Position paper on the sustainable use of cooling water from the Wadden Sea

Date: 20 October 2010

Author: Zwanette Jager (ZiltWater Advies)

Commissioned by: Waddenacademy-KNAW

TABLE OF CONTENTS

1. Introduction

The energy policy which was revised in 2008 (3rd Power Structure Plan, SEVIII) has resulted in a trend towards the construction of more new power plants at coastal sites. This involves both the replacement of older plants and an expansion of production capacity. Within the Dutch Wadden Sea, Eemshaven is now on the way to becoming a major energy cluster, partly because of its access to deep or deepened water, enabling fuel for the power plants (coal) to be transported in large vessels. The unlimited availability of cooling water and plentiful volume of receiving surface water is another important criterion.

Cooling water is a key factor in electricity generation (see Figure 1). It is used to reduce and remove the residual heat generated during different phases of the process. In systems with a large capacity, at sites where sufficient cooling water and receiving surface water are available, flow-through cooling is usually employed. If the available volume of cooling water is restricted, recirculation systems (cooling towers) or hybrid cooling systems are used.

From the production point of view, flow-through cooling is an energy-efficient method; cooling water consumption is roughly 86 $m^3/h/MW_{th}$.

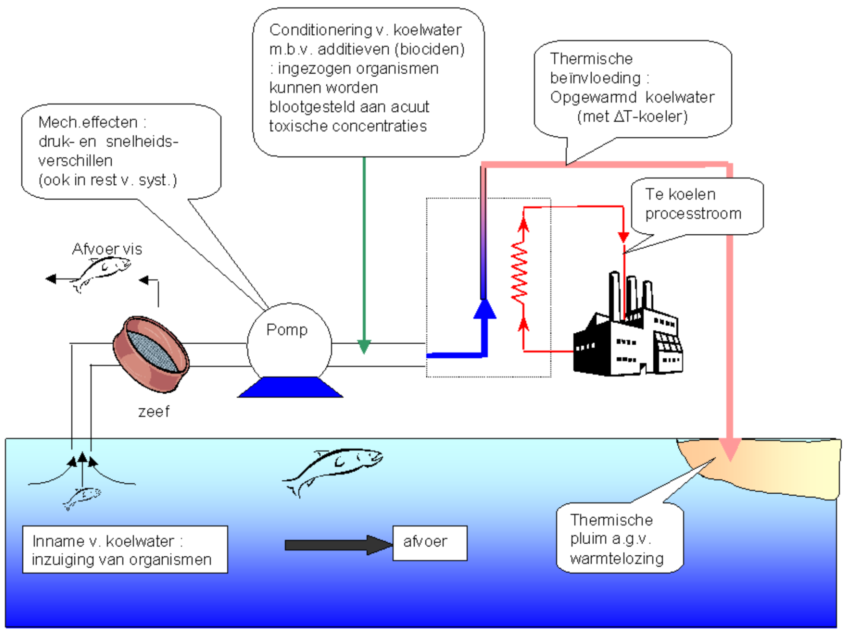

Figure 1. Schematic representation of cooling water used in electricity generation (CIW, 2005).

Mech. effecten: druk en snelheidsverschillen (ook in rest v. syst.	Mechanical effects: pressure and velocity difference (also in rest of system)
Conditionering v. koelwater m.b.v. additieven (boiciden): ingezogen organismen kunnen wordern blootgesteld aan acuut toxische concentraties	Conditioning cooling water with additives (boicides): organisms sucked in may be exposed to highly toxic concentrations
Thermisch beïnvloeding: Opgewarmd koelwater (met ΔT-koeler)	Thermal effect: cooling water heated (using ΔT cooler)
Te koelen processtroom	Process flow to be cooled
Afvoer vis	Fish return
Zeef	Sieve
Pomp	Pump
Inname v. koelwater: inzuiging van organismen	Cooling water intake: organisms sucked in
Afvoer	Return
Thermische pluim a.g.v. warmtelozing	Thermal plume resulting from heat discharge

The effects of cooling water are the abstraction of surface water including living organisms and also the thermal discharge of heated cooling water. To protect the condensers, the cooling water is usually filtered first through a coarse grid and then through a fine-meshed rotating sieve. The debris and organisms that remain on the sieve are returned to the surface water. This treatment causes damage and mortality of organisms. In addition, there is the need to apply anti-fouling treatment in cooling systems. Thermal shock or chemical treatment (chlorination) is applied as anti-fouling. The residues are discharged to surface water.

The thermal discharge takes place in an ecosystem that is already subject to rising temperatures due to climate change. This already leads to shifts in species composition and it disturbs the balance in physiological and ecological processes. If the artificially added thermal discharge exceeds critical thresholds it can have an unexpected impact, which is a consideration when making strategic decisions about the planning of new power plants at coastal locations.

What are the implications of large-scale cooling water extraction from current and future power stations for the Wadden Sea ecology? Can sustainable cooling water withdrawal be achieved and if so how? What technical options are available? What problems, bottlenecks and knowledge gaps exist and how can they be solved? The above issues are addressed in the present document.

2. Power Structure Plan SEV III

The 3rd Power Structure Plan (SEVIII) was adopted in 2008 and aims to guarantee sufficient capacity for the large-scale production and transport of electricity. The SEVIII describes the contours of spatial planning reservations for possible large-scale sites where at least 500 MW of electricity can be generated, as well as global routes of potential high-voltage lines of 220 kV and more. The use of surface water for cooling is possible at each location listed in the SEVIII. If in specific cases the availability of cooling water is a problem, alternatives to cooling will have to be provided.

In the Dutch Wadden Sea, Eemshaven has been designated as a location for large-scale electricity generation. Moreover, Eemshaven is one of the 3 designated safeguarding sites (besides Borssele and Maasvlakte I) for the location of a nuclear power plant. This means that at these locations no developments are allowed which would prevent or seriously hamper the future construction of nuclear power plants at these sites.

To become less dependent on one type of fuel (e.g. natural gas), there is a trend towards diversifying the fuels used in power generation. For the supply of certain fuels (e.g. coal) on large vessels, a location with deep water is a major factor.

3. The new cooling water discharge guidelines in the Netherlands

Due to a series of extremely warm summers in recent years, the limits of cooling capacity in rivers have stretched. This was a stimulus to build large new power plants at coastal locations. The Commission on Integrated Water Management (CIW, 2005) drew up new guidelines for the discharge of cooling water in the Netherlands. The parameters and criteria are summarised in Table 1.

Table 1. Summary of the CIW guidelines for thermal discharges (after CIW, 2005).

Parameter	Old ABK guideline[1]	New CIW guidelines
	Emission demands (generic)	
T cooling water (fresh / marine)	≤ 30 °C	-
ΔT cooling water	Fresh: summer ≤ 7 °C winter ≤ 15 °C Marine: summer ≤ 10 °C winter ≤ 15 °C	-
	Immission demands (generic)	
Heating[2]	≤ 3 °C	≤ 3 °C relative to background T to a maximum of 28 °C[3,4,7]
	Immission demands (water system related)	
Channels/tidal harbours/rivers		
Withdrawal	-	▪ no significant effects in spawning and nursery areas of fish, ▪ proper fish return system, ▪ reduced cooling water flow (optimization)[8]
Mixing zone (T >30 °C)[5,6]	-	< 25% cross section[7]
Estuaries		
Withdrawal	-	▪ striving for the minimum possible withdrawal, ▪ not in spawning and nursery areas of fish or migration route, ▪ proper fish return system[8]
Mixing zone (T >25 °C)[5,9]		< 25% cross section
North Sea		
Withdrawal	-	▪ striving for the minimum possible withdrawal, ▪ not in spawning and nursery areas of fish or migration route, ▪ proper fish return system[8]
Mixing zone (T >25 °C)[5,9]	-	the mixing zone may not touch the sea bed

1. The criteria mentioned in the Table are generally applicable. For the full overview, please refer to appendix 2 of the guideline.
2. Permitted heating is 3°C for cyprinid waters, 2°C for shellfish water and 1.5°C for salmonid waters.
3. Heating is related to the background temperature at the edge of parts of the water system.
4. 28°C for cyprinid waters, 25°C for shellfish water and 21.5°C for salmonid waters.
5. The part of the water system (near a discharge point) which is brought to a temperature of ≥ 30°C due to the thermal discharge and is bounded by the spatial 30°C-isotherm (fresh water) or 25°C-isotherm (marine waters).
6. Exceptional case at high background temperatures (> 25°C): during a continuous period of up to 1 week in July/August, the temperature at the edge of the mixing zone is allowed to rise to 32ºC, strictly limited to 1 week per year. If this approach leads to problems with its practical implementation, the administrator can make a reasoned deviation.
7. The administrator can make a reasoned deviation based on specific information regarding the considered water system.
8. Particularly important for fresh water during the biological spring (1 March to 1 June) and for marine waters during the biological spring (1 February to 1 May) and the biological autumn (1 September to 1 December). Quantitative, generic criteria for withdrawal cannot be provided. For new situations, EIA procedures must be used to assess whether, based on local specific information, the activity can be allowed or not.
9. Assuming a background temperature of 22°C.

While the limits of heat discharge have been reached in inland waters (rivers), similar heat discharge at sea is far less of a problem, provided the discharges are sufficiently far out to sea and the mixing zone of the heated water cannot reach the sea bed. This is due to intensive mixing (tidal currents) and the presence of very large bodies of water that can absorb and discharge the heat (CIW, 2005). Mobile organisms can avoid the warm water and the flora and fauna is accustomed to the great dynamism in temperature, salinity and turbidity that occurs naturally in estuaries and prevails in the Wadden Sea. Against the backdrop of climate change and rising water temperatures that accompany it, a future problem may arise where this is not the case at present.

The determining factor for the potential environmental impact of thermal effluents on marine waters is rather the withdrawal of cooling water that contains organisms. In this respect, a distinction is made between ‘entrainment’ (organisms which are drawn through the cooling system) and ‘impingement’ (organisms left on the sieve). From an ecological viewpoint, the coastal zone and estuaries (especially when it comes to spawning and nursery areas for juvenile fish) are classified as very valuable. It is therefore important to minimize removal, not to withdraw from fish spawning and nursery areas or migratory routes, and to ensure that there is a proper fish return system (CIW, 2005).

On 4 May 2010, the Policy on the Use of Coastal and Estuarine Waters for Power Plant Cooling was adopted in California. The policy applies to 19 existing power plants that currently withdraw more than 15 billion gallons of cooling water per day (equivalent to > 56x106 m3) from coastal waters and estuaries. Under the new California regulations, such power plants will have to stop using flow-through cooling from 2015 and find alternatives to reduce their impact on marine life.

4. Best available techniques

Following EU Directive 96/61/EC on Integrated Pollution Prevention and Control (IPPC), now replaced by Directive 2008/1/EC, a reference document “BREF industrial cooling” (IPPC, 2001) was prepared, describing the application of best available techniques (Best Available Techniques, BAT) in industrial cooling systems. Companies are required to apply the best available proven technology.

BAT is in fact a combination of several site-specific measures. Some BAT principles on the selection of sites (no withdrawal in spawning and nursery areas for fish or migratory routes) or design (proper fish return system) are included in the CIW guidelines. In new installations, the design must take account of the specific requirements of the location, the design and construction of the facility and the opportunities to minimize the use of cooling water. The retrofitting of technical facilities is often much more expensive and less effective. An overview of the available techniques is given in Bruijs (2007). The following combination of measures is often used in flow-through cooling to reduce impingement. It can be implemented in the technical design in many different ways:

1. Reduce the flow velocity of the cooling water as much as possible (<0.1-0.3 m/s)
2. Use a coarse grid for the capture of debris
3. Use a fine-meshed 5x5 mm sieve to stop juvenile fish
4. Use a proper fish return system to safely return the impinged fish back to the surface water.

The vulnerability to impingement is fish species-specific, and so is survival on the screens. For vulnerable species, it is important to avoid impingement as much as possible since the chances of surviving impingement on the screens are minimal; more robust species, once trapped, may benefit to some extent from the shortest possible stay on the screens and a proper fish return system.

5. Monitoring

In order to assess the impact of cooling water withdrawal, a minimum requirement is to quantitatively estimate the relevant cooling water parameters (volume of cooling water, entrainment and impingement).

The conventional monitoring of cooling water consists of a periodic sampling of fish on the screens (impingement), sometimes accompanied by sampling of fish populations in the vicinity of the plant. The sampled fish are sorted by species, counted and weighed/measured. This makes monitoring of impingement/ entrainment very labour-intensive and therefore expensive.

A complicating factor is that the fish fauna in tidal waters are subject to many sources of variation: year, season, spring/neap cycle, tidal phase, day/night differences. It is therefore difficult to take a representative sample by using a limited monitoring effort. Large over or underestimates can occur when the numbers of impinged fish are extrapolated to annual impingement estimates, on the basis of unrepresentative or too few samples.

The proportion drawn through the cooling system ('entrainment') is even more difficult to monitor and often unknown. The sampling of the coarse grid is also not always included, though that is where (occasional) species such as sharks, marine mammals and birds can be found. A coastal power station can be considered as a powerful monitoring instrument, because of the large volumes of environmental water that are almost continuously filtered. Until now, cooling water has only been sampled on an ad-hoc basis. An improvement in the ongoing use of monitoring opportunities offered by power station cooling water is feasible, in which the development or use of more automated (less labour-intensive) techniques would be desirable.

According to a recent sampling of cooling water for the Eemscentrale power station (Van Giels, 2008), the fish impingement amounted to 12.6×10^6 individuals or more than 17 tonnes (1 Sept. - 31 Dec. 2007, only impingement), or 275 individuals or 182.8×10^6 tons (15 March - 31 July 2008, combined impingement and entrainment). The impingement averaged 30 or 44 fish per 1000 m^3 of cooling water. This is a high concentration compared with other coastal plants. Herring accounted for 59% and 37% of the number of impinged individuals. Furthermore, Nilsson's pipefish (23%) and gobies (12-14%) were numerous in the impingement. No reliable extrapolation to an entire year can be made based on this monitoring frequency.

6. Impact Assessment

The extent of the withdrawal ('impingement') of organisms in various coastal plants has now been demonstrated to some extent by monitoring, but the meaning of these effects for the aquatic environment or at the population level is insufficiently known. There is still no generally accepted method for evaluating the effects of cooling water. To assess the impact of the removal of fish, a reference is needed: satisfactory knowledge of the biology and population dynamics of the species withdrawn, a reliable estimate of the amount of fish present in the vicinity of the cooling water intake and the proportion of these which have been extracted (establishing the "biological removal area") and determining the survival of recirculated fish after impingement. For the more passive fish larvae or plankton, the "physical withdrawal area" has to be modelled, taking into account factors such as residence time and refreshment rate of water bodies and water movement along the central, as well as larval supply.

In commercially fished species, the ecology and population dynamics of which have been most frequently studied, the withdrawal mortality may be related to the estimated fishing mortality. Although the effects of a power plant at the population level may appear small, the removal of juvenile herring may have a local impact on birds such as the common tern (species protected under Natura 2000) which are faced with less available food for their growing young and in the worst-case scenario suffer food limitations which reduce breeding success. For non-commercial fish species there are more gaps in the knowledge required to carry out an impact assessment. A species as the three-spined stickleback is probably susceptible to impingement, because, due to the small size, not only juveniles but also adult individuals during their spawning migration are at risk.

The effect of heat discharge is not easy to assess either. The modelling of the discharge plume in a tidal area is a first step towards determining its impact level. Is the impact limited to the immediate vicinity of the discharge point or does it extend further, and how large are the uncertainties in this estimate? Only when this step can be mapped out can a quantitative estimation of the impact on the ecology begin. What effect has a structural heat discharge on organisms living in the area and is the impact the same in different seasons? The effect of a warm mixing zone on the wintering or migration of fish or introduced exotic species is still little studied in practice. How does this impact on the ecosystem's complex interactions? And how do we assess the impact against the background of temperature rise due to climate change?

With the information currently available, we are not able to quantify the impact of long-term large-scale cooling water abstraction, let alone the cumulative effect of several plants.

7. Implementation in the Wadden Sea Region

According to a survey in 2009, 16 large and smaller plants are operational in the Wadden region with an installed capacity of 9,511 MW, and there were plans for 12 new plants (10 in Germany and 2 in the Netherlands) with a total capacity of 11,730 MW. Three of the existing power stations are coal-fired, the rest are gas-fired or nuclear (Germany). Of the planned new power stations, 90% are coal-fired and the remaining 10% gas-fired (Gabriel et al., 2009).

In the Netherlands, a third new plant was provided in Eemshaven in 2010 and in Germany several plans were actually abandoned between late 2009 and mid-2010 (Dong Energy: Emden power station, GDF Suez / Electrabel: Stade coal-fired power station, E.ON: 50plus power station in Wilhelmshaven). Other plans announced may not go ahead due to the withdrawal of partners or because there have not yet been any applications for permits. In Germany, in particular, there is much public opposition to building new coal-fired plants (“Klimakiller Kohle" – climate-killer coal).

An updated overview of existing and planned power stations (Table 2) shows that there is currently 5,960 MW of large (> 500 MW) power plants installed, which withdraw their cooling water from the Wadden Sea or estuaries. If all the plans which are now in progress are to be implemented in the near future, this capacity will almost double to 11,660 MW. Moreover, there are plans for a further 4400 MW which are uncertain. Smaller plants have been disregarded.

All the power stations referred to, except for Advanced Power in Eemshaven, will use flow-through cooling with fluxes varying between 30-65 m^3/s per station. These power plants consume 82-171 m^3 per hour of cooling water per MW generated. Advanced Power is using hybrid cooling and will therefore consume much less cooling water, about 1 m^3/s or 3 m^3 per hour per MW. On an annual basis, the existing power plants together withdraw a maximum of 7.7×10^9 m^3 cooling water from the Wadden Sea (estuaries). Including the existing Eemscentrale and the initiatives for three new plants in Eemshaven, a total of 165 m^3/s of cooling water will be extracted from the Ems Estuary alone within a few years and discharged in a heated state. The amount of water that flows in and out of the estuary during each tide at the mouth of the estuary (the tidal flow) is approximately 1×10^9 m^3 per half tide in the Ems Estuary (Mulder, 1998). At half tide, about 3.5×10^6 m^3 cooling water is ingested or 0.36% of the tidal flow. Annualized, this amounts to a cooling water volume up by 5.2 billion m^3, approximately equal to the volume of the Wadden Sea (5.4 billion m^3, Hoeksema et al, 2004). The total cooling water flow of current and future major power plants combined is estimated at 416 m^3/s (Table 2). This is a volume of over 13.1 billion m^3 of cooling water annually, or 2.4 times the volume of the entire Wadden Sea.

Table 2. Overview of existing (operational) and planned power plants (> 500 MW) adjacent to the Wadden Sea (estuaries).

Name (company)	Capacity(MW)	Water type	Fuel type	Status/start	Cooling water (m^3/s)
Operational					
Kernkraftwerk Brokdorf (E.ON)	1410	Elbe estuary	nuclear	operational since 1986	60
Kernkraftwerk Brunsbüttel (E.ON/Vattenfall)		Elbe estuary	nuclear	operational since 1976; out of operation since July 2007	33
Kernkraftwerk Unterweser (E.ON)	1345	Weser estuary	nuclear	operational since 1979	64
Kraftwerk Wilhelmshaven (E.ON)	747	Jade basin	coal	operational since 1976	33
Eemscentrale Eemshaven (Electrabel)	2417	Eems estuary	gas	operational since 1977	55
In procedure (planned)					
Kohlekraftwerk Wilhelmshaven GDF/Electrabel	830	Jade basin	coal	planned in 2012	30
Kohlekraftwerk Brunsbüttel (GDF/Electrabel)	830	Elbe estuary	coal	in procedure	30
Kraftwerk Eemshaven (RWE)	1600	Eems estuary	coal	in procedure	65
Nuon Magnum (Nuon)	1200	Eems estuary	multifuel	in procedure	45
Eemsmond Energie (AP)	1300	Eems estuary	gas	EIA completed	1
Status uncertain					
Kohlekraftwerk (Südweststrom/Iberdrola)	1800	Elbe estuary	coal	Iberdrola has withdrawn	?
Kohlekraftwerk Brunsbüttel (Getec Energie)	800	Elbe estuary	coal	no procedure started	?
Kohlekraftwerk Stade (E.ON)	800	Elbe estuary	coal	no procedure started	?
Kohlekraftwerk Stade (Dow)	1000	Elbe estuary	coal	partner has withdrawn (EnBW)	?
TOTAL **operational** **in procedure** **status uncertain**	**16060:** **5960** **5700** **4400**				**416**

Based on the cooling water flow given in the above table, the annual cooling water volume has been estimated using an assumed maximum flow for 365 days per year (Figure 2). The volumes of cooling water have increased significantly since the late 1970s and since 1995 have remained roughly at current levels until 2007, when the Brunsbüttel NPP was shut down because of frequent failures. This resulted in a drop in the cooling water volume to 6.7 billion m^3 per year. After 2012, an annual volume of cooling water of over 12 billion m^3 is forecast.

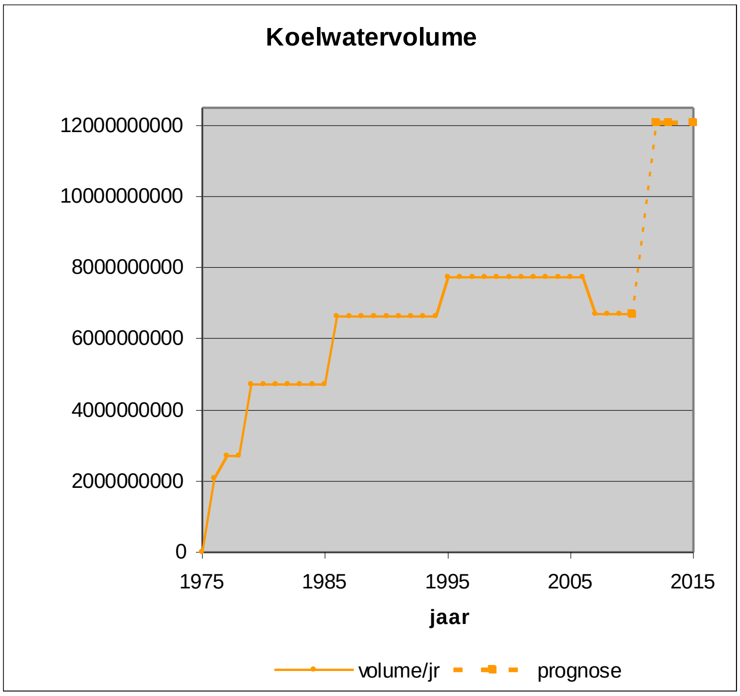

Figure 2. Trends in annual cooling water volume (m^3) by power plant >500 MW along the Wadden Sea coast and estuaries in the Netherlands, Germany and Denmark, calculated from data in Table 2.

Koelwatervolume	Cooling water volume
Jaar	Year
Volume/jr	Volume/yr
Prognose	Forecast

8. Discussion

It is assumed as a matter of course that new plants will use flow-through cooling. In the reference document for industrial cooling (IPPC BREF), the use of flow-through cooling for large water bodies (including coastal waters) is identified as the best available technique (BAT), all things considered. This is based primarily on the use of biocides and auxiliary materials and energy consumption (CO_2 emissions), but the impact of fish entrainment/impingement is not included in terms of quantity. Flow-through cooling involves large volumes of cooling water withdrawal, especially with the increasing size of plants. There are alternatives to once-through cooling. The advantages and disadvantages of different types of cooling would have to be compared taking into account the environmental damage caused by the removal of organisms.

One obstacle to innovation is the fact that companies prefer to use proven technology and are reluctant to experiment with new techniques and fish facilities. This can be attributed to the large investment involved in an installation and the high level of operational reliability that must be assured. On the other hand, newly developed technologies or measures to reduce fish entrainment are difficult to test except in a practical situation. This is likely to become an impasse which has to be addressed. The lack of sufficient understanding of the cumulative effects of withdrawal (how bad is it?) plays a role, which does not stimulate the need to look for alternatives.

We should be asking why it is considered a good idea to locate power stations on the edges of the Wadden Sea, a relatively closed water system with a slow refreshment rate, which, on the basis of these properties, is also very suitable as a nursery ground for fish and shellfish and as a resting and foraging place for birds.

Why should the internationally recognized nature reserve of the (trilateral) Wadden Sea, recently granted World Heritage status (UNESCO, 2009), be turned into an energy exporting region on account of its large-scale power generation combined with the considerable geographical distance to customers?

Given the developments initiated, the Wadden Sea region has an opportunity NOW to design the planned new power plants so as to minimize the impact of the expected large-scale use of cooling water. This aspect needs serious attention and requires adjustments and optimization at the earliest possible stage of the design. Since similar developments in the Netherlands and Germany are at issue, international coordination on this topic is essential.

9. Knowledge Gaps

Policy and Guidelines

- How to deal with uncertainties
- Suitable precautionary principle? / Evaluation of CIW guidelines
- Consequences of special World Heritage status of the Wadden Sea
- Alternatives to flow-through cooling?
- How to apply strategic planning and stimulate collaboration and innovation
- Use power stations as a biological monitoring tool

Technical measures

- What knowledge is needed for an optimal design?
- How to minimize or optimize the use of cooling water
- How to minimize the intake of fish at the entrance
- How to optimize the fish return system
- Opportunities to automate monitoring

Monitoring and Impact Assessment

- The reliable quantification of impingement and entrainment, taking into account the sources of variability
- The ecology of non-commercial species
- Response of the ecosystem to thermal discharge
- Quantifying the effects of cooling water withdrawal
- How to assess the cumulative effects of multiple power stations

10. References

Bruijs, M.C.M., 2007. Bureaustudie naar technische en operationele maatregelen bij koelwaterinlaten om de effecten van visinzuiging te reduceren. KEMA Technical & Operational Services, 50763027-TOS/MEC 07-9183. In opdracht van Rijkswaterstaat, Waterdienst

CIW, 2005. Beoordelingssystematiek warmtelozingen. Ministerie van Verkeer en Waterstaat, Rijkswaterstaat.

Gabriel, J., K. Jahn, S. Eilmes, H. Ludewig, 2009. Inventory and Analysis of Impacts of Power Plants in the Wadden Sea Region. Commissioned by Wadden Sea Forum Secretariat / BMU.

Hoeksema, H.J., H.P.J. Mulder, M.C. Rommel, J.G. de Ronde, J. de Vlas, 2004. Bodemdalingsstudie Waddenzee 2004. Vragen en onzekerheden opnieuw beschouwd. Rapport RIKZ/2004,025.

IPPC, 2001. Reference Document on the application of Best Available Techniques to Industrial Cooling Systems. European Commission, 335 p.

Mulder, H.P.J., 1998. Geomorfologische en hydrologische ontwikkelingen. In: Essink, K. and P. Esselink (eds.) - Het Eems-Dollard estuarium: interacties tussen menselijke beinvloeding en natuurlijke dynamiek. Rapport RIKZ-98.020.

Van Giels, J., 2008. De effecten van onttrekking van koelwater op vis. Metingen voorjaar 2008. Projectnummer: 20080249. ATKB Stellendam, in opdracht van RWS Waterdienst.