation. • Less time to feed young. • Foodchain effects.

Controls	• Recycling of waste oil.
	• Reduced leakage: equipment maintenance.
	• Bund walls.
	• Ship tanker design.
	• Double hulls.
	• Twin engines/rudders.
	• Ship tanker operation:
	  • inert gas oil tank systems
	  • recirculation of washing water
	  • improved navigation systems eg GPS
	  • offshore shipping routes
	  • oil interceptors
	  • oil spill clean-up:
	    • inflatable booms
	    • skimmers
	    • absorbent materials
	    • polymerising materials
	    • dispersants
	    • steam cleaning
	    • bioremediation.

3.4.3.2.8 Pesticides

Content	Additional information
Examples of different pesticide groups should be used to illustrate the main pollutant properties:	• Toxicity. • Systemic/contact action. • Specificity. • Persistence. • Liposolubility. • Bioaccumulation. • Biomagnification. • Mobility. • Synergism.
Effects	• Direct toxic impacts on non-target species. • Toxic impacts after increased concentration. • Indirect effects: food chain impacts, loss of inter-species relationships.
Control	Restrictions on use of selected pesticides, eg organochlorines, organophosphates.

3.4.3.2.9 Nutrient pollution

Inorganic nutrients: nitrates and phosphates

Content	Additional information
Source	Nitrates (leachate/runoff) and phosphates (sewage effluent).
Effect	Eutrophication (combined effects of nitrates and phosphates).
Nitrates and human health	• Methaemoglobinaemia/blue baby syndrome. • Possible human carcinogen.
Controls	Nitrates: • use of low solubility fertilisers • nitrate vulnerable zones. Phosphates: iron phosphate precipitation.

Organic nutrient pollutants

Content	Additional information
Sources	Organic wastes (sewage, manure, silage fluids, effluent from processing of wood and paper).
Effect	Deoxygenation caused by microbial aerobic decomposition.

Content	Additional information

Controls	The major stages in treatment of organic wastes:
	• pre-treatment:
	  • grit traps, screens.
	• primary treatment
	  • primary sedimentation
	• secondary treatment
	  • aerobic bacterial decomposition: activated sludge/filter beds
	  • secondary sedimentation.
	• tertiary treatment
	  • phosphate removal
	  • bacterial microfilters.
	• anaerobic sludge digestion.

3.4.3.2.10 Acid mine drainage

Content	Additional information
Sources	• Oxidation of sulfide ores in mine spoil/rocks. • Drainage water/leachate.
Effects	• Reduced pH – acid damage. • Increased solubility and mobilisation of toxic metals.
Control	Collection of drainage water and neutralization with lime.

3.4.3.2.11 Heavy metals

Content	Additional information
The properties of heavy metals should be analysed to understand why they have caused pollution problems and the strategies used to prevent pollution.	

Lead

Content	Additional information
Properties	• Neurotoxicity. • Liposolubility. • Bioaccumulation. • Biomagnification.

Content	Additional information
Controls	• Discontinued uses, eg paint, petrol additives, lead pipes, solder for water pipes, lead fishing weights. • Waste storage at high pH to reduce solubility.

Mercury

Content	Additional information
Properties	• Neurotoxicity. • Liposolubility. • Bioaccumulation. • Biomagnification.
The effect of chemical form on pollutant toxicity	• Elemental mercury. • Inorganic mercury. • Organic mercury.

3.4.3.2.12 Solid wastes

Content	Additional information
Students should understand that the treatment method for solid wastes depends upon its properties. The methods appropriate for each waste type should be analysed.	
Domestic wastes	The advantages and disadvantages of the treatment options should be evaluated: • landfill • incineration • recycling • composting.
Specialist solid wastes	Solid wastes with particular risks should be separated and treated individually.
Radioactive waste	The sources and properties of the three waste categories should be understood to identify appropriate disposal methods: • high-level waste • intermediate-level waste • low-level waste. The need for sealed storage, monitoring, encapsulation, use of absorbers and cooling should be evaluated for each waste level.

Content	Additional information
Asbestos	Secure, permanent, sealed storage.
Cyanide	Incineration.

3.4.3.2.13 Noise

Content	Additional information
The scientific principles of sound that affect noise pollution: • frequency range of human hearing • logarithmic nature of the dB scale • volume threshold of human hearing.	
The effects of noise on non-living objects: • acoustic fatigue • shock impacts.	

The effects of noise on living organisms:
• Humans:
  • hearing damage
  • stress, ulcers, heart disease
  • behavioural changes.	

Other organisims: • livestock injuries • disturbance of breeding birds • reduced feeding success: bats, owls, dolphins • hearing damage/behavioural changes: cetaceans.	

The sources and control of noise

Students should be able to explain how different control methods can be used to control noise in a wide range of situations.

Aircraft noise

Content	Additional information
Sources	• Engine noise, especially at high thrust. • Air turbulence.

Content	Additional information
Controls	Airport design and location: • location away from major population centres • taxi areas away from residential areas • provision of acoustic insulation • land-use restrictions • baffle mounds/acoustic insulation. Aircraft design: • engine designs to reduce noise emissions • aerodynamic surfaces. Airport operation: • the use of airport take-off and landing noise footprints in planning mitigation programmes • flight paths avoid urban areas • altitude restrictions • constant descent angle • night flight restrictions • noisy aircraft banned • fines for excessive noise • engine test restrictions • reduced use of reverse thrusters.

Railway noise

Content	Additional information
Sources and controls	• Wheel vibration – track polishing, sound absorbing ballast. • Engine noise – sound absorbing suspension. • Pantograph turbulence – aerodynamic fairing. • Wheel squeal on corners – lubrication of wheels/track. • Braking squeal – use of composite material brakes.

Road traffic noise

Content	Additional information
Sources and controls	• Wheel vibration/tyre noise – sound absorbing road surface, acoustic fences. • Engine noise – acoustic insulation. • Air turbulence – improved aerodynamics.

Industrial noise

Content	Additional information
Sources	• Air compressors. • Pile drivers, stamping machines. • Drills. • Mine blasting, military sonar.
Controls	• Worker ear protection/remote operation. • Acoustic insulation/mats/baffle mounds. • Restrictions on timing of operations. • Alternative procedures, eg pressing instead of stamping. • Drilling instead of pile-driving.

Domestic noise

Content	Additional information
Sources	• Appliances – acoustic insulation. • Music – volume limiters.

3.4.3.2.14 Ionising radiation

Content	Additional information
Uses	• Nuclear weapons. • Nuclear electricity. • Ship propulsion. • Manufacturing industry. • Healthcare. • Agriculture.
Scientific principles	• Half-life and health risk. • Type of radiation and health risk: Relative Biological Effectiveness (RBE). • Exposure vs contamination. • Activation products. • Units: Becquerels, Grays, Sieverts.
Effects	• Free radical production, DNA damage. • Acute and chronic effects. • Somatic and gonadic effects.
Control of exposure to radioactive materials.	

Content	Additional information
Principles of control	• Exposure should be: As Low As Reasonably Achievable (ALARA). • Equipment should be: Best Available Technology Not Entailing Excessive Cost (BATNEEC). • The use of Risk:Benefit analysis.
Controls	• Closed sources to prevent contamination. • Radiation absorbers. • Distance from source: the inverse square law. • Reduced period of exposure. • Worker monitoring at work/on leaving work.
Radioactive waste management (see specialist solid wastes)	• High-level waste. • Intermediate-level waste. • Low-level waste.
The principles of environmental monitoring	Critical Pathway Analysis (CPA), involves identifying the most likely route a material will take, based on its properties and features of the environment, eg: • wind and water current velocity and direction • geology and hydrology • food chain pathways. Environmental sampling: • atmospheric dust • soil • water • seaweeds, molluscs, fish • milk, vegetables, meat. Critical Group Monitoring (CGM). CGM involves identifying those members of the public who, because of their lifestyles, are most at risk. They are monitored. If they are safe, everyone else should be safe too.

3.4.3.3 The use of scientific knowledge to develop new pollution control technologies

Students should understand that a wide range of new technologies is available to provide better control of pollution.

Content	Additional information
Control technologies	• Methods to prevent pollutant release. • Monitoring impacts. • Treating contaminated areas by leachate collection. • Satellite monitoring of oil spills. • GPS ship tracking to monitor navigation and reduce accidents. • Adsorption of heavy metals using polymers. • Phytoremediation of land contaminated with heavy metals. • Bioremediation of hydrocarbon spills.

3.4.4 Opportunities for skills development and independent thinking

Mathematical skill number	Opportunities for skills development and independent thinking
MS 0.3	Students could calculate percentage yields, eg in pollution control.
MS 0.5	Students could use a calulator to find and use logarithmic values for noise levels.
MS 1.4	Students could use the term probability appropriately when investigating casual relationships such as the link between human health problems and urban pollutants.
MS 1.5	Students could analyse data collected using random or systematic sampling, eg Simpson's index of diversity to compare the biodiversity of habitats exposed to different pollution types.
MS 1.9	Students could use the chi-squared test to assess the impacts of different pesticides on non-target insect species.
MS 1.10	Students could calculate the standard deviation of tropospheric ozone levels in a city.
MS 2.5	Students could convert between the logarithmic dB scale and linear scales of relative sound pressure.
MS 3.1	Students could interpret a 3-D graph of fish mortality at different concentrations of a toxic metal and different pHs.
MS 3.2	Students could demonstrate their understanding that data may be presented in a number of formats and be able to use these data, eg dissolved oxygen levels expressed numerically as percentage saturation or mg l^{-1} and in table or graphical form.
MS 3.3	Students could select an apppropriate format for presenting data, bar charts, histograms, graphs and scatter graphs, eg organic matter and oxygen depletion in water.
MS 3.5	Students could read the intercept point from a graph to find the temperature at which oxygen levels fall too low to support particular aquatic species.

Mathematical skill number	Opportunities for skills development and independent thinking
MS 3.6	Students could calculate rates of temperature change with altitude in the atmosphere, in the context of photochemical smogs.

Working scientifically

Students could plan activities to investigate environmental issues related to pollution which they could carry out eg:

- students could monitor atmospheric pollution using a lichen biotic index at different distances downwind of an urban centre
- students could monitor water pollution at different locations using an aquatic invertebrate biotic index
- students could measure the effect of inorganic nutrient concentration on the growth of algae.

Students could plan activities in a range of broader environmental contexts related to pollution, including ones where first hand experience of practical activities may not be possible eg:

- students could plan a study to collect the information needed for a Critical Pathway Analysis around a pollutant source
- students could plan a study to investigate the impact of a new potential pollutant on long-term human health.

Practical skill number	Opportunities for skills development and independent thinking
PS 1.2	Students could assess the information needed to construct a Critical Pathway Analysis: • wind direction and velocity patterns • precipitation patterns • impact of geology on movements • impact of hydrology on movements • biota.
PS 1.3	Students could identify the properties that may be important in predicting problems that may be caused by a new industrial waste.
PS 4.1	The practical skills of using equipment within scientific studies are expanded, as appropriate, in detail in the selected methodologies and sampling techniques below.

Opportunities to investigate the required methodologies of which students must have first hand experience. Further details can be found in Appendix A: Working scientifically

Methodology skill number	Opportunities for skills development and independent thinking
Me 2	Students could use a transect to measure noise levels with increasing distance from a road.
Me 5	Students could investigate the effect of sample timing on noise levels near a road.

Opportunities to investigate the required sampling techniques of which students must have first hand experience. Further details can be found in Appendix A: Working scientifically

Sampling technique skill number	Opportunities for skills development and independent thinking
ST 1	Students could measure nitrate and phosphate levels to monitor water pollution in different locations.
ST 2	Students could use an appropriate quadrat to measure percentage cover and species present to monitor atmospheric pollution.
ST 6	Students could use pond nets, kick sampling or surber samplers to collect samples for biotic index analysis.

3.5 Biological resources

Students must develop an understanding of the challenge posed by the need to provide food and forest resources for a growing human population without damaging the planet's life support systems. The interaction of the production of biological resources with other areas of the subject should be emphasised, including with conservation of biodiversity, energy resources, pollution and the physical environment.

3.5.1 Agriculture

Students should understand that agriculture involves the control of food webs to divert photosynthetic energy into human food. This involves the control of abiotic and biotic factors to maximise production.

3.5.1.1 Agroecosystems

Content	Additional information
The selection of species Suitability of the environment: • temperature • light: intensity, day length • water availability • soil fertility • topography • relief • pest problems.	

Technological factors:
• availability of energy
• pesticides
• machinery/equipment
  • irrigation
  • transport infrastructure.	

Content	Additional information
The biotic factors that affect productivity. Pest control: predators, competitors, pathogens, eg insects, fungi, weeds, bacteria.	
Cultural pest control: • crop rotation/cultivation management • barrier crops • companion crops • predator habitats • biological control: introduced predators/pathogens • sterile male techniques • pheromone traps • genetic resistance.	
Pesticides	How the properties of pesticides influence their effectiveness and environmental impacts: • toxicity • specificity • persistence • solubility in water/lipids • mode of action: contact/systemic. A comparison of insecticide groups to consider their relative advantages and disadvantages: • organochlorines • organophosphates • pyrethroids • neonicotinoids.
Antibiotics: • as growth promoters • to prevent infection • to treat infections.	
Pollinators: • controlled use of pesticides that harm bees and other pollinators • introduction of bee hives to flowering crops.	
Nutrient supply: maintenance of soil biota: detritivores and decomposers.	

Content	Additional information
Food chain energy losses: • control movement • temperature control • species selection: different food conversion ratios (FCRs).	
The abiotic factors that affect productivity	Abiotic factors controlled in agroecosystems: • temperature • light: intensity, day length • water availability • nutrient supply • topography • relief • pH • carbon dioxide • soil fertility • soil salinity.

3.5.1.2 Manipulation of food species to increase productivity: the advantages and disadvantages of the methods that are available to improve crop and livestock gene pools

Content	Additional information
Genetic manipulation: • selective breeding • asexual reproduction/vegetative propogation/cloning • genetic engineering/transgenics/GM.	
Agricultural energetics The ways in which agricultural energetics can be quantified and their applications: • productivity • efficiency • intensive/extensive systems • energy subsidies: machinery, fertilisers, pesticides, transport, processing • energy ratios and efficiency: a comparison of intensive and extensive systems.	

Content	Additional information
Manipulation of food species to increase productivity: • stocking/crop density • monocultures: advantages and disadvantages.	

3.5.1.3 Environmental impacts of agriculture

Content	Additional information
Habitat impacts: • habitat clearance • wetland drainage • ploughing of grassland • reduced biodiversity • genetic contamination • soil degradation and erosion.	
Pollution • pesticides • nutrients • GHGs: methane, carbon dioxide, NO_x.	
Changes to the hydrological cycle: • unsustainable irrigation • changes in evapotranspiration.	

3.5.1.4 Social/economic/political factors which influence agricultural production

Content	Additional information
Consumer choice: • social factors • cultural factors • religious factors • ethical factors.	
Economic factors: • subsidies • guaranteed prices • quotas.	

Content	Additional information
Political factors: • trade controls • economic controls • subsidies • guaranteed prices • quotas.	

3.5.1.5 Strategies to increase the sustainability of agriculture

Content	Additional information
Pest control.	
Reduced use of chemical pesticides.	
Reduced use of antibiotics.	
Cultural pest control: • weeding • mulching • crop rotation • barrier crops • biological control • predator habitats • polyculture/companion crops.	
Integrated control.	
Nutrient supplies: Use of natural processes: • nitrogen-fixing bacteria • decomposition • crop rotation.	
Increased use of natural processes to supply nutrients: • recycling of organic matter • crop rotation • permaculture • growth of legumes • conservation of soil biota.	

Content	Additional information
Energy inputs: • use of natural processes instead of artificial fertilisers • low tillage techniques.	
Water management to ensure sustainable supplies.	
Social impacts: the control of environmental impacts on rural communities.	

3.5.1.6 Opportunities for skills development and independent thinking

Mathematical skill number	Opportunities for skills development and independent thinking
MS 1.3	Students could construct tables on fish population data to draw conclusions on overfishing risks.
MS 1.9	Students could use the Mann-Whitney U test to compare the effect of pest control methods on crop growth.
MS 1.10	Students could calcuate the standard deviation of a data set, eg of crop yield for a given nutrient input.
MS 2.1	Students could use symbols in assessing fish populations and fish catches.
MS 2.2	Students could change the subject of equations when calculating energy efficiencies and energy ratios when comparing agricultural production systems.
MS 3.3	Students could select an appropriate format for presenting data, on nutrient inputs and yield increase.

Working scientifically

Students could plan activities in a range of broader environmental contexts related to food production systems, including ones where first-hand experience of practical activities may not be possible eg: monitoring how the use of GM fodder may affect energy ratios and food conversion ratios.

Practical skill number	Opportunities for skills development and independent thinking
PS 3.1	Students could plot and interpret graphs on the use of nitrate fertilisers and nitrate levels in aquifers.
PS 4.1	The practical skills of using equipment within scientific studies are expanded, as appropriate, in detail in the selected methodologies and sampling techniques below.

Opportunities to investigate the required methodologies of which students must have first-hand experience. Further details can be found in Appendix A: Working scientifically

Methodology skill number	Opportunities for skills development and independent thinking
Me 2	Students could plan a survey to assess the impact of livestock on soil compaction.
Me 6	Students could use a t-test to assess the statistical significance of a yield change following the introduction of a new crop variety or fertiliser.

Opportunities to investigate the required sampling techniques of which students must have first-hand experience. Further details can be found in Appendix A: Working scientifically

Sampling technique skill number	Opportunities for skills development and independent thinking
ST 3	Students could measure the soil moisture and organic matter content of fields with different management regimes.

3.5.2 Aquatic food production systems

Students should understand that fishing is the last large-scale human hunting activity. While aquatic species are renewable resources, humans can easily exploit populations above the Maximum Sustainable Yield.

Aquaculture allows humans to control productivity of aquatic species but has not yet increased food supplies in the way that agriculture has on land.

3.5.2.1 Marine Productivity

Content	Additional information
The role of nutrients in controlling biological productivity	Nutrient availability. Variations in light levels: photic/aphotic zones.
A comparison of productivity in open oceans, coastal areas, areas with upwelling	Students should understand how light and nutrient supplies control productivity in different areas.

3.5.2.2 Fishing

Content	Additional information
The advantages and disadvantages of the main fishing methods	Catch effectiveness, catch selectivity, energy inputs, environmental impacts: • pelagic trawling • demersal trawling • purse seining • drift netting • long lining • shellfish traps.

Content	Additional information
Environmental impacts of fishing	Population decline caused by overfishing. Changed age structure. By-catch. Ghost fishing. Damage to seabed, coral reefs, seagrass beds. Food web impacts.
The methods of estimating fish populations and Maximum Sustainable Yield	The relationship between biomass, recruitment, growth, mortality and catch. Population sampling from the commercial catch: • catch size • catch per unit fishing effort • mean fish size • mean age. Data from research: • breeding success – egg/larvae density/survival.
Methods of reducing environmental impacts of fishing	Catch quotas. Net design: • mesh design • mesh size • escape panels • acoustic deterrent devices (‘dolphin pingers’). Restricted fishing effort. No-take zones/protected breeding areas closed-seasons. Minimum catch size. Maximum catch size/protected individuals. Captive rearing and release to boost wild populations. Biodegradable/radio tracked equipment to reduce ghost fishing.

3.5.2.3 Aquaculture

Content	Additional information
The relative merits of extensive and intensive aquaculture	Productivity, energetics and environmental impacts.

Content	Additional information
Principles of aquaculture and their application to extensive and intensive systems	Species selection. Stock selection. Breeding/genetic control. Disease control. Control of competition. Control of nutrition. Control of abiotic factors: • temperature • dissolved oxygen • light levels • water flow.
The extent to which aquaculture can replace fishing	Food requirements. Trophic level efficiency.
Methods of reducing environmental impacts of aquaculture	Fish farm location. Control of organic wastes. Lower stocking density. Control escapes. Control of species and methods of collecting food for fish. Reduced use of pesticides/antibiotics. Feeding control.

3.5.2.4 Opportunities for skills development and independent thinking

Mathematical skill number	Opportunities for skills development and independent thinking
MS 0.1	Students could convert between different units when estimating changes in total biomass, mean mass, fecundity and growth rates when assessing MSY.
MS 1.3	Students could construct tables on fish population data to draw conclusions on overfishing risks.
MS 1.6	Students could calculate or compare the mean, median and mode of a set of data, eg of yields of fish farmed under different conditions or fish from commerical catches.
MS 2.1	Students could use symbols in assessing fish populations and fish catches.
MS 2.2	Students could use and manipulate an equation to estimate the maximum sustainable yield of a fish population.

3.5.3 Forest resources

Trees are a renewable resource but their slow growth rate and the need for land for other purposes has caused a significant reduction in global forest area.

3.5.3.1 The resources and life-support services gained from forests

Content	Additional information
Resources: • timber • fuel • food • fibres • medicines.	
Ecosystem services: • atmospheric regulation • habitat and wildlife refuge • regulation of the hydrological cycle • climate regulation • soil conservation • recreation/amenity uses.	

3.5.3.2 The relationship between forest productivity and biodiversity

Content	Additional information
The impacts on productivity and biodiversity of: • growth of non-indigenous species • single-species plantations • close planting • simple age structure.	

3.5.3.3 Deforestation

Content	Additional information
The causes of deforestation	Exploitation above the MSY. Clearance for alternative land use.
The effect of deforestation on resources, biodiversity, hydrology, soil and climate	Loss of resources: • timber, fuel, fibres, medicines • reduced biodiversity • loss of species • fragmentation of remaining forest areas.

Content	Additional information
Changes to hydrology: • reduced interception and transpiration • increased runoff.	
Impact on soil: • less dead organic matter • increased soil erosion • less protection of soil by vegetation and leaf litter • reduced root binding.	
Climate impacts: • increased albedo • reduced carbon sequestration and carbon reservoir • reduced rainfall downwind.	
Sustainable forest management	Mixed species plantations. Indigenous species. Mixed age structure. Selective logging.

3.5.3.4 Opportunities for skills development and independent thinking

Mathematical skill number	Opportunities for skills development and independent thinking
MS 0.3	Students could use data on percentage forest clearance to estimate changes in area, biomass and carbon storage.
MS 0.4	Students could estimate changes in forest area using satellite images.
MS 1.4	Students could use mean tree mass and tree spacing to estimate biomass and carbon storage per hectare.
MS 1.9	Students could use the t-test to compare the timber yield of two tree species.

Working scientifically

Students could plan activities to investigate environmental issues related to forestry which they could carry out eg:

- the effect of tree cover on the abiotic factors that affect wildlife in the woodand
- the effect of tree species diversity on the biodiversity of wildlife.

Students could plan activities in a range of broader environmental contexts related to forestry, including ones where first hand experience of practical activities may not be possible eg: the use of aerial survey data to monitor changes in forest area.

Practical skill number	Opportunities for skills development and independent thinking
PS 2.2	Students could evaluate the methods used to estimate tree biomass and assess potential inaccuracies.
PS 2.3	Students could identify the other variables that may affect a study of humidity within a forest.
PS 3.1	Students could construct a graph to show changing abiotic factors along a transect into a woodland.
PS 4.1	The practical skills of using equipment within scientific studies are expanded, as appropriate, in detail in the selected methodologies and sampling techniques below.

Opportunities to investigate the required methodologies of which students must have first hand experience. Further details can be found in Appendix A: Working scientifically

Methodology skill number	Opportunities for skills development and independent thinking
Me 5	Students could assess the effect of sample timing on a survey of abiotic factors in a forest.

Opportunities to investigate the required sampling techniques of which students must have first hand experience. Further details can be found in Appendix A: Working scientifically

Sampling technique skill number	Opportunities for skills development and independent thinking
ST 1	Students could use light meters, temperature data loggers, humidimeters and anemometers to measure abiotic factors within a forest.
ST 3	Students could investigate the impact of different management systems or tree types on soil organic matter content.

3.6 Sustainability

The subject principles that are the focus in all topics should be used to develop a holistic understanding of sustainability and the circular economy. Examples should be taken from throughout the areas of study to gain an understanding of the interconnected nature of environmental problems and solutions to these problems. Students should consider sustainability on local, national and global scales.

3.6.1 Dynamic equilibria

Students should understand the role of dynamic equilibria in natural and human systems and how this understanding may be used to develop sustainable human societies.

3.6.1.1 Negative feedback mechanisms which resist change

Content	Additional information
Global Climate Change eg: • increased temperatures causing increased cloud cover and a higher albedo • increased carbon dioxide levels leading to greater photosynthesis and carbon sequestration.	
Hydrological cycle eg: increased evaporation leading to increased precipitation.	
Population regulation eg: homeostatic population regulation caused by density-dependent factors.	

3.6.1.2 Positive feedback mechanisms which increase change

Content	Additional information
Global Climate Change.	Increased temperatures may increase the following features involved in positive feedback mechanisms: • melting of permafrost • ocean acidification • decline of albedo • methane hydrate releases • forest and peat fires • formation of cirrus clouds • soil decomposition rates.

3.6.1.3 Equilibrium tipping points which lead to new equilibria

Content	Additional information
Global Climate Change.	These are natural processes that become self-sustaining due to human activities eg forest fires, methane hydrate releases, permafrost melting.

3.6.1.4 Diverse systems are more likely to be resistant to change

Content	Additional information
High diversity natural systems: • coral reefs, tropical rainforests • low diversity human systems • agroecosystems.	

3.6.2 Energy

Students should understand that future energy will be affected by changing availability, the development of new technologies, economic factors and environmental concerns.

Natural systems are driven by energy in very different ways from anthropogenic systems.

The principles of natural systems being driven by renewable, low energy-density processes at low temperatures should be contrasted with human systems to consider how copying natural systems could help the development of a sustainable society.

3.6.2.1 Natural processes are driven by renewable energy, especially solar power

Content	Additional information
Hydrological cycle. Carbon cycle. Nitrogen cycle. Atmospheric circulation. Thermohaline circulation.	The use of renewable energy resources in natural processes provides long-term sustainability in contrast to anthropogenic processes reliant on non-renewable energy resources.

3.6.2.2 Natural processes use low energy-density resources

Content	Additional information
All the natural processes driven by solar energy are driven by low energy-density resources.	Natural processes that rely on low 'energy-density solar energy' capture the energy at a low energy density. It may be used in natural processes at a low energy density or may be converted into other energy forms with a higher energy-density which may be applied more easily to human activities.

3.6.2.3 Most natural processes occur at low temperatures

Content	Additional information
Eg: • photosynthesis produces carbohydrates • enzymes reduce the activation energy of reactions • nitrogen fixation.	Students should compare the natural systems that use low temperatures with human systems that use high temperatures eg biological fixation of nitrogen compared with the Haber process using fossil fuels.

3.6.2.4 Carbon footprints and sustainable development

Content	Additional information
The concept of carbon footprints introduced in the Physical Environment should be re-considered in evaluating the contribution of mimicking natural energy systems to achieve sustainability.	

3.6.3 Material cycles

The use of mineral resources should be re-considered to evaluate how an understanding of natural cyclical processes may increase the sustainability of human systems.

3.6.3.1 Linear human systems lead to resource depletion and waste generation

Content	Additional information
The use of fossil fuels	The reliance on non-renewable energy resources cannot be sustainable. Inefficient use and use when renewable resources are available accelerates depletion rates.
The use of mineral resources	Human use of minerals often involves dispersal after use or produces mixtures from which separation is difficult. These make recovery and re-use difficult so sustainable exploitation is reduced.

3.6.3.2 Natural processes often link together in sequences that create cycles, with the waste products of one process being the raw materials for other processes

Content	Additional information
Natural processes use a relatively small number of elements, which build into monomers. These build to produce a wide range of polymers eg carbohydrates, proteins.	Students should consider how the use and re-use of abundant, simple raw materials in natural cycles results in sustainability and how this principle may be applied to human systems.

3.6.3.3 Natural waste products are either non-toxic or do not build up to cause toxicity

Content	Additional information
The molecules produced by natural processes are biodegradable and can be broken down to non-toxic products that are the raw materials for other natural processes.	Students should consider how the low toxicity of the wastes of natural systems and the natural processes that process them minimise environmental problems and provide sustainable supplies.

3.6.4 The circular economy

The circular economy should be evaluated as a possible development strategy that engages in a benign way with natural systems. These should be considered in terms of the development of sustainable lifestyles using circular economy principles.

Students should reconsider the sustainability of natural processes studied throughout the course, especially those emphasised in sections Dynamic equilibria (page 77), Energy (page 79)and Material cycles (page 80), to evaluate the ways human society may become sustainable.

3.6.4.1 The application of the principles of the circular economy to the development of sustainable lifestyles

Content	Additional information
	Students should select examples studied throughout the course to illustrate the possible inclusion of natural principles into the circular economy eg:
Cycling of materials	Biogeochemical cycles and recycling.
Energy derived from renewable sources	Solar and non-solar renewable energy in natural and human systems.
Human activities should support ecosystems.	The inclusion of ecosystem conservation in human planning eg agriculture, forestry, fisheries, energy use, waste management.
Separation of technical and biological materials.	Separation of biodegradable wastes from other materials eg metals to enable reuse.
How diverse systems are more resistant to change.	Diverse ecosystems and diverse technical systems eg the use of a range of renewable energy resources.
Connected systems where the waste product of one process is the raw material for another process.	Natural biogeochemical cycles compared with pollution caused by human wastes.
Design of products for end of life reuse.	Design to enable re-use of components or materials eg vehicles, domestic equipment.

Content	Additional information
Optimum production rather than maximum production.	Consideration of natural system where over-production supports processes upon which the system relies eg plant products which support pollinators, seed dispersal agents and microbes such as decomposers and mycorrhizal fungi. This can be contrasted with agroecosystems which aim for maximum harvested yields.
Technologies to design new products and improve system effectiveness.	Improved designs to increase energy use, reduce material use and enable dismantling for re-use
Students must evaluate the extent to which the principles of the circular economy can be applied to human activities to develop sustainable lifestyles in the following activities:	
• land uses that support natural ecosystems	The inclusion of living organisms into urban landscapes to conserve wildlife and improve quality of life.
• water supplies	Water conservation and catchment management.
• mineral supplies	Increasing reserves by exploiting low-grade ores.
• waste management	Reduced use, reuse, repurposing, recycling.
• pollution control	A move from post-production treatment to non-release by changes in technology eg from internal combustion engines to fuel cells.
• energy supplies	The use of renewable energy resources and the development of low-temperature manufacturing processes.
• food production.	The inclusion of natural processes in nutrient supply, pest control and soil maintenance.

3.6.4.2 Biocapacity and ecological footprints: a comparison of the factors controlling the impact of different ecological footprints on biocapacity

Content	Additional information
Review of different regions of the world, including use of the WWF Living Planet Report, Living Planet Index and ecological footprint calculations.	Students should consider how the strategies that can be implemented to achieve sustainability could be used to reduce ecological footprints and maintain or enhance biocapacity in different regions of the world.

3.6.5 Opportunities for skills development and independent thinking

Mathematical skill number	Opportunities for skills development and independent thinking
MS 1.7	Students could intepret a scatter graph to compare human development index with the environmental footprint of different countries.
MS 1.8	Students could compare per capita, national and global data for the use of a range of resources.
MS 2.5	Students could use logarithmic data when comparing rates of change in human populations.
MS 3.2	Students could use data from graphs to calculate rates of change in human populations.
MS 3.4	Students could calculate rates of carbon sequestration from data on changes in mean tree biomass and forest area.
MS 3.5	Students could interpret computer models on population growth to estimate dates when global population will reach a particular size.
MS 3.6	Students could use data on carbon emissions, sequestration/removal rates and atmospheric CO_2 concentrations and estimate future temperature change.

Working scientifically

Practical skill number	Opportunities for skills development and independent thinking
PS 1.2	Students could analyse data on fossil fuel use and hydrocarbon reserves to assess future supply problems.
PS 1.4	Students could identify the impacts of fossil fuel use and plan a monitoring programme to assess the impacts of changing to renewable energy resources.
PS 3.1	Students could interpret graphs on population growth, resource consumption, biodiversity loss and pollution emissions within the context of sustainable lifestyles.
PS 3.2	Students could analyse data on resource reserves to consider margins of error and the problems of basing decisions on uncertain data.

3.7 Research methods

Research methods include details of the methods used to investigate a wide range of environmental issues. It is not expected that students will have first hand experience of all of these although, where this is possible, it will enhance their learning experience. The required practical skills are detailed in Appendix A: Working scientifically and opportunities for developing these skills are signposted throughout the subject content.

Students must understand the general principles of scientific methodology and be able to apply these to a wide range of environmental situations and techniques.

Preliminary studies may be used to ensure the study will produce representative data.

Practical activities should be carried out with consideration of their environmental impacts and how these can be minimised.

Students must undertake experimental and investigative activities, inlcuding appropriate risk management, in a range of environmental contexts. They must also know how to safely and correctly use a range of practical equipment and materials.

Students must carry out practical activities using the best contemporary practices for risk assessment and safe working in the laboratory and during fieldwork.

3.7.1 Scientific methodologies

Content	Additional information
Sample location: random sampling	Importance of the avoidance of bias.
Sample location: systematic sampling	Regular sample intervals. Transects – applied to 'environmental gradients': • line transects • belt transects • continuous/interrupted transects.
Sample timing	To ensure data variability is detected. Selection of time intervals between samples.
Sample size	Dependent on sample homogeneity.
Number of samples	Dependent on data variability. To enable analysis of statistical significance.
Standardisation of techniques	To allow comparisons between different studies/ ensure consistent reliability.
Collection of statistically significant data	Experimental design should allow the assessment of statistical significance of the data collected.

3.7.2 Sampling techniques

3.7.2.1 Standard environmental techniques

Content	Additional information

Methods:
• quadrats
  • quadrat size selection
• types of quadrat
  • open frame quadrat
  • grid quadrat
  • point quadrat
• kick sampling
• surber samplers
• colonisation media
• pitfall traps
• sweep nets
• beating trays
• light traps
• Tüllgren funnel
• extraction of earthworms from soil.
Quantitative/comparative/numerical measures:
• abundance scales, eg DAFOR scales
• species richness
• species diversity
• species frequency
• species density
• percentage cover
• Lincoln Index
• Simpson's Index of Biodiversity.
Measurement of abiotic factors:
• light intensity
• temperature
• wind velocity
• humidity
• water turbidity
• water pH
• water ion concentration, eg nitrates
• soil analysis:
  • texture: sedimentation, sieving
  • pH
  • water content
  • organic matter content
  • measurement of bulk density
  • the use of a soil triangle.
	Students must understand the following features of each technique:
	• purpose/application of the method
	• how the method is carried out
	• limitations.

3.7.2.2 Fieldwork and laboratory activities

Content	Additional information
Fieldwork and laboratory activities. These should include, but not be limited to, the following: ecological studies in suitable available habitats: • population size/density • species frequency • species distribution • biodiversity • soil analysis. The effects of climatic variability on the use of renewable energy resources: insolation intensity, wind velocity. Factors affecting the rate of heat loss: insulation, volume. The use of biotic indices in monitoring pollution: lichens, aquatic invertebrates. The effect of pH on seed germination. The effect of water turbidity on light penetration. The effect of inorganic nutrients on the growth of aquatic plants/algae. Factors affecting noise levels: distance from source, acoustic insulation. The effect of slope and vegetation on rain splash soil erosion. The effect of trees on microclimates.	

3.7.2.3 Specialist techniques

Content	Additional information
Knowledge/understanding/application of the following techniques is required, but first-hand experience is not. Photography: • motion sensitive cameras • databases of physical features may be used to identify individuals, eg tiger stripe patterns, whaleshark spots, whale and dolphin fin damage. Marking: tags, rings, collars etc. Auditory monitoring (sounds)/sonograms: birds, bats, cetaceans. Radio/GPS/satellite tracking. Data collected by satellite sensors, eg to monitor habitat change, water availability, rock density, ice cover, ice thickness. Databases of blood/tissue samples/DNA/eDNA. Indirect evidence – shows the presence of the species even if it is not actually seen: • nests/burrows • droppings – can give information on diet, gender, territories • feeding marks, eg nuts, fruit • owl pellets – also give information on diet • tracks/footprints • territorial marks, eg scratching posts.	

3.7.3 Opportunities for skills development and independent thinking

Mathematical skill number	Opportunities for skills development and independent thinking
MS 0.3	Students could estimate mean percentage vegetation cover using data from a range of quadrats.
MS 1.1	Students could use appropriate numbers of significant figures in calculations of population, soil composition and reservoir mass in biogeochemical cycles.
MS 1.2	Students could calculate mean population densities of ground flora from quadrat survey data.

Mathematical skill number	Opportunities for skills development and independent thinking
MS 1.3	Students could represent a range of variables collected along a transect in a table, eg population density, % cover, biodiversity, light levels, humidity.
MS 1.4	Students could assess the probability of a link between changes in an abiotic factor and species distribution.
MS 1.5	The principles of sampling and data collection are fundamental to all the practical skills.
MS 1.6 + MS 1.10	Students could calculate mean values wherever multiple samples are collected and use standard deviation to assess the degree of scatter of values and the significance of difference between means.
MS 1.7	Students could construct and interpret a scatter graph.
MS 1.9	Students could use the t-test to assess the effect of different tree planting densities on abiotic factors, eg humidity, wind velocity.
MS 1.11	Students could use a preliminary study to establish an appropriate sample size for a specific level of sample variability.
MS 2.3	Students could use ecological algebraic formulae, eg Simpson's index of biodiversity or the Lincoln index.
MS 3.1	Students could construct kite diagrams of abundance along a transect.
MS 3.2	Students could use data tables from field studies to construct line graphs of changing variables along a transect.
MS 3.3	Students could construct a line graph of mean seed germination rates for a range of pHs.

Working scientifically

Where appropriate, the research methods included in Section 3.7 can be incorporated into the required methodologies and sampling techniques included in Appendix A: Working scientifically, of which students must have first hand experience.

The methodologies and sampling techniques of which students must have experience should not be carried out in isolation. They should be set in a clear environmental context, as exemplified throughout the other sections of the specification.

4 Scheme of assessment

Find past papers and mark schemes, and specimen papers for new courses, on our website at aqa.org.uk/pastpapers

This specification is designed to be taken over two years.

This is a linear qualification. In order to achieve the award, students must complete all assessments at the end of the course and in the same series.

A-level exams and certification for this specification are available for the first time in May/June 2019 and then every May/June for the life of the specification.

All materials are available in English only.

Our A-level exams in Environmental Science include questions that allow students to demonstrate their ability to:

- demonstrate knowledge and understanding of the content developed in one section or topic, including the associated mathematical and practical skills or
- to apply mathematical and practical skills to areas of content they are not normally developed in or
- draw together different areas of knowledge and understanding within one answer.

A range of question types will be used, including those that require extended responses. Extended response questions will allow students to demonstrate their ability to construct and develop a sustained line of reasoning which is coherent, relevant, substantiated and logically structured. Extended responses may be in written English, extended calculations, or a combination of both, as appropriate to the question.

4.1 Aims

Courses based on this specification must encourage students to:

- develop essential knowledge and understanding of different areas of environmental science and how they relate to each other
- develop and demonstrate a deep appreciation of the skills, knowledge and understanding of the scientific methods used to investigate the environment
- develop competence and confidence in a variety of practical, mathematical and problem solving skills related to environmental issues and the sustainable use of resources
- understand the importance of basing decisions on reliable data which allows evidence-based analysis of environmental issues
- develop interest in and enthusiasm for the subject, including developing an interest in further study and careers associated with the subject
- understand how society makes decisions about environmental issues and how these contribute to the success of the economy and society.

4.2 Assessment objectives

Assessment objectives (AOs) are set by Ofqual and are the same across all A-level Environmental Science specifications and all exam boards.

The exams will measure how students have achieved the following assessment objectives.

- AO1: Demonstrate knowledge and understanding of scientific ideas, processes, techniques and procedures, including in relation to natural processes/systems and environmental issues.
- AO2: Apply knowledge and understanding of scientific ideas, processes, techniques and procedures, including in relation to natural processes/systems and environmental issues.
- AO3: Analyse, interpret and evaluate scientific information, ideas and evidence, including in relation to environmental issues, to make judgements and draw conclusions.

4.2.1 Assessment objective weightings for A-level Environmental Science

Assessment objectives (AOs)	Component weightings (approx %)		Overall weighting (approx %)
	Paper 1	Paper 2	
AO1	17–19	14–16	30–35
AO2	19–21	20–22	40–45
AO3	11–13	13–15	25–30
Overall weighting of components	50	50	100

10% of the overall assessment of A-level Environmental Science will contain mathematical skills equivalent to Level 2 or above.

At least 15% of the overall assessment of A-level Environmental Science will assess knowledge, skills and understanding in relation to practical work.

4.3 Assessment weightings

The marks awarded on the papers will be scaled to meet the weighting of the components. Students' final marks will be calculated by adding together the scaled marks for each component. Grade boundaries will be set using this total scaled mark. The scaling and total scaled marks are shown in the table below.

Component	Maximum raw mark	Scaling factor	Maximum scaled mark
Paper 1	120	x 1	120
Paper 2	120	x 1	120
		Total scaled mark:	240

5 General administration

You can find information about all aspects of administration, as well as all the forms you need, at aqa.org.uk/examsadmin

5.1 Entries and codes

You only need to make one entry for each qualification – this will cover all the question papers, non-exam assessment and certification.

Every specification is given a national discount (classification) code by the Department for Education (DfE), which indicates its subject area.

If a student takes two specifications with the same discount code, further and higher education providers are likely to take the view that they have only achieved one of the two qualifications. Please check this before your students start their course.

Qualification title	AQA entry code	DfE discount code
AQA Advanced Level GCE in Environmental Science	7447	TBC

This specification complies with:

- Ofqual *General conditions of recognition* that apply to all regulated qualifications
- Ofqual GCE qualification level conditions that apply to all GCEs
- Ofqual GCE subject level conditions that apply to all GCEs in this subject
- all other relevant regulatory documents.

The Ofqual qualification accreditation number (QAN) is 603/0978/7.

5.2 Overlaps with other qualifications

There is overlapping content in the AS and A-level Environmental Science specifications. This helps you teach the AS and A-level together.

5.3 Awarding grades and reporting results

The A-level qualification will be graded on a six-point scale: A*, A, B, C, D and E.

Students who fail to reach the minimum standard for grade E will be recorded as U (unclassified) and will not receive a qualification certificate.

5.4 Re-sits and shelf life

Students can resit the qualification as many times as they wish, within the shelf life of the qualification. NEA results can be carried forward for any students re-sitting the qualification. NEA results can be carried forward for any students re-sitting the qualification.

5.5 Previous learning and prerequisites

There are no previous learning requirements. Any requirements for entry to a course based on this specification are at the discretion of schools and colleges.

However, we recommend that students should have the skills and knowledge associated with at least GCSE Combined Science or equivalent (see Appendix C: Previous science learning (page 111)).

5.6 Access to assessment: diversity and inclusion

General qualifications are designed to prepare students for a wide range of occupations and further study. Therefore our qualifications must assess a wide range of competences.

The subject criteria have been assessed to see if any of the skills or knowledge required present any possible difficulty to any students, whatever their ethnic background, religion, sex, age, disability or sexuality. Tests of specific competences were only included if they were important to the subject.

As members of the Joint Council for Qualifications (JCQ) we participate in the production of the JCQ document *Access Arrangements and Reasonable Adjustments: General and Vocational qualifications*. We follow these guidelines when assessing the needs of individual students who may require an access arrangement or reasonable adjustment. This document is published at jcq.org.uk

Students with disabilities and special needs

We're required by the Equality Act 2010 to make reasonable adjustments to remove or lessen any disadvantage that affects a disabled student.

We can make arrangements for disabled students and students with special needs to help them access the assessments, as long as the competences being tested aren't changed. Access arrangements must be agreed **before** the assessment. For example, a Braille paper would be a reasonable adjustment for a Braille reader.

To arrange access arrangements or reasonable adjustments, you can apply using the online service at aqa.org.uk/eaqa

Special consideration

We can give special consideration to students who have been disadvantaged at the time of the assessment through no fault of their own – for example a temporary illness, injury or serious problem such as family bereavement. We can only do this **after** the assessment.

Your exams officer should apply online for special consideration at aqa.org.uk/eaqa

For more information and advice visit aqa.org.uk/access or email accessarrangementsqueries@aqa.org.uk

5.7 Working with AQA for the first time

If your school or college hasn't previously offered our specifications, you need to register as an AQA centre. Find out how at aqa.org.uk/becomeacentre

5.8 Private candidates

This specification is available to private candidates.

A private candidate is someone who enters for exams through an AQA approved school or college but is not enrolled as a student there.

A private candidate may be self-taught, home schooled or have private tuition, either with a tutor or through a distance learning organisation. They must be based in the UK.

If you have any queries as a private candidate, you can:

- speak to the exams officer at the school or college where you intend to take your exams
- visit our website at aqa.org.uk/privatecandidates
- email privatecandidates@aqa.org.uk

5.9 Use of calculators

Students may use a calculator in the exam. They must ensure that their calculator meets the requirements as set out in the *JCQ Instructions for conducting examinations*. These instructions make it clear what the requirements are for calculators (what they must be) and what they are not (what they must not be). The instructions are regularly updated and can be found at jcq.org.uk

6 Appendix A: Working scientifically

Scientific research is a fundamental part of Environmental Science and good research skills are needed to collect representative data so that reliable conclusions can be formulated.

Students must be given the opportunity to carry out investigative/practical activities which cover the following requirements. These activities should be carried out within clear environmental contexts. Opportunities for developing the required practical skills are signposted within the subject content. Opportunities should also be taken to incorporate the required mathematical skills.

Students must undertake fieldwork which meets the minimum requirement of 4 days of fieldwork for A-level. If a mixture of fieldwork and laboratory-based activities is chosen then the equivalent minimum requirement would be 2 days of fieldwork plus 12 laboratory-based activities.

Schools and colleges are required to provide a practical work statement that confirms each student has been given the opportunity to fulfil this requirement. Schools and colleges must provide the practical work statement by 15 May in the year of entry. Any failure to provide this statement in a timely manner will be treated as malpractice or maladministration (under Ofqual's General Condition A8 (Malpractice and maladministration)).

Assessment of the knowledge and understanding of the practical skills in the A-level specification will be by written exams only. Overall, at least 15% of the marks for A-level Environmental Science qualification will require the assessment of practical skills.

Students must undertake experimental and investigative activities, including appropriate risk management, in a range of environmental contexts. They must also know how to safely and correctly use a range of practical equipment and materials.

Students must carry out practical activities using the best contemporary practices for risk assessment and safe working in the laboratory and during fieldwork.

Investigative/practical activities undertaken throughout the course should enable students to develop the following skills:

6.1 Practical skills for assessment in the written papers

Table 2: Independent thinking

Practical skill number	Description of skill
PS 1.1	solve problems set in practical contexts
PS 1.2	analyse and evaluate existing scientific knowledge
PS 1.3	apply scientific knowledge to practical contexts
PS 1.4	plan scientific investigations and apply investigative approaches and methods to practical work.

Table 3: Use and application of scientific methods and practices

Practical skill number	Description of skill
PS 2.1	comment on experimental design and evaluate scientific methods
PS 2.2	evaluate results and draw conclusions with reference to measurement uncertainties and errors
PS 2.3	identify variables including those that must be controlled
PS 2.4	collect and present information and data in a scientific way.

Table 4: Numeracy and the application of mathematical concepts in a practical context

Practical skill number	Description of skill
PS 3.1	plot and interpret graphs
PS 3.2	process and analyse data using appropriate mathematical skills as exemplified in the mathematical requirements
PS 3.3	consider margins of error, accuracy and precision of data.

Table 5: Instruments and equipment

Practical skill number	Decription of skill
PS 4.1	Know and understand how to use experimental and practical instruments, equipment and techniques appropriate to the knowledge and understanding included in the specification, including: • using appropriate apparatus/instruments to record quantitative measurements (for example temperature, length and pH) • using appropriate apparatus/instruments and methodologies to measure abiotic and biotic factors (for example, light intensity, humidity, population size) • sampling techniques (for example pitfall traps, Tüllgren funnel, soil texture analysis, water turbidity, light traps).

These skills can be developed through the following methodologies and sampling techniques and opportunities are signposted throughout the subject content.

6.2 Required practical activities

Students must develop a knowledge and understanding of all the scientific methodologies and sampling techniques included in Research methods (page 83).

In addition to this, they must have first-hand experience of the methodologies Me1, Me2, Me3, Me4, Me5, Me6 and all the practical sampling techniques included in ST1, ST2, ST3, ST4, ST5 and ST6. These can be carried out through a range of practical activities based in the laboratory or during fieldwork. This practical work will build upon the knowledge and understanding gained from Research methods (page 83).

6.3 Methodologies

These are the underlying principles which are essential in the planning of good scientific research. It is important that students understand how to plan environmental studies as well as how to carry out the specific techniques.

Students should have an understanding of all the methodologies covered in Research methods (page 83), which would always be included in the planning of any environmental study. In addition, suitable opportunities must be provided to allow students to investigate all of these methodologies in detail: Me1, Me2, Me3, Me4, Me5 and Me6. Students should develop an understanding of how these methodologies enable the planning of better scientific research so they can evaluate their impact on the reliability of the data collected.

To gain the greatest education benefit from these activities, the investigations should be planned within an environmental context where the results would inform environmental decision-making, eg the effect of abiotic factors on plant distribution in a nature reserve, the control of invasive plant species, the effect of field cultivation on river water or nutrient concentration or the effect of different farming techniques on soil organic matter content.

It is important that students understand that the methodologies for which they develop skills can be applied to any environmental research project, including those in locations they cannot visit and those which require equipment which they do not have. It is still possible to apply their planning skills in these theoretical contexts. This will help them develop their knowledge throughout the specification within the context of independent thinking and scientific research.

Table 6: Planning for representative data

Methodology skill number	Description of skill
Me 1	Sample location – random sampling, where there is no directional difference in sample results or there is no environmental gradient.
Me 2	Sample location – systematic sampling, where there is an environmental gradient or fixed sample intervals are appropriate.
Me 3	Number of samples – an assessment of the number of samples needed, as influenced by the variability between samples.
Me 4	Sample size – an assessment of how large each sample should be, as influenced by the homogeneity of the subject matter.
Me 5	Sample timing – when a temporal variable may affect the reliability of results, eg weather-related, seasonal or diurnal changes.
Me 6	Standard deviation – an analysis of the variability of results by calculating the Standard Deviations of mean values. An assessment of the statistical significance of results by selecting and carrying out an appropriate statistical test.

6.4 Sampling techniques

These are the techniques that should be carried out to develop a knowledge and understanding of the practical methods used to collect representative, reliable data about the environment.

The first-hand experience of practical techniques should build on the theory of the use of all of the techniques, as covered in Research methods (page 83).

Students should gain first-hand experience of the sampling techniques included in ST1, ST2, ST3, ST4, ST5 and ST6. The techniques should be carried out within environmental context that highlight how the data gained can be used to reach conclusions that inform future decision making.

Table 7: Sampling techniques

Sampling technique skill number	Description of skill
ST 1	**Measurement of abiotic factors:** • Light intensity • Temperature • Wind velocity • Humidity • Water turbidity • Water ion concentration, eg nitrates, phosphates • pH

ST 2	**The use of quadrats to measure biotic factors:**
	Population size, species richness, species distribution, biodiversity
	• Selection of suitable quadrat size
	• Types of quadrat:
	  • Open frame quadrat
	  • Grid quadrat
	  • Point quadrat

ST 3	**Measurement of edaphic factors** Soil texture: • Sedimentation • Soil sieves • Soil triangle Soil water content Soil organic matter content Soil pH Soil bulk density
ST 4	**The use of methods to measure biotic factors related to animal taxa on the soil surface and in soil:** Population size, species richness, species distribution, biodiversity • Pitfall traps • Tüllgren funnel • Extraction of earthworms from soil

Sampling technique skill number	Description of skill
ST 5	**The use of methods to measure biotic factors related to animal taxa on foliage and flying animals:** Population size, species richness, species distribution, biodiversity • Light traps • Sweep nets • Beating trays • Bat detector
ST 6	**The use of aquatic sampling methods to measure biotic factors:** Population size, species richness, species distribution, biodiversity • Pond net • Kick sampling • Surber samplers • Colonisation media

There is no prescribed list of compulsory investigations that must be carried out. Centres and teachers must choose appropriate practical activities that allow students to gain first-hand experience of the required methodologies and sampling techniques.

It is anticipated that the time devoted to practical activities would equate to two full days of fieldwork or one day of fieldwork plus six sessions of laboratory-based activities.

Practical activities should be carried out with the consideration of their environmental impacts and how these can be minimised. All activities should be planned and carried out to ensure the safety of the students and other people.

6.5 Scientific principles

Throughout the course, students must be given opportunities to develop the following skills and knowledge.

6.5.1 Use theories, models and ideas to develop scientific explanations of environmental processes

Students must be given opportunities to use theories, models and ideas to develop scientific explanations of environmental processes.

Suitable opportunities for this include:

- the control of ecological succession in conserving plagioclimax habitats. Students should understand the processes in ecological succession that can inform conservation strategies
- global climate change: how interconnected natural systems cause environmental change
- the processes in the carbon cycle that are affected by human activities
- the processes in the nitrogen cycle that are affected by human activities
- factors that affect (pollutant) dispersal
- marine productivity: The role of nutrients in controlling biological productivity.

6.5.2 Use knowledge and understanding to pose questions, define scientific problems, present scientific arguments and scientific ideas related to the environment

Students must be given opportunities to use knowledge and understanding to pose questions, define scientific problems, present scientific arguments and scientific ideas related to the environment.

Suitable opportunities for this include:

- setting conservation priorities. Students could evaluate the information available to decide which taxa and habitats should be conserved
- difficulties monitoring and predicting climate change
- ozone depletion. Collection, analysis and interpretation of data, an evaluation of data collection methods available and the reliability of data produced
- reserves and resource. Students could consider how data from exploration and the development of new exploratory and extraction techniques affect estimates of mineral reserves
- strategies to secure future energy supplies. Students should analyse and evaluate key issues and quantitative data to evaluate the potential future contribution of each resource
- developments in energy storage technologies. Students could analyse the impact of new storage technologies on the use of renewable energy resources
- Critical Pathway Analysis. Students could consider how an understanding of environmental pollutant pathways and the information that must be collected, can help prevent pollution problems
- Critical Group Monitoring. Students could analyse the information needed to predict the members of the public most at risk of pollution impacts
- the extent to which aquaculture can replace fishing.

6.5.3 Use of appropriate methodology, including information and communication technology (ICT), to answer scientific questions and solve scientific problems

Students must be given opportunities to use ICT to access environmental information and data, and to manipulate data.

Suitable opportunities for the use of ICT include:

- data on IUCN Red List species
- interactive maps on protected areas
- IWC catch quotas
- current atmospheric CO_2 levels
- tracking satellites that monitor the cryosphere
- climate modelling
- carbon footprint calculations
- tracking satellites that research mineral deposits
- current data on wind velocities and windfarm output
- current data on wave height and direction
- locations of current and planned renewable energy locations
- changes in electricity supply and sources
- monitoring atmospheric pollution in selected locations
- monitoring noise levels around airports

- monitoring road traffic noise
- research methods:
  - use of statistical analysis software
  - tracking wildlife.

6.5.4 Undertake experimental and investigative activities, including appropriate risk management, in a range of environmental contexts

Students must be given opportunities throughout the course to undertake experimental and investigative activities, including appropriate risk management, in a range of environmental contexts.

Suitable opportunities for this include:

- research methods
- sampling techniques.

6.5.5 Analyse and interpret quantitative and qualitative data to provide evidence, recognising correlations and causal relationships

Students must be given opportunities throughout the course to analyse and interpret quantitative and qualitative data to provide evidence, recognising correlations and causal relationships.

Suitable opportunities for this include:

- the importance of ecological monitoring in conservation planning
- ozone depletion: collection, analysis and interpretation of data, an evaluation of data collection methods available and the reliability of data produced
- evaluation of the effectiveness of the methods used to restore the ozone layer
- reserves and resource
- Lasky's principle
- the Universal Soil Loss Equation. Students could use data to estimate soil erosion rates in different agricultural scenarios
- features of energy resources. Quantitative data should be used to compare different energy resources and evaluate the potential for energy resources in the future
- strategies to secure future energy supplies. Students should analyse and evaluate key issues and quantitative data to evaluate the potential future contribution of each energy resources
- the methods of estimating fish populations and Maximum Sustainable Yield. The relationship between biomass, recruitment, growth, mortality and catch
- research methods.

6.5.6 Evaluate methodology, evidence and data, and resolve conflicting evidence to make judgements and reach conclusions and develop and refine practical design and procedures

Students must be given opportunities throughout the course to:

- evaluate methodology, evidence and data, and resolve conflicting evidence to:
  - make judgements and reach conclusions
  - develop and refine practical design and procedures.

  Suitable opportunities for this include:

- regulation of sustainable exploitation. Students could analyse data on populations and exploitation rates to assess the effectiveness of the strategies
- management and conservation of habitats. Students could evaluate secondary data to assess the effectiveness of habitat conservation methods
- how population control and the management of desired and undesired species affects the conservation of biodiversity
- difficulties monitoring and predicting climate change
- ozone depletion: collection, analysis and interpretation of data, an evaluation of data collection methods available and the reliability of data produced
- the hydrosphere: analysis and evaluation of strategies for sustainable management
- strategies to secure future energy supplies. Students could analyse and evaluate key issues and quantitative data to evaluate potential future contribution of each energy resource
- ionising radiation: the use of risk:benefit analysis
- strategies to increase the sustainability of agriculture: Permaculture, use of natural processes, integrated pest control
- research methods and working scientifically. Students could apply their knowledge of scientific methodologies and sampling techniques to plan studies to collect more data and to critically analyse methods of data collection in scenarios throughout the specification.

6.5.7 Know that scientific knowledge and understanding of the environment develops over time

Students must be given opportunities throughout the course to develop and understand that scientific knowledge and understanding of the environment develops over time.

Suitable opportunities for this include:

- management and conservation of habitats
- changes in concentrations of greenhouse gases and the impact of global climate change
- changes in ozone depletion
- changes in mineral reserves
- strategies to secure future mineral supplies
- strategies to secure future energy supplies
- developments in energy storage technologies
- new energy conservation technologies
- the use of scientific knowledge to develop new pollution control technologies
- strategies to increase the sustainability of agriculture.

6.5.8 Communicate information and ideas in appropriate ways using appropriate terminology

Students should understand and use the subject technical terminology used throughout the specification.

6.5.9 Consider applications and implications of environmental science and evaluate their associated benefits and risks

Students must be given opportunities throughout the course to consider applications and implications of environmental science and evaluate their associated benefits and risks.

Suitable opportunities for this include:

- the importance of the conservation of biodiversity
- the advantages and disadvantages of the methods used in sustainable management of the carbon cycle
- strategies to secure future energy supplies
- selection and control technologies: to reduce production, reduce release and mitigate damage caused
- the benefits and costs of pollution control including ALARA and BATNEEC
- manipulations of food species
- the circular economy.

6.5.10 Consider ethical issues in the treatment of humans, other organisms and the environment

Students must be given opportunities throughout the course to consider ethical issues in the treatment of humans, other organisms and the environment.

Suitable opportunities for this include:

- human influence on biodiversity
- regulation of sustainable exploitation
- management and conservation of habitats
- global climate change
- the impact of unsustainable exploitation of the hydrosphere
- the environmental impacts of soil erosion
- the sustainability of current energy resource exploitation
- environmental impacts of fishing
- sustainability.

6.5.11 Evaluate the role of the scientific community in validating new knowledge and ensuring integrity

Students must be given opportunities throughout the course to consider the way that peer review within the scientific community is used to validate new knowledge and ensure its integrity.

Suitable opportunities for this include:

- species population monitoring for:
  - IUCN Red List species categorisation
  - CITES trade control categorisation
  - setting quotas for IWC, EU CFP and ITTO
  - monitoring rates of tropical rainforest loss
  - monitoring rates of coral reef bleaching
- difficulties monitoring and predicting climate change. Students should understand the limitations in the available data when attempting to predict future natural and anthropogenic climate change. They should be able to evaluate the reliability of existing information and discuss the methods that are used to fill gaps in current knowledge including remote sensing
- the Rowland-Molina hypothesis
- monitoring ozone depletion
- evaluation of the effectiveness of the methods used to restore the ozone layer
- analysis and evaluation of the strategies for sustainable management of the hydrosphere
- strategies to secure future mineral supplies

- strategies to secure future energy supplies
- risk:benefit analysis for the uses of ionising radiation
- comparison of the advantages/disadvantages of the use of different pesticide groups
- manipulation of food species, particularly GM crops
- the extent to which aquaculture can replace fishing.

6.5.12 Evaluate the ways in which society uses science to inform decision making

Students must be given opportunities throughout the course to evaluate the ways in which society uses science to inform decision making.

Suitable opportunities for this include:

- categorisation of species for CITES appendices
- management and conservation of habitats
- the importance of ecological monitoring in conservation planning
- the control of ecological succession in conserving plagioclimax habitats. Students should understand the processes in ecological succession that can inform conservation strategies
- how population control and the management of desired and undesired species affects the conservation of biodiversity. Students should understand r- and k- selection strategies and how these affect the ease with which species can be over-exploited
- evaluation of the effectiveness of the methods used to restore the ozone layer
- impact of unsustainable exploitation of the hydrosphere. Students should be able to use the technical terminology related to the hydrological cycle to discuss anthropogenic changes and strategies that may allow sustainable exploitation
- strategies to secure future energy supplies. Students should analyse and evaluate key issues and quantitative data to evaluate the potential future contribution of each energy resource
- selection and control technologies. Students should understand the properties of pollutants and environmental features so they can analyse and evaluate the changes in human activities and strategies that can be used to minimise pollution
- the use of scientific knowledge to develop new pollution control technologies
- the methods of estimating fish populations and Maximum Sustainable Yield
- methods of reducing environmental impacts of fishing:
  - catch quotas
  - no-take zones
  - minimum and maximum catch size
- the application of the principles of the circular economy to the development of sustainable lifestyles.

7 Appendix B: Maths requirements and examples

In order to be able to develop their skills, knowledge and understanding in Environmental Science, students need to have been taught, and to have acquired competence in, the appropriate areas of mathematics as indicated in the table of coverage below.

Overall at least 10% of the marks in assessments for Environmental Science will require the use of mathematical skills. These skills will be applied in the context of environmental science and will be at least the standard of higher tier GCSE mathematics.

The following tables illustrate where these mathematical skills may be developed during teaching or could be assessed.

This list of examples is not exhaustive. These skills could be developed or assessed in other areas of specification content. Other areas where these skills could be developed have been exemplified throughout this specification.

Table 8: Arithmetic and numerical computation

Mathematical skill number	Mathematical skills	Exemplification of mathematical skill in the context of A-level Environmental Science (examples are not limited to those given below)
MS 0.1	Recognise and make use of appropriate units in calculations	Students should demonstrate their ability to: • convert between units such as length and volume, eg calculating surface area: volume ratios in energy conservation • select appropriate units and values for a calculation, eg estimating water and organic matter content of soils.
MS 0.2	Recognise and use expressions in decimal and standard form	Students should demonstrate their ability to: • use an appropriate number of decimal places in calculations, eg calculating mean population density from multiple sample sites in a habitat • carry out calculations using numbers in standard and ordinary form, eg when comparing production of different energy resources • convert between numbers in standard and ordinary form, eg when using masses in biogeochemical cycles.

Mathematical skill number	Mathematical skills	Exemplification of mathematical skill in the context of A-level Environmental Science (examples are not limited to those given below)
MS 0.3	Use ratios, fractions and percentages	Students should demonstrate their ability to: • calculate percentage yields, eg in pollution control • calculate surface area to volume ratios and relate this to heat loss • calculate and compare percentage loss, eg of rain forests over a given time period or of declining populations of endangered species.
MS 0.4	Estimate results	Students should demonstrate their ability to: • estimate results to sense check that the calculated values are appropriate, such as when calculating residence times in different water reservoirs.
MS 0.5	Use calculators to find and use power, exponential and logarithmic functions	Students should demonstrate their ability to: • interpret population growth curves • compare noise values quoted in decibel units.

Table 9: Handling data

Mathematical skill number	Mathematical skills	Exemplification of mathematical skill in the context of A-level Environmental Science (examples are not limited to those given below)
MS 1.1	Use an appropriate number of significant figures	Students should demonstrate their ability to: • report calculations to an appropriate number of significant figures given raw data quoted to varying numbers of significant figures, eg in calculating indices of biodiversity • understand that calculated results can only be reported to the limits of the least accurate measurement, eg in estimating lifetimes of mineral reserves.
MS 1.2	Find arithmetic means	Students should demonstrate their ability to: • find the mean of a range of data, eg mean power output of a wind farm.

Mathematical skill number	Mathematical skills	Exemplification of mathematical skill in the context of A-level Environmental Science (examples are not limited to those given below)
MS 1.3	Construct and interpret frequency tables and diagrams, bar charts and histograms	Students should demonstrate their ability to: • represent a range of data in a table with clear headings, units and consistent decimal places, eg to compare the energy density, production cost, carbon intensity and mean load factor for a range of energy resources • interpret data from a variety of tables, eg data relating to aquifer flow rates • plot a range of data in an appropriate format, eg atmospheric carbon dioxide levels, atmospheric temperature and solar output over time represented on a graph • interpret data from a variety of graphs, eg change in electricity cost from renewable energy sources, industrial output and level of financial incentives/tax over a number of years.
MS 1.4	Understand simple probability	Students should demonstrate their ability to: • use the term probability appropriately when investigating causal relationships such as the link between human health problems and urban pollutants.
MS 1.5	Understand the principles of sampling as applied to scientific data	Students should demonstrate their ability to: • analyse random data collected by an appropriate means, eg use Simpson's index of diversity to compare the biodiversity of habitats exposed to different pollution types or management regimes • analyse systematic data along a transect to monitor impacts of pollution with increasing distance from a copper smelter.
MS1.6	Understand the terms mean, median and mode	Students should demonstrate their ability to: • calculate or compare the mean, median and mode of a set of data, eg of yields of fish farmed under different conditions or fish from commercial catches.
MS 1.7	Use a scatter diagram to identify a correlation between two variables	Students should demonstrate their ability to: • interpret a scatter graph, eg to compare human development index with environmental footprint of different countries.

Mathematical skill number	Mathematical skills	Exemplification of mathematical skill in the context of A-level Environmental Science (examples are not limited to those given below)
MS 1.8	Make order of magnitude calculations	Students should demonstrate their ability to: • compare storage volumes of natural water reservoirs and transfer rates • calculate national energy use from population and individual use data.
MS 1.9	Select and use a statistical test	Students should demonstrate their ability to select and use: • the chi-squared t test (goodness of fit and association) • the Student's t-test • Spearman's rank • Mann-Whitney U test
MS 1.10	Understand measures of dispersion, including standard deviation and range	Students should demonstrate their ability to: • calculate the standard deviation, eg of crop yield for a given nutrient input • understand why standard deviation is a useful measure of dispersion for a given set of data, eg for comparison with other data sets with different means such as populations of endangered species under different management regimes.
MS 1.11	Identify uncertainties in measurements and use simple techniques to determine uncertainty when data are combined	Students should demonstrate their ability to: • calculate percentage error where there are uncertainties in measurement, eg estimating total population using sub-samples in a preliminary study.

Table 10: Algebra

Mathematical skill number	Mathematical skills	Exemplification of mathematical skill in the context of A-level Environmental Science (examples are not limited to those given below)
MS 2.1	Understand and use the symbols : = < << >> > and ~.	No exemplification required.
MS 2.2	Change the subject of an equation	Students should demonstrate their ability to: • use and manipulate equations, eg nutrient transfer rates, energy conversion efficiencies and fish maximum sustainable yields.

Mathematical skill number	Mathematical skills	Exemplification of mathematical skill in the context of A-level Environmental Science (examples are not limited to those given below)
MS 2.3	Substitute numerical values into algebraic equations using appropriate units for physical quantities	Students should demonstrate their ability to: • use a given equation, eg Simpson's index of diversity: $D = \frac{N(N-1)}{\Sigma n(n-1)}$ to assess the impact of a new habitat management regime.
MS 2.4	Solve algebraic equations	Students should demonstrate their ability to: • solve equations in an environmental context, eg calculations using the universal soil loss equation to assess the effectiveness of soil conservation programmes.
MS 2.5	Use logarithms in relation to quantities that range over several orders of magnitude	Students should demonstrate their ability to: • use a logarithmic scale in the context, eg of noise pollution levels.

Table 11: Graphs

Mathematical skill number	Mathematical skills	Exemplification of mathematical skill in the context of A-level Environmental Science (examples are not limited to those given below)
MS 3.1	Understand data presented in a variety of graphical forms	Students should demonstrate their ability to: • interpret data in a range of graphical forms, including line graphs, which may involve logarithmic scales, bar charts, stacked bar charts, histograms, kite diagrams, pie graphs, scatter graphs, 3-dimensional graphs, flow diagrams, Sankey diagrams and circular (radar) diagrams to enable a wide variety of data to be analysed.
MS 3.2	Translate information between graphical numerical and algebraic forms	Students should demonstrate their ability to: • understand that data may be presented in a number of formats and be able to use these data, eg dissolved oxygen levels, soil erosion rates.

Mathematical skill number	Mathematical skills	Exemplification of mathematical skill in the context of A-level Environmental Science (examples are not limited to those given below)
MS 3.3	Plot two variables from experimental or other data	Students should demonstrate their ability to: • select an appropriate format for presenting data, bar charts, histograms, graphs and scattergraphs, eg organic matter and oxygen depletion, nutrient inputs and yield increase.
MS 3.4	Understand that y = m x + c represents a linear relationship	Students should demonstrate their ability to: • predict/sketch the shape of a graph with a linear relationship, whether with a positive or negative correlation, eg the relationship between insolation and solar panel output
MS 3.5	Determine the intercept of a graph	Students should demonstrate their ability to: • read an intercept point from a graph, eg the temperature at which oxygen levels fall too low to support particular aquatic species.
MS 3.6	Calculate rate of change from a graph showing a linear relationship	Students should demonstrate their ability to: • calculate a rate from a graph, eg rate of infiltration through rocks with different permeabilities.
MS 3.7	Draw and use the slope of a tangent to a curve as a measure of rate of change	Students should demonstrate their ability to: • use this method to measure the gradient of a point on a curve, eg rate of heat loss through double glazing with varying gaps.

Table 12: Geometry and trigonometry

Mathematical skill number	Mathematical skills	Exemplification of mathematical skill in the context of A-level Environmental Science (examples are not limited to those given below)
MS 4.1	Calculate the circumferences, surface areas and volumes of regular and irregular shapes	Students should demonstrate their ability to: • calculate the circumference and area of nature reserves to assess the impact of the edge effect on wildlife conservation programmes • calculate the surface area and volume of cylinders or spheres, eg to estimate rates of heat loss in energy conservation programmes.

8 Appendix C: Previous science learning

To develop skills and knowledge in A-level Environmental Science, students should have the skills and knowledge associated with at least GCSE Combined Science or equivalent. While an understanding of all GCSE Combined Science or equivalent topics is advantageous, there are a number of topics that have particular applications in A-level Environmental Science.

The following table illustrates the GCSE Combined Science topics that have particular applications in the development of skills and knowledge in A-level Environmental Science.

GCSE Combined Science topic	Application in A-level Environmental Science
Osmosis	Hydrosphere: unsustainable exploitation.
Levels of organisation within an ecosystem	Conservation of biodiversity. Life processes in the biosphere and conservation planning.
The principle of material cycling	Biogeochemical cycles. Sustainability.
Biodiversity	Conservation of biodiversity. Life processes in the biosphere and conservation planning. Sustainability.
The genome	The importance of the conservation of biodiversity: • genetic resources • captive breeding and release programmes. Agriculture: genetic manipulation.
Variation and evolution	The importance of the conservation of biodiversity: • genetic resources • captive breeding and release programmes. Agriculture: genetic manipulation.

GCSE Combined Science topic	Application in A-level Environmental Science
Selective breeding and gene technology	The importance of the conservation of biodiversity: • genetic resources • captive breeding and release programmes. Agriculture: genetic manipulation.
Chemical symbols, formulae and equations, including reaction stoichiometry and masses of reactants and products	Global climate change Ozone depletion Biogeochemical cycles Energy Pollution
Chemistry of acids	Pollution: • acid precipitation • acid mine drainage • heavy metals.
Electrolysis	Energy: • fuel cells • the hydrogen economy.
Exothermic and endothermic reactions	Energy Sustainability
Carbon compounds	Energy Sustainability
Life cycle assessment and recycling	Mineral resources Sustainability
Fractional distillation of crude oil and cracking	Energy: fossil fuels.
Different methods of extracting and purifying metals	Mineral resources Sustainability
The composition and evolution of the Earth's atmosphere since its formation	Atmosphere
Carbon dioxide and methane as greenhouse gases	Atmosphere Sustainability: carbon footprints.
Common atmospheric pollutants and their sources	Pollution

GCSE Combined Science topic	Application in A-level Environmental Science
The Earth's water resources and obtaining potable water	The hydrosphere
Conservation, dissipation and national	Energy
Atomic structure	Energy: nuclear power. Pollution: ionising radiation.

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