Scottish Natural Heritage

Gravel Working in the River Tay System
A Code of Good Practice

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Scottish Natural Heritage
All of nature for all of Scotland

UNIVERSITY OF STIRLING

Conservation of Atlantic Salmon in Scotland

NATURA 2000

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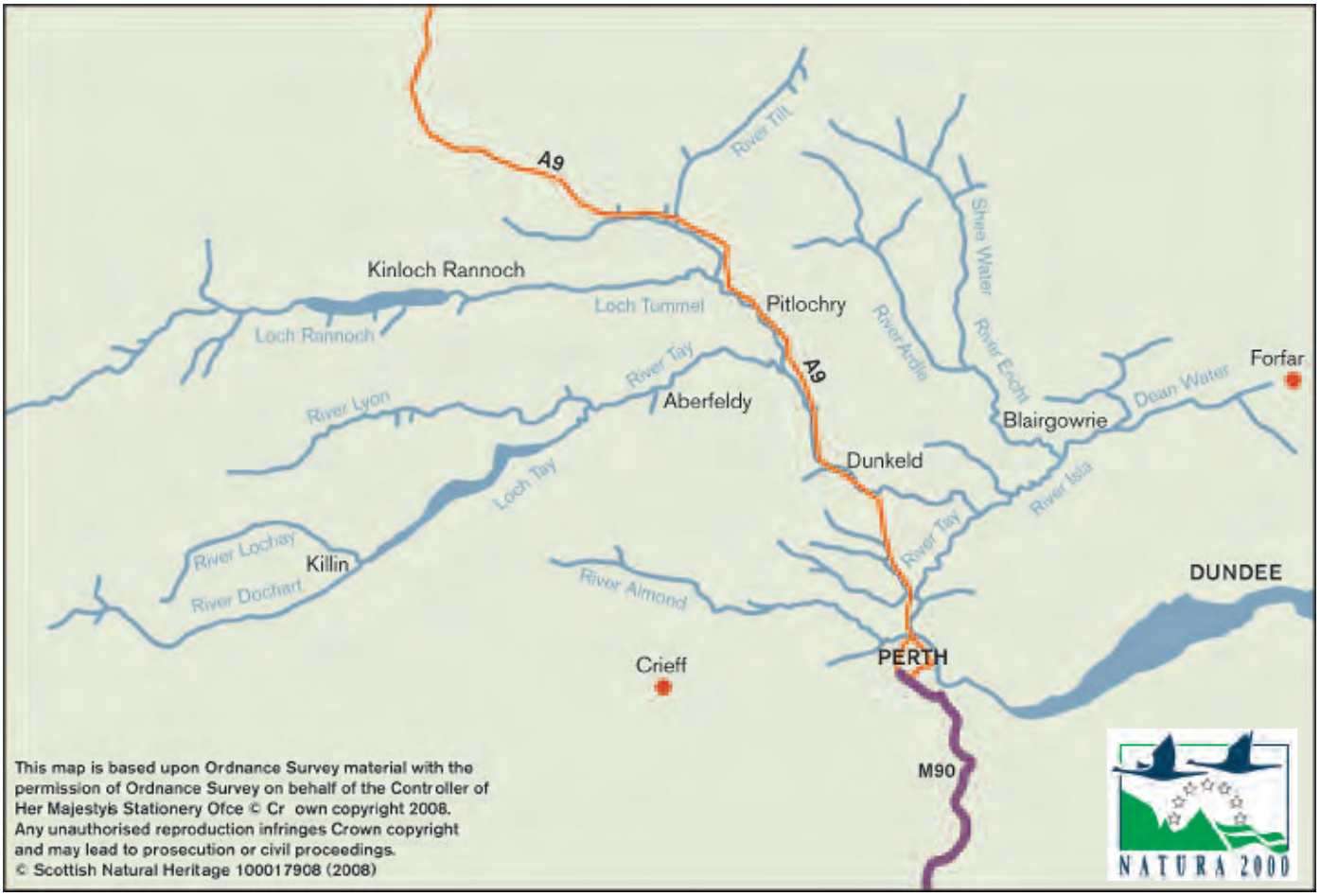


Map showing extent of River Tay SAC

INTRODUCTION

This guidance provides good management practice advice for anyone considering gravel extraction or management in the River Tay and its tributaries.

It is for gravel works associated with flood alleviation, land drainage, aggregate working, fisheries improvements, flood protection and the protection of bridges and culverts.

It supplements sediment management guidance from SEPA, the responsible authority for sediment management under the *Water Environment (Controlled Activities) (Scotland) Regulations 2005*.

THE IMPORTANCE OF RIVER GRAVEL

What is gravel?

- Gravel is a highly mobile material which erodes in some areas and deposits in others.
- River gravel comprises a mixture of particles larger than sand (greater than 2mm in diameter) but smaller than boulders (less than 256mm in diameter).

Why is gravel important?

- Natural gravel movements create a varied river channel with deep pools, shallows and exposed accumulations of gravel. These in turn create various types of flow and so provide a mosaic of habitats for fish and other species under normal, drought and flood conditions.
- Gravel provides a habitat on and within which many aquatic organisms complete one or more stages of their lifecycle, and is used by them to escape hostile floodwaters.
- Exposed accumulations of gravel are important as havens for a range of terrestrial plants and animals.

What is special about the River Tay's gravel resource?

- The River Tay contains one of the largest volumes of gravel found in any river in the UK.
- The flood flows of the River Tay are the largest of any UK river. The most significant movements of gravel in a river system occur during flood flows because the energy available to lift and carry gravel will be at its greatest and because of the amount of gravel in the River Tay, its movement during flood flows will be among the largest in the UK.
- The River Tay hosts five freshwater species of European importance: the Atlantic salmon, brook, river and sea lampreys and the freshwater pearl mussel. All these species depend on gravel for their survival.

For the above reasons, the gravel resource in the River Tay is among the most important and the most vulnerable in the UK. Any gravel extraction or management work will have substantial impacts.
Appropriate gravel management is ESSENTIAL!

Bridge pedestal at Pass of Killiecrankie during summer (above) and during a winter (below) flood.

By kind permission of Mr Thomas Rattray

Gravel Working: A Position Statement for the River Tay and its tributaries

The shape of a river's channel is in a constant state of flux as it adjusts to changes in the amount of water, and so energy flowing through it; rivers are then said to be in a state of 'dynamic equilibrium'. Interference, such as gravel extraction, with natural river systems upsets this state and often leads to problems outwith the area of interference, frequently downstream. This, combined with the high wildlife interest associated with gravel in the River Tay, means that **there is a presumption against gravel working in the Tay except in the case of flood alleviation and protection work**.

In these specific circumstances authorisation MUST be granted by SEPA under the Controlled Activities Regulations. **If permission is not obtained you will be committing an offence.** Phone your local SEPA office or check their website for further details **www.sepa.org.uk/wfd/index.htm**.

"As a river scientist, having observed and studied the River Tay for almost 20 years, the ever-changing character of the river bed and its importance to plants and animals still impresses me. The present generation of river managers and riparian owners need to change the way they view their gravel resource and safeguard its existence for the future well-being of the river"

Dr David Gilvear, University of Stirling

Why is this guidance important to me?

- Both the position of the River Tay and the amount of gravel in its channel as it passes through your land are constantly changing.

- The undisturbed natural movement of gravel from headwaters to river mouth allows the channel and flow to maintain the 'dynamic equilibrium'. Interference in this process by extraction or manipulation of gravel may impair the natural process and produce unpredictable results i.e. gravel work to ease flooding in one place may result in erosion or worse flooding further downstream.

- Extraction and manipulation of gravel will damage the bed armour which will lead to loss of gravel and channel destabilisation – flood damage will increase.

- Due to natural and man made sediment traps in the River Tay, natural gravel replenishment will decline over time. Extraction operations will speed the rate of decline and hasten the reduction in total gravel volume. Less gravel may lead to more erosion and endanger flood protection structures.

- Changed river flows, as a result of climate change are likely to increase natural gravel re-working throughout the Tay catchment. This may result in large local accumulations of gravel. However gravel should be viewed as a precious and finite resource, which must be protected.

SUMMARY GUIDANCE

This table summarises activities which are presumed against by SNH on the River Tay Special Area of Conservation. We recommend alternatives. Relevant authorisations from SEPA under the Controlled Activity Regulations must still be granted prior to any work being carried out.

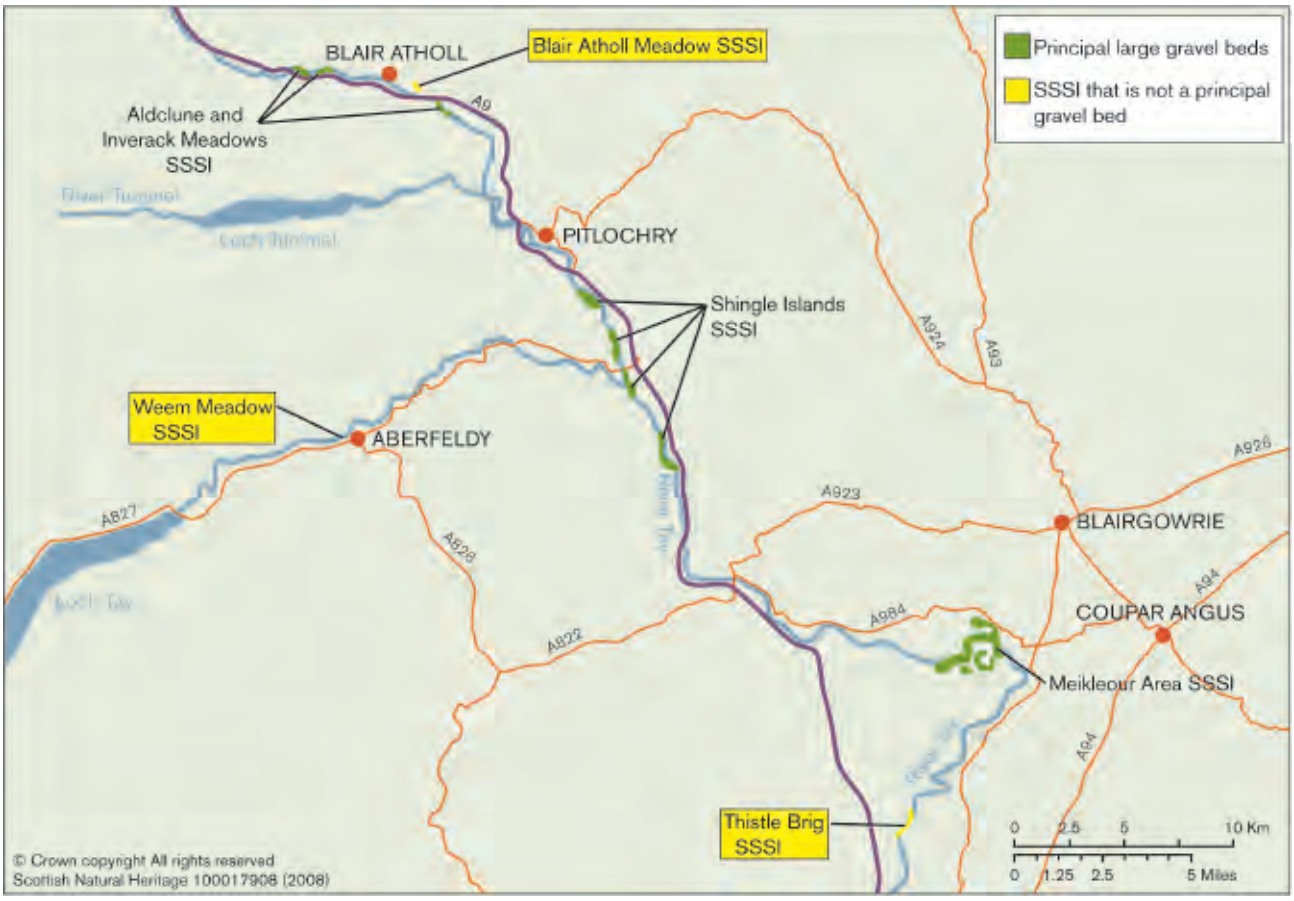
Activity	Avoid	Recommendations
Land drainage	• Removing gravel to increase flow of water and deepen river. All this might do is cause erosion and flooding problems downstream • Skimming off the top layer of gravel to increase flows, this is the "armour layer" and could destabilise large gravel beds in medium - high flows	• Alternatives such as sediment source control or channel restoration should be considered. SNH and SEPA must be consulted. • Remove small amounts of gravel accumulation which have formed around outfalls from field drains • Prevent sedimentation of gravels downstream of work • Carry out any gravel work during period of least ecological sensitivity i.e. June to October
Aggregate extraction	• Taking gravel from dry beds in the channel when they are exposed during low flows • Taking gravel from plant-rich stable beds just outwith the river channel • Carrying out in-river gravel extraction • Taking gravel from bars • Skimming off the top layer of gravel, this is the "armour layer" and could destabilise large gravel beds in medium - high flows	• Take gravel from dry borrow pits, above the water table, elsewhere on land away from river • Ensure pits are located outside the riparian zone • Do not process or wash gravel where waste water can contaminate waterways • Implement a fish rescue plan when fish become trapped in pits during floods. • Locate pit in an area where there is minimal possibility of future stream connection. Hydrogeomorpholgical studies can help predict this.
Fisheries management	• Cleaning out pools, using river gravels for croy repair or carrying out channel modification. Feedback from fisheries managers and others is that there is little need for gravel removal for fisheries on the Tay and often it is not feasible due to the size and depth of the river.	• Undertake planned habitat restoration work which directly improves salmonid habitat. SNH, SEPA and the Tay District Salmon Fishery Board should be consulted. • Carry out any work during period of least ecological sensitivity i.e. June to October

Activity	Avoid	Recommendations
Flood alleviation	• Undertaking small-scale flood alleviation works unless in case of emergency. There is little objective or scientific evidence that the perceived benefits are real or more than temporary. Flood alleviation works could have serious knock-on effects downstream	• Before implementing a major flood alleviation scheme, impacts on sediment transport should be modelled and investigations of the causes of flooding and an appraisal of all alternatives should be made. SEPA should be contacted for advice on how to do this • Ensure there is negligible increase in bed scour to preserve spawning beds • Avoid bar removal to maintain channel complexity if possible • Prevent sedimentation of gravels downstream of work • Carry out any flood alleviation work during period of least ecological sensitivity i.e. June to October • Use excavated gravel to replenish the river system down-stream, don't remove from site. • Avoid riparian areas and stable vegetated bars if possible • Leave woody debris if possible
Protection of bridges & culverts	• Undertaking small-scale protection works unless in case of emergency. Any works could have serious knock-on effects downstream	• Justified on small scale to protect integrity of structures. Recurring problems suggest the need to undertake specialist work to find a longer term solution • Prevent sedimentation of gravels downstream of work • Carry out any protection work during period of least ecological sensitivity i.e. June to October • Use excavated gravel to replenish the river system downstream, don't remove from site. • Avoid riparian areas if possible • Leave woody debris if possible

See links to further guidance on page 27

THE CHANGING NATURE OF THE GRAVEL RESOURCE IN THE RIVER TAY

Where are the large gravel beds in the Tay system at present?



How much gravel is there in the River Tay?

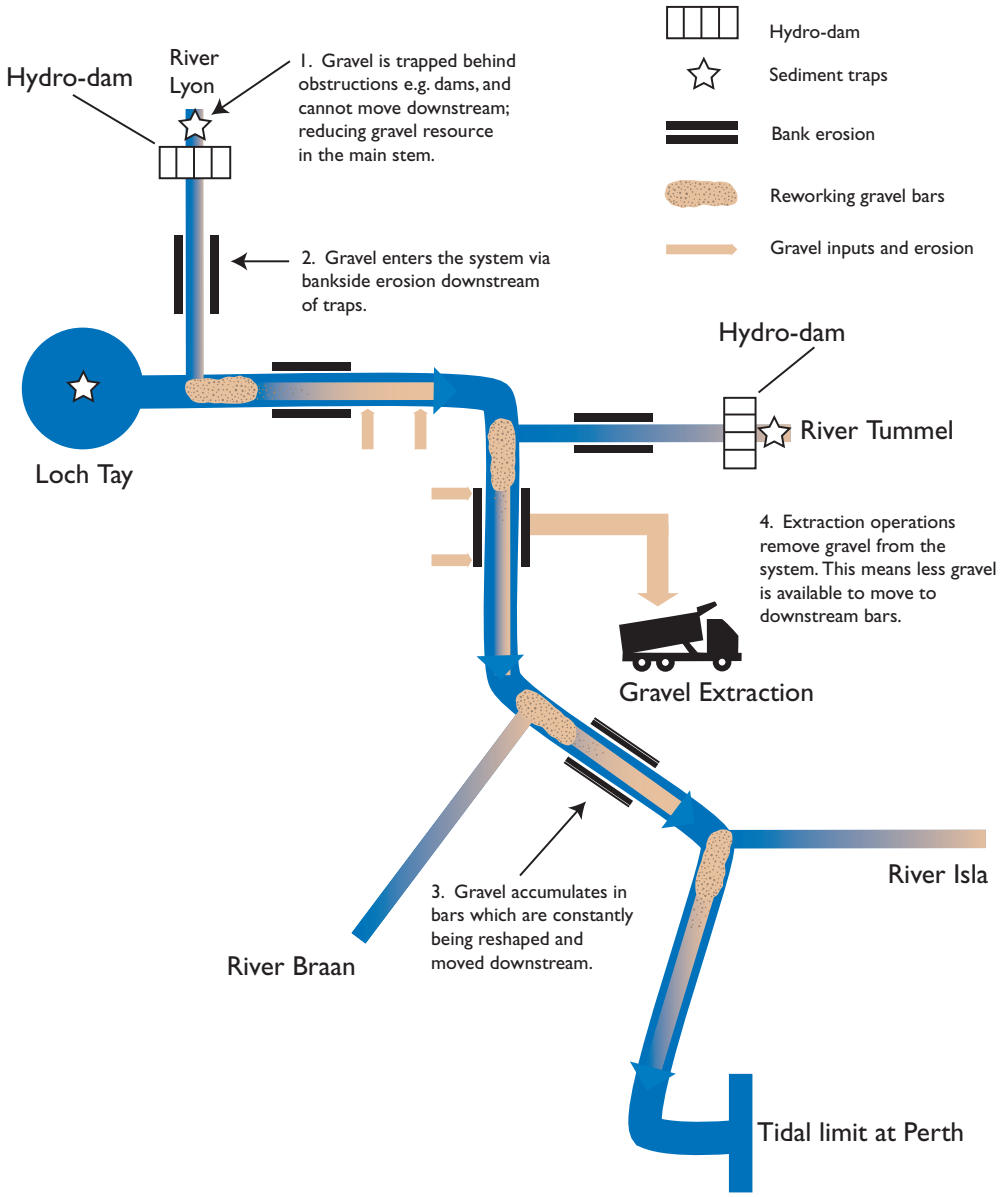
It has been calculated that the total gravel resource downstream of Loch Tay on the main stem of the Tay is over 3.3 million tonnes (t) with figures ranging from zero in bedrock reaches at locations such as Grandtully and Stanley falls, to 30-40,000t at locations such as Shingle Islands near Ballinluig and the Bloody Inches at Meiklour.

This was calculated through a sediment audit. The sediment audit was done primarily using colour aerial photography and measuring the width and area of submerged and exposed gravels. Bed material size was measured at various locations along the river.

Gravel transport through the River Tay

Significant movements of gravel in a river system occur during flood flows because the energy available to entrain and transport gravel will be at its greatest. Volumes of sediment in one reach change over the course of a year as they accumulate and dwindle in response to changes in flow. The movement of gravel along a river channel has been likened to a 'jerky conveyor'. Gravel extraction interrupts this process. If the volume taken from a reach equals or exceeds the rate of natural replenishment the conveyor is broken and the amount of gravel available for transport to downstream reaches diminishes. Depriving downstream reaches of sediment may lead to erosion and harm to species that depend upon gravel for their survival.

A useful tool to help predict the effects of management work in gravels is a sediment transport model. A sediment transport model uses an equation that predicts sediment transport for particular channel and flow characteristics. Accurate and detailed information on gravel size, channel shape, bed slope and the range of possible scenarios is needed for the model to estimate how any alterations to the natural set of conditions would impact on sediment transport.



5. Gravel leaves the system through the Firth of Tay. As more sediment is trapped or extracted, transportation through the system will decrease.

The diagram on page 13 shows the main processes of, and factors affecting, gravel movement through the River Tay. These are erosion, transport, deposition and reworking, sediment traps and removal of gravel from the system.

Erosion

The high velocity of water in the headwaters of the Tay river system causes natural erosion of stream banks and beds. The material produced from this erosion is gravel - a legacy of the last glaciation period that ended about 10,000 years ago. Unregulated (natural, unengineered) tributaries are the main source, but re-working of gravel islands and bank erosion on the main river stem provides a further gravel input in a few limited reaches. In recent history, bank protection works have prevented this erosion leading to 'starving' the system of gravel in the long-term.

Transport

The river acts as a giant conveyor belt moving the historical store of gravel from the headwaters to the river mouth. Material lost downstream is replenished by erosion in the upper reaches of the river. Only during flood events are significant levels of gravel transported and gravel islands re-worked. This creates a river bed with deep pools and shallows and areas of slow and fast moving water. Large accumulations of gravel above the normal water level are natural features of the river.

Fresh gravel dumped within the River Tummel during a flood event

"The floods of December 2006 caused new pools to form on the River Lyon whilst others disappeared. Pools which filled up with gravel were cleared out again in subsequent floods"

Dr David Summers,
Tay District Salmon Fishery Board

The surface layer of gravel bed rivers is often armoured with a layer of generally coarser particles providing a protective blanket to an assortment of finer gravel beneath. The armour prevents the fine gravel from being lifted and transported under all but flood flow conditions. The armoured layer is important to maintain the gravel resource and partially stablise the channel.

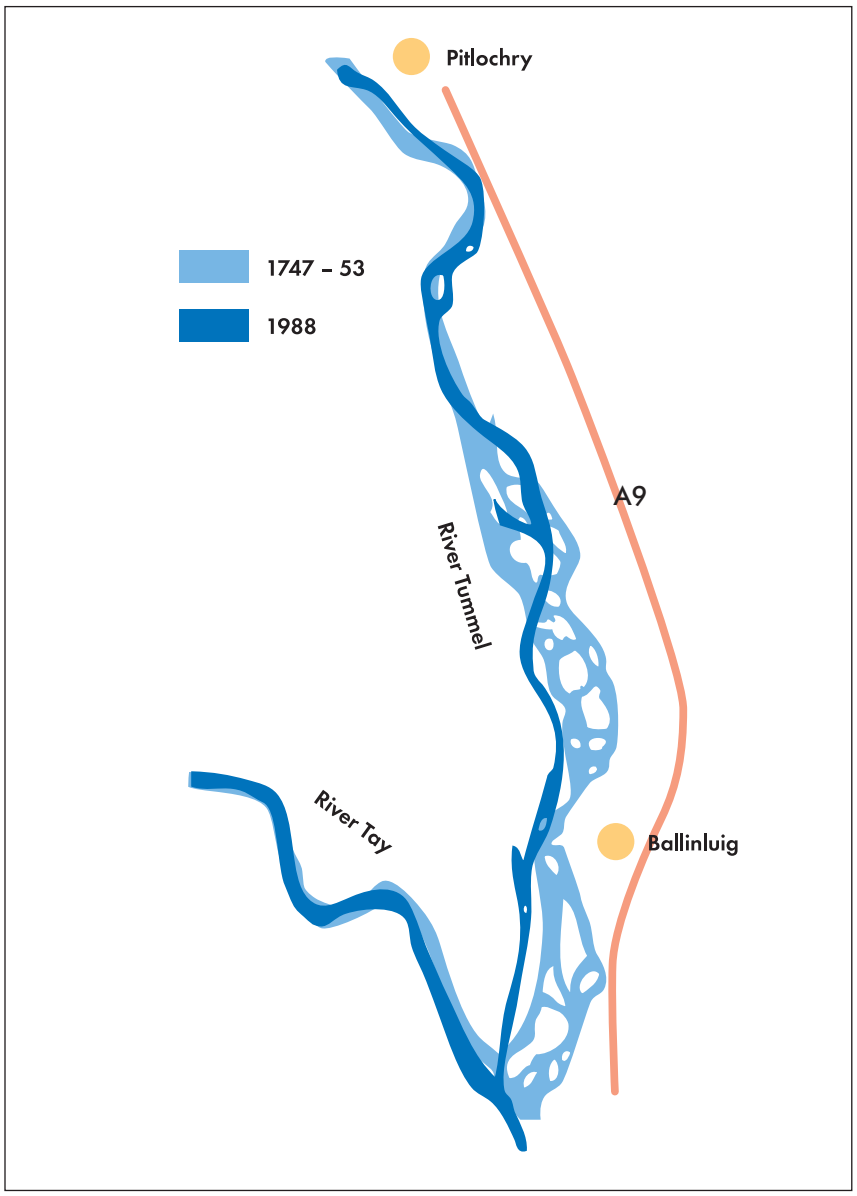
Deposition and reworking

Gravel is deposited in areas of slower flow to create gravel bars and islands. Some of these islands can be in various stages of vegetation colonisation, creating unique habitats which have been given protected status. Gravel bars and islands create a multi-channelled river mainstem.

Floodwaters move and deposit gravel to create a channel that is in 'equilibrium' with the river flow.

This means large gravel deposits are reworked and river channels change position over time. The River Tay has undergone extensive morphological (structural) alterations over the last few centuries in the form of bank protection, straightening and embanking. This has now "straight-jacketed" the channel reducing the level of sediment input from bank erosion and thus the extent of gravel based habitats. This is illustrated in the figure overleaf which shows the historical change in river channel position near Dowally. This artificial management of the river has affected the natural deposition and reworking of gravel, leading to the need for more management of the river system. A natural river system means less management is required.

Channel changes on the River Tummel over time



Based on an original by Dr Sandra Winterbottom, University of Stirling

Sediment traps

For the 'conveyor belt' to function effectively there must be replenishment of gravel from the upper reaches to replace the gravel lost through the river mouth. However, man-made sediment traps in the River Tay system mean that the conveyor belt has been interrupted. Loch Tay and extensive reservoirs and dams in the west of the catchment are trapping sediment and 'starving' the system downstream of gravel. Most gravel movement and replenishment today is from existing deposits. For these reasons, along with reduced erosion due to bank protection works, gravel within the watercourses that make up the River Tay should be viewed as a non-renewable resource.

Removal from the system

Commercial and individual operations to extract gravel for a number of purposes are widespread on the River Tay. Any extraction operation depletes the gravel resource and contributes towards 'starvation' of the river system of gravel further downstream.

Gravel extraction exacerbates the problems of downstream gravel replenishment caused by sediment traps and bank protection works. It disrupts the 'conveyor belt' and reduces the ability of the river to redistribute gravel to accommodate floodwaters. Flood damage will increase.

Gravel transport and climate change

Due to climate change, the increasing severity of storm events will likely cause an increase in frequency and magnitude of floods. Reworking of gravel deposits will in turn increase to help the river cope with flood events.

Whilst the overall amount of gravel replenishing the system is reducing, the recent large number of severe storm events and floods have re-worked the bed of the river with some reaches experiencing infilling of deep pools, and large banks of gravel accumulating in others. Indeed, given that climate change is happening, large accumulations of gravel are likely to be an even more visible phenomena.

During storm events some minor tributaries have and will continue to inject gravel, creating locally impressive accumulations but these volumes do not make up for those lost downstream in the main river during large floods such as that seen in December 2006. Locally, gravel may seem in plentiful supply but the reality is that it is a precious and diminishing resource. This is reflected in some previously shallow reaches having been scoured to bed rock and replaced by deeper water.

Creation of single thread channels

When the rate of gravel extraction exceeds replenishment rates, or when gravel extraction reduces the amount of sediment available to be transported downstream, single-thread channels are formed over time. This means during floods the capacity of the river to accommodate excess water is reduced and floodwaters will spread further over the floodplain. Flood water flowing through a single channel is faster and more erosive and thus may cause more damage to riverbanks and surrounding land.

WHAT IMPACTS CAN GRAVEL WORKING HAVE ON THE WATER ENVIRONMENT OF THE RIVER TAY?

Gravel working, in-river and immediately adjacent to the river, can have seriously damaging impacts on both the physical structure and processes of the river and the associated special wildlife interests.

Potential impacts on the physical environment

Any amount of gravel working can have long-term impacts over large distances downstream. Ill-conceived gravel working can compound problems and lead to conditions where more and more management is necessary. This can be very costly. Land and fishery managers may face a losing battle and instead should adapt to the changing circumstances.

The main, and most serious, impacts are loss of gravel from the system, loss of the river bed 'armour layer', and formation of single thread channels.

Loss of gravel from the system

Gravel extraction will interrupt the jerky 'conveyor belt' movement of sediment downstream. If the amount taken from a reach equals or exceeds the natural input, the conveyor will be broken at that point and the volume of gravel in downstream reaches will slowly diminish over time. Where the volume of gravel removed is less than that of natural replenishment the downstream system will be deprived of the same volume to that removed. Impacts worsen over the long-term with the effects being felt further and further downstream.

Dry removal from exposed bars will have the same effect. Gravel from bars and islands will not be available for remobilisation during floods as the resource has been depleted.

The following table provides further details of what physical effects loss of gravel from the system has and the consequences of these effects.

Element of instream sediment removal	Physical effect	Consequence
Removal of gravel from a location or from a limited reach	Scour of upstream riffles Loss of bed surface armouring Channel incision / bed erosion	Net loss of gravel from system. River's ability to accommodate floodwater is reduced. Flood damage increases. Channel degradation increases erosion and flood damage increases Habitat degradation reduces ability of gravel-dependant species to survive
Removal of gravel from exposed bars	Loss of gravel downstream Less lateral variation in depth and reduced prominence of the pool-riffle sequence Channel degradation	Net loss of gravel from system. River's ability to accommodate floodwater is reduced. Flood damage increases. Channel degradation increases erosion and flood damage increases Habitat degradation reduces ability of gravel-dependant species to survive
Removal of gravel in excess of the input or reduced downstream gravel supply.	Complex channels regress to single thread channels Loss of bed surface armouring Erosion of banks and bars	Increase in current speed increases erosion and causes more flood damage
Removal of vegetation and woody debris from bars and banks	Reduction in shade Decreased channel complexity Decrease in food inputs	Reduction in cover for river species Reduction in number and depth of pools and salmon spawning areas Decrease stream productivity

Loss of the river bed 'armour layer

If gravel work is done by skimming off the top layer of gravel to slightly lower the depth of the bed across a wide area, the natural bed armour will be disrupted allowing bed erosion and increasing bedload transport locally. This results in more gravel being lost from the system.

The table shows the effect of the presence or absence of an armour layer. At discharges close to the threshold for sediment transport the presence of an armour layer can prevent the movement of the underlying material and reduce transport rates substantially. Once flows are large enough to cause disruption of the armour layer modelled rates will be approximately the same with or without its presence.

The effect of substrate armouring on bedload mobilisation under medium and severe flood conditions

Flow	Total Mobilised Bedload (1000 t)		
	Amoured Layer	No Amoured Layer	Difference
Severe flood	1939.9	2364.5	424.6
Medium flood	8.5	769.5	761.0

Old road being washed out beside River Garry – Invervack (Peter McPhail, SNH)

Consequences of climate change for gravel extraction

Increased strength and frequency of floods associated with climate change will have the capacity to move larger volumes of gravel. Flood alleviation schemes need to take account of this.

The volume of sediment movement can be estimated by examining the River Tay sediment audit model output for a 1 in 5 and 1 in 100 flood event. In a 1in 5 year flood, nearly 600,000 tonnes of material are modelled as being mobilised, moving an average distance of 3.17 metres downstream. In a 100 year flood event nearly 2 million tonnes of material is modelled as being mobilised, moving an average of 36 metres downstream.

With the frequency of higher magnitude floods increasing, the model demonstrates that larger amounts of gravel will be moved further downstream with the result of increasing the rate of loss of gravel from the system. This will have consequences in the future as the risks of flood damage will become higher and more severe. The gravel resource will need to be conserved and extraction and management operations strictly managed in order to reduce loss from the system and help lessen the effects of climate change.

Potential impacts on the ecology

Why is the River Tay so important ecologically?

The River Tay and its tributaries has an abundance of wildlife interests which directly depend upon gravel habitats for their survival. Six of these species have a special protected status. The Tay and its many tributaries also have the highest wildlife accolade as part of the Natura 2000 network – a series of internationally important wildlife sites throughout Europe. Additionally, along the banks of the Tay, grasslands and woodlands dependent on the large accumulations of gravel have been notified as Sites of Special Scientific Interest. This means the River Tay contains precious and vulnerable species and habitats which need to be conserved for the future.

Salmon

The Tay is one of the top three salmon rivers in Scotland and supports good numbers of salmon along its length and tributaries. The overall catch in 2006, as with the previous two years, is likely to have been around 10,000.
(Tay District Salmon Fisheries website)

The salmon homing instinct draws them back to spawn in the river of their birth. This behaviour has resulted in genetically distinct stock within individual rivers and in large rivers such as the Tay there is further genetic distinctiveness in the many tributaries.

The high proportion of the River Tay accessible to salmon has resulted in the river supporting the full range of life history types found in Scotland, with adult salmon entering the River Tay throughout the year to spawn in different parts of the catchment. Clean gravel is required for spawning as this is where salmon excavate 'redds' and deposit eggs, and where the young hatchlings remain for the early stages of their lives.

Freshwater pearl mussel

Freshwater pearl mussel (FWPM) are long-lived (100+ years) molluscs that live buried or partially-buried in the sand and gravel on river beds. Due to pearl fishing and pollution they are now an extremely rare species. The remaining Scottish populations are thought to represent at least half of the known worldwide populations.

Juvenile pearl mussels are particularly vulnerable to any increases in fine sediment in a river.

Lamprey

Lampreys are primitive, jawless fish resembling eels, but unlike most fish they have a sucker-like mouth. They belong to the family Petromyzonidae, which translates literally as 'stone sucker'.

The River Tay SAC supports populations of all three lamprey species (brook, river and sea) and these are distributed throughout the catchment.

The lamprey population has declined in some parts of Europe due to increased pressure on its habitat, such as loss of gravel for spawning and silt beds for the juveniles. Habitat has been lost due to water pollution, siltation clogging the gravel beds, and river engineering destroying important habitats or impeding migration.

Herb rich grasslands

Along the river and gravel banks on the shallow, gravel and sandy soils, diverse calcareous and neutral grasslands have often formed. Neutral and calcareous grasslands such as Weem meadow, Shingle Islands and Thistle Brig Sites of Special Scientific Interest comprise a rich diversity of wild flowers and grasses. Throughout Britain these herb rich grasslands have been lost at an enormous rate to

agricultural improvement with 10% lost between the 1940's and 1970's. Riverbanks on the Tay and its tributaries form a stronghold for these once extensive grasslands with six Sites of Special Scientific Interest notified (see map on page 12).

Alluvial Forest

Alluvial forest is found on floodplains on islands in river channels to low-lying wetlands alongside the channels. Alluvial forest is a restricted habitat. In the UK there are only 16 Special Areas of Conservation where this habitat is the primary reason for site selection.

On the Tay system alluvial forests are found primarily within the Rivers Tay and Tummel between Dunkeld and Pitlochry and further downstream at Meikleour. Alluvial forest is part of a dynamic system of successional habitats consisting of a series of extensive riverine shingle areas in various stages of colonisation from bare shingle to mixed woodland, and includes old abandoned river channels. The woodland canopy is varied but dominated by alder, with frequent willows, ash and downy birch. This habitat type usually occurs in small fragments.

River engineering, and modification of the river system by canalisation, abstraction and drainage, has the potential to alter the supply of water and sediment and affect the dynamic nature of the alluvial forest.

Potential ecological impacts on wildlife interests

What might the impacts on the special wildlife interest be?

Salmon and lamprey

Salmon are found throughout the River Tay and lamprey are also widespread, although sea and river lamprey, which are migratory, can not get into the Tummel system above Faskally Dam nor probably above medium sized waterfalls on the Lochay, Lyon, Ericht and Dochart.

The removal of gravel reduces the availability of it for salmon redds or spawning areas of lamprey. The resultant increase in erosion causes the scour of riffles used by juvenile fish and reduces pool areas where adult salmon lie. If fine sediment is released into the watercourses during gravel management, this could result in the gills of salmon being smothered, or their upstream passage impeded. It could also smother the gravels used for spawning salmon and lamprey or the areas used by juvenile fish, making them unsuitable.

Freshwater pearl mussels can be found throughout those parts of the site where salmon have had historical access to – the young larva released by female pearl mussels depend on being inhaled by young salmon or trout to attach themselves to their gills for survival. As pearl mussels are filter feeders and pass considerable amounts of water through their digestive system, they are very vulnerable to water pollution. Juvenile pearl mussels, in particular, are vulnerable to any reduction in water quality as they tend to live entirely buried within the river substrate, therefore they could be affected by sediment loading and untreated gravel washings entering the river.

Residual alluvial forests depend on the ever changing face of the braided river sections of the Tay system. Floods bring new supplies of gravel deposits and remove others so that the transitions from open to more closed communities and from wet to dry woodland are maintained. Gravel management such as gravel removal, bank work and flood protection all result in a reduction in supply and movement of gravels.

Neutral grasslands

These, often narrow, strips of grassland along river banks have formed on the free draining skeletal soils overtopping gravel deposits. They benefit from flooding to bring nutrients and remove rank vegetation. Formed on these narrow strips of land, areas have been lost to erosion due to inappropriate flood protection. Gravel removal, from these vegetated stable beds, for on-farm repairs and for flood bank repair has destroyed areas of this scarce type of habitat.

Freshwater pearl mussel crushed by plant working in river gravel © SNH

Gravel removed from the natural system
David Summers TDSFB

USEFUL RESOURCES

www.sepa.org.uk/pdf/wfd/guidance/engineering/positionstate_sedimentman.pdf

Guidance for competent authorities when dealing with proposals affecting SAC freshwater sites – SNH 2006

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Guidance for competent authorities when dealing with proposals affecting SAC freshwater sites – SNH 2006

www.snh.org.uk

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All of nature for all of Scotland