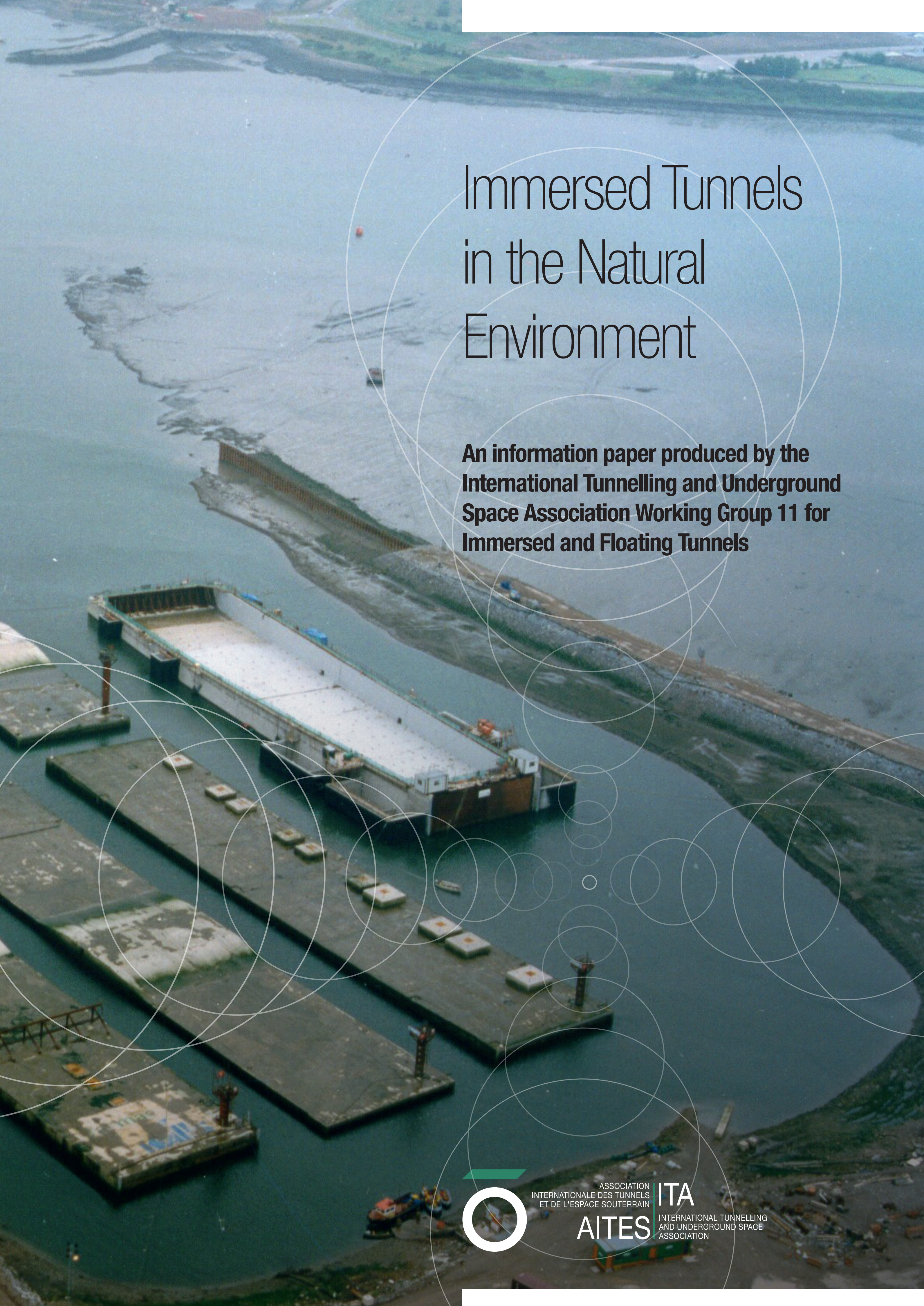

Immersed Tunnels in the Natural Environment

An information paper produced by the International Tunnelling and Underground Space Association Working Group 11 for Immersed and Floating Tunnels

ASSOCIATION INTERNATIONALE DES TUNNELS ET DE L'ESPACE SOUTERRAIN
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ENVIRONMENTAL PROTECTION IS AN IMPORTANT ISSUE TO THE ITA

Society has developed an increased awareness of the environmental impact caused by construction projects.
Immersed tunnels can create underground connections that can be environmentally favourable compared to surface structures. But by going underground we must be careful to protect the environment during construction works.
Most authorities and owners are very responsible in their approach when assessing the impact a project has on its surrounding environmental. However practice varies worldwide and there is a history of unbalanced evaluation of immersed tunnels compared to other forms of crossings. Since not all areas in the world have experience in the immersed tunnel technique it is easy to misunderstand the possible impact. The main objective of this paper is to Increase awareness of how potential environmental impacts arising from immersed tunnel construction can be successfully managed. The main objective of this paper is to inform authorities on this form of tunnelling regarding the impact it has on its environment and to emphasize the benefits and potential mitigations.

WHAT IS AN IMMERSED TUNNEL?

An immersed tunnel is named after its construction method. Prefabricated tunnel elements are floated and transported to the site, where they are immersed and connected underwater to each other, one by one. An immersed tunnel is generally installed in a trench that has been dredged previously in the bottom of a waterway between terminal structures that are constructed in the dry.

The space between the trench bottom and the underside of the tunnel can be a previously prepared gravel bed or a sand bedding layer. Ground improvement is sometimes used where soil conditions require it. As construction proceeds, the tunnel is backfilled. The completed tunnel is usually covered with a protective layer of stone/rock over the roof.

MAIN CONSTRUCTION PROCESSES THAT NEED ENVIRONMENTAL CONSIDERATION

The main construction processes that need environmental considerations are:

- Dredging of the trench
- Breaking through river walls
- Excavation of approaches
- Building casting basins
- Construction in concrete and steel
- Backfilling the trench
- Placing protection on top of tunnel
- Prevention of salt water migrating inland
- Archaeological finds

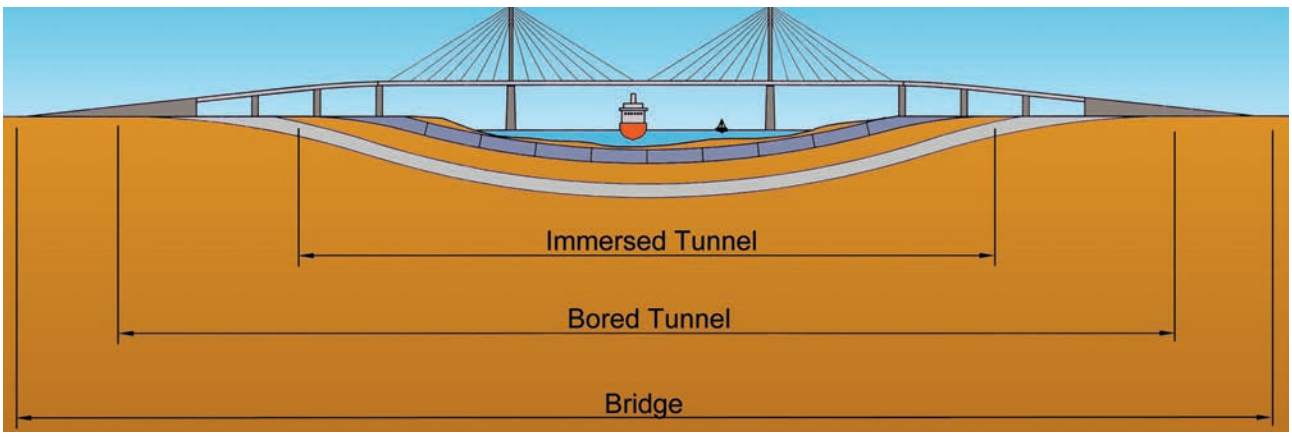
The potential impacts which are typical for the immersed tunnel technique are mostly related to the marine environment.
In particular the disturbance and potential loss of habitat due to the dredging activities may require special attention, and can temporarily affect marine life over a large distance.

COMPARISON OF IMMERSED TUNNELS WITH BRIDGES AND BORED TUNNELS

An immersed tunnel could be the lowest cost solution in certain circumstances. Therefore is it worthwhile to make detailed environmental evaluations of options to make an informed decision. The following environmental aspects can be taken into consideration:

- **Excavated volumes:** Dredging and excavation volumes are greatest for the immersed tunnel, but it should not be overlooked that quantities are large for bridges and bored tunnels also.
- **Sediment spill:** Sediment spill is specific for dredging activities and can have an effect on a large distance but the phenomena is well understood, it can be planned for. Mitigation measures can be applied when needed.
- **Ship traffic and navigation:** Bridges not only restrict the size of vessels, but also introduce the risk of collision.
- **Air traffic:** Near airports construction in the air space is often prohibited which restricts the height of long span bridges to avoid interference with aerial navigation.
- **Alteration of landscape:** Tunnels are invisible, and therefore they do not disturb the landscape for centuries. The portal structures of an immersed tunnel can be positioned closest to the shoreline which is sometimes an advantage.
- **Alteration of seabed:** Although the area is larger for an immersed tunnel compared to a bridge, the impact is only short term.
- **Hydrological alterations:** Impact is short term only (and therefore not permanent) for an immersed tunnel – this can be modelled and understood, and mitigation works can be applied.
- **Noise and vibration:** Noise emissions for tunnels are much lower compared to bridges. Immersed tunnels require the smallest portals which is beneficial for limiting noise disturbance. The effect of underwater noise to the environment during construction can be relevant to immersed tunnels and bridges but can be managed and mitigated.
- **Light pollution:** For the tunnel solutions the light pollution is focussed on the portals rather than the length of a bridge crossing.
- **Air quality:** The issues are the same for bored and immersed tunnels – concentrations of pollutants at the portals need to be managed.
- **Social-economic factors:** Local contractors can construct both bridge and tunnel. Specialist knowledge is only required for small part of the scope.
- **Visual intrusion:** The public can have a very strong opinion towards visual impact when it concerns above-ground structures.
- **Cultural heritage:** The bored tunnel is a trenchless construction method, but does require larger portal structures on land compared to immersed tunnels.
- **Carbon footprint:** All forms of crossings use large volumes of steel and concrete. Immersed tunnels probably have the greatest volumes unless the bridge crossing is a high level, multi-modal crossing. But due to smaller elevation in height the energy consumption of the users will be lower and therefore the footprint during the operation may be lower for immersed tunnels.

ENVIRONMENTAL ASPECTS	Excavated volumes	Sediment spill	Ship traffic and navigation	Air traffic	Alteration of landscape	Alteration of seabed	Hydrological alterations	Noise and vibration	Light pollution	Air quality	Social-economic factors	Visual intrusion	Cultural heritage	Carbon footprint construction	Carbon footprint operation
Immersed tunnel	4/4	4/4	1/4	0/4	2/4	2/4	0/4	1/4	2/4	3/4	1/4	0/4	1/4	4/4	2/4
Bored tunnel	3/4	0/4	0/4	0/4	3/4	0/4	0/4	2/4	2/4	3/4	3/4	1/4	1/4	2/4	3/4
Bridge	2/4	2/4	4/4	4/4	4/4	4/4	4/4	4/4	4/4	2/4	2/4	4/4	4/4	4/4	4/4



CASE STUDY: FEHMARNBELT TUNNEL

The fixed link across the Fehmarnbelt will be approximately 18 km long and carry a four lane motorway alongside a twin track electrified railway. It will be built as an immersed tunnel, which was the recommendation following a detailed planning process, during which both a cable-stayed bridge and a bored tunnel were considered and examined. Besides technical and financial arguments there were also environmental considerations which lead to this recommendation such as:

Immersed tunnel vs. cable-stayed bridge:

- Unlike a bridge, the tunnel would not affect navigational safety for marine traffic on the Fehmarnbelt during the operation phase. The risk of a collision between a vessel and the bridge can be minimized, but not eliminated.
- The cable-stayed bridge would have a lesser but permanent impact on the marine environment since its pillars could affect the water exchange in the Fehmarnbelt.
- Unlike a tunnel, a bridge would also be at risk of impairing bird migration in the region.

Both alternatives had proved to be feasible in construction terms and were possibly approvable on environmental grounds, however, it was concluded that the immersed tunnel would be the best overall solution.

Immersed tunnel vs. bored tunnel

- While the construction of the bored tunnel would require a larger construction site on Fehmarn, its effects on Lolland would be less severe compared to those of the immersed tunnel.
- The bored tunnel would avoid a direct impact on the Fehmarnbelt's marine environment. However, the immersed tunnel's impact would be predominantly temporary in that it would be confined to the construction phase.

The overall technical challenge with the construction of a bored tunnel is perceived much higher than for an immersed tunnel and it would pose a significant challenge to the tunnel boring machines. The estimated construction costs for the bored tunnel would be about 25% higher and it would take longer time to construct the bored tunnel (8 years compared to 6.5 years for the immersed tunnel). The repayment period for the project would therefore be longer.

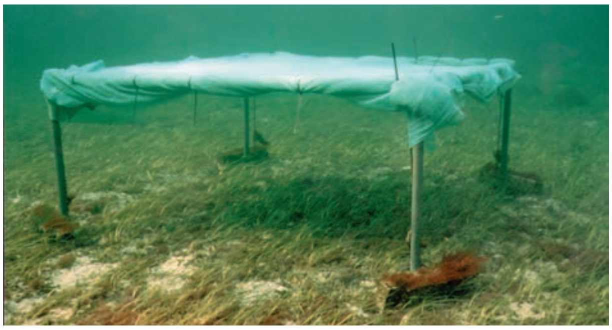
DREDGING WORKS AND THE ENVIRONMENT

The main difference in environmental impact between an immersed tunnel and other forms of crossing is the dredging works, which is essential to create the tunnel trench. During these dredging works there will be a degree of sediment spill. The suspended (and resuspended) materials originating from the dredging activities and leaving the excavation area can cause turbidity of the water. This means less sunlight will be able to penetrate the water and can thus affect plant growth and food availability for fish and birds. Additional effects can be oxygen depletion in the water column and changes to nutrient levels effecting algae growth.

The sediment spilled will normally be quickly dispersed by the currents over large areas and thus it will settle in very thin layers. Only close to the tunnel trench the sediment layers will be thicker and will have a temporary impact. It is important to understand if the ecosystem is naturally accustomed to large amounts of sediment in the water, and will therefore be resilient to small additional amounts arising from the dredging works. To minimize the impact on the marine environment it is normally possible and important to plan the works so the spill will be limited in sensitive seasons in sensitive areas. Modern computer modelling methods can ensure such good planning.

ENVIRONMENTAL MITIGATION FOR MARINE ECOLOGY

Environmental impact assessment is an important prerequisite for all construction projects. For immersed tunnels this process should be used to mitigate possible effects of dredging or disposal on the physical environment, wildlife, habitats, fisheries, archaeology and many other interests.



Control of how much sediment is spilled, is an important parameter in relation to the marine impacts on flora and fauna and is therefore also important in relation to any remedial action (altering dredging intensity or methods) that can be used if sediment dispersal varies significantly from the approved levels.
Some mitigation methods that can be used are:

- Controlled excavation methods to minimise spill
- Shrouded or environmental grabs for containment
- Adjusting dredging methods due to modelling and monitoring of sediment plumes
- No dredging in sensitive areas during sensitive periods
- Provision of compensation sites for feeding/breeding
- Use of silt curtains

By using such mitigation measures the impacts to marine ecology can be successfully managed in all cases provided there is sufficient understanding of the ecology and sufficient effort put into the project planning.

CASE STUDY: BJØRVIKA TUNNEL

The Bjørvika tunnel was built across Oslo's harbour to place traffic underground and improve the surface environment. The river Aker, which runs out into the Bjørvika bay has brought waste and effluent from the saw mills, textile factories, ironworks, mills and paper factories that were located along the river for many decades. Environmentally hazardous substances have therefore been washed straight out into the harbour.

In particular enormous amounts of sawdust have been deposited from historic since saw mill activities. The deposit had become highly acidic with time, containing hydrogen sulphide. The immersed tunnel route also cuts right through a historic dry dock and there were therefore very high levels of ground pollution present.
The sediments in the harbour bed contained heavy metals, oil and organic compounds. The construction works required the most extensive harbour clean-up project ever carried out in Norway. The polluted materials were removed from the seabed of the fjord, from piers and the land areas at either side of the tunnel. Sediment containing heavy metals was removed and neutralized and transported to approved land tips and deep sea fill sites. Clean clay from the dredging works was also used to cap contaminated sediments in other areas of the fjord.
Propeller wash from ships and small boats spreads particles containing environmentally hazardous substances through the water and these are therefore easily available for absorption by marine organisms. Therefore all dredging and excavation works was carried out within silt curtains to contain the sediments.

The River Aker is an active migration route to spawning sites for Atlantic salmon and trout. Water quality had to be preserved during construction and minimum oxygen levels were specified that had to be maintained during dredging and excavation works.
In addition, no blockage to the river entrance was permitted between the months of July and November. Dredging rates and dredging equipment were also restricted to allow monitoring and the recovery of archaeological relics from the harbour that included the remains of a medieval boat.
As the immersed tunnel was the correct technical solution for this site, the effort was put into developing environmental mitigation measures such as restricted dredging rates and the use of silt curtains that led to a successful outcome to the project.

EXAMPLES OF SUSTAINABLE CONSTRUCTION

Immersed tunnel projects can be delivered in a sustainable manner and there are many good examples where creative solutions have been applied to create socio-economic and environmental benefits.

Some examples are:

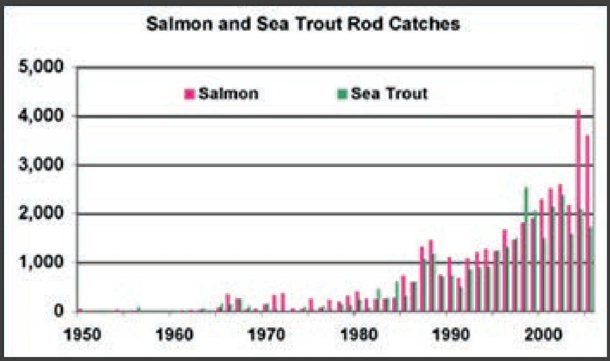
- Most dredged and excavated material is clean and options for beneficial use are numerous sites for example in Copenhagen-Malmö for the Øresund project the dredged material was used to reclaim the Island Peberholm, and it was also used as construction material to build dikes and embankments.
- Another option is to re-use the dredged material again as backfilling material e.g. in Amsterdam for the North South Metroline the dredged material from the tunnel trench was temporarily stored and reused again as backfill.
- Alternatively the backfill material can also be import surplus material from other projects e.g. in Oslo for the Bjørvika tunnel the backfill material consisted of conventional rock tunnelling surplus material.

One step further is re-using dredged and excavated materials for creating ecological habitats, landscaping and mitigation of visual intrusion e.g. in Denmark for the future Fehmarnbelt project the approach of 'Building with Nature' has been adopted in the design of the reclamation areas.

CASE STUDY: NEW TYNE CROSSING

The River Tyne in Newcastle has been impaired by over a century of heavy industrial pollution. Prior to construction of the New Tyne Tunnel intense environmental protection resulted in the recovery of the water quality and the fish populations. Consultation with the environmental agency had led to agreement on a programme of fish monitoring and water quality monitoring, combined with mitigation measures.

Until 1959 no salmon was caught but they returned when the water quality improved, and nowadays the river Tyne has arguably been the finest salmon river in Great Britain. An extensive fish monitoring campaign included upgrading the existing fish counter and fish trap, an angler log book scheme, tagging and installing transponders on salmon and trout, and acoustic tracking of adult fish.$



The dredging of the tunnel trench in the River Tyne took place in the fall/winter of 2009, when the impact on the fish is lowest. The dredging was undertaken using a cutter suction dredger where the dredged material was pumped via a pipe line into a disposal point in a redundant dock. By using this material as fill the dock was reclaimed and later suitable to be redeveloped.

To further optimise the settlement of suspended solids a sheet pile wall was erected, and silt curtains were deployed. At the location where the solids overflow into the river the water quality was monitored with AWQM buoys starting 12months prior to dredging operations. Highly accurate sensors continuously measured dissolved oxygen, turbidity, current velocity and temperature. Further sampling also included monitoring of sediment toxicity chemical contaminants and endocrine disruptors.

The monitoring of the works demonstrated that the estuary system was not negatively affected during the course of the project and the growth of fish population also continued in the construction period.

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