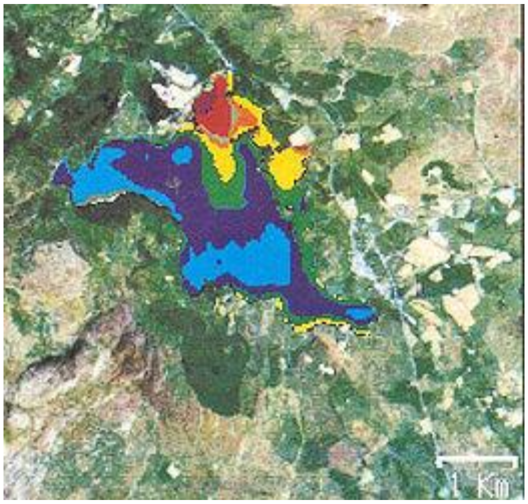
Thermal pollution

Lake Trawsfyndd, Wales, recipient of power plant thermal discharge.



Landsat image of Lake Trawsfyndd, Wales illustrating color differentiation of temperature differences induced by power plant thermal pollution. Source: NASA

Thermal pollution is the act of altering the temperature of a natural water body, which may be a river, lake or ocean environment. This condition chiefly arises from the waste heat generated by an industrial process such as certain power generation plants. The concept is most frequently discussed in the context of elevating natural water temperature, but may also be caused by the release of cooler water from the base of reservoirs into warmer rivers. Elevated river temperatures can also arise from deforestation or urbanization that can reduce streamshading. Thermal pollution is one parameter of the broader subject of water pollution.There can be significant environmental consequences of thermal pollution with respect to surface receiving waters such as rivers and lakes; in particular, decrease in biodiversity and creation of an environment hospitable to alien aquatic species may occur. Regulation of thermal pollution has been more elusive than for other forms of water pollution, although straightforward mitigation measures are available, especially in the case of elevated temperature discharges.

Theory of thermal release

Early work on mathematical modeling of thermal pollution took place in the 1960s with works by Edinger, Geyer and Tichenor; the first hydrological treatments addressed the equilibrium geometry of a **thermal plum**e, or iso-contour of elevated temperature within the receiving waters.[1] These models considered the mixing of a stream of admixed differing temperature water into a natural water body.

Slightly later more advanced models arose which allowed the analysis of thermal plumes across an extensive data base of historical meteorological statistics, so that the full impacts of thermal pollution could be considered in relation to diurnal, seasonal and climate change fluctuations.[2] In any case the technology exists to forecast thermal contours in receiving waters for a proposed or hypothetical thermal source.

Extent of thermal pollution

Diablo Canyon nuclear power plant, San Luis Obispo County, California. This plant was found to have produced kills of abalone and other marine organisms, when thermal discharges were inadequately analyzed or mitigated. Source: David Searls

Given the demand for cooling in power generation and other industrial processes, the extent of thermal pollution worldwide is considerable, particularly in the industrialized countries of Europe, North America, Asia and Australia. For example in the United Kingdom, it is estimated that one half of all river flow is used for cooling purposes and hence leads to some elevated discharge of higher temperature water.[3] As early as the 1980s in the USA thermal discharges amounted to one sixth of the total national river flow. In Australia, there are many instances of warm water discharge subsequent to cooling uses; however, cold water release downstream of reservoirs is at least as great a problem; for example, in New South Wales it is thought that up to 3000 river kilometres may be adversely affected by such coldwater releases.[4]

The adverse affects of thermal pollution are often comjoined with other forms of water pollution such as chemical contamination or biological contamination,[5] such that the combined effects of two or more pollution types can create severe stresses on aquatic ecosystems.

Ecological impacts

Rainbow trout, a species sensitive to water temperature change. Source: Ken Hammond, USDA

Waste heat discharged to natural waters typically depresses the dissolved oxygen content, affecting aquatic species such as fish.amphibians and copepods.[6] The resulting higher water temperature typically raises the metabolic rate of aquatic organisms; for example, increasing enzyme activity occurs, that causes plants and animals to take in greater quantities of nutrients and either carbon dioxide or oxygen. These metabolic changes can alter the balance of species composition,[7] and may also lead to faunal migration, as species attempt to adapt to changed thermal conditions. As a result, original species may migrate away, and alien species may enter a local aquatic system. In some cases significant loss of biodiversity can arise, and in some instances total bio-productivity can increase at the expense of species declines. The most readily observable phenomenon is that of mass fish kills in a surface water body; in this case, there are often large numbers of dead fish seen floating in the water or washed up on the water banks. Juveniles or fish fry are particularly vulnerable to small changes in water temperature.

Many aquatic organisms are very sensitive to small temperature changes of as little as one degree Celsius; not only can the temperature change alter metabolic rates, but adverse changes in other cellular biological may arise, including reduction of cell wall permeability, harming osmotic processes; in addition, alteration of enzyme metabolism can be effected as well as coagulation of cell proteins. In many cases these cellular level impacts can affect reproductive success and even impact organism mortality. A large increase in temperature can lead to the denaturing of life-supporting enzymes by breaking down hydrogen and disulphide bonds within the quaternary structure of the enzymes. Decreased enzyme activity in aquatic organisms can cause problems such as the inability to break down lipids, which leads to malnutrition.

Primary producers are affected by thermal pollution since elevated water temperature increases aquatic plant growth rates, potentially resulting in a shorter lifespan and species overpopulation. This can cause an algae bloom which reduces the water's oxygen content in the water. The higher aquatic vegetative density leads to an increased plant respiration rate and also to a reduced underwater light intensity. The outcome is similar to the eutrophication that occurs when watercourses are polluted with leached agricultural inorganic fertilizers.

In the case of injection of cooler water from a reservoir into a warmer stream or river below, there can also be significant impacts upon fish, especially in the egg and larval stage; upon macroinvertebrates and upon total aquatic productivity in the receiving river.[8] These cold water forms of thermal pollution can also create a modified aquatic environment such that certain alien species may have a competitive advantage over native species.

Mitigation

Hyperbolic cooling towers, Didcot fossil fuel power station, Oxfordshire, England.

This design of cooling towers is often chosen due to enhancement of convective cooling as well as inherent structural strength of the geometry. Source: Owen Cliffe

There are several means of reducing impacts of warm water termal discharges, including use of cooling ponds, cooling towers and also productive use of the heated water for a secondary industrial process or space heating.[9] In the case of cold water discharge from reservoir bottoms, the mitigation is not as straightforward, and can often be very expensive. Since there are seasonal variations in the degree of vertical thermal stratification, the timing of water releases can sometimes be conducted to minimize cold water differents in the discharge, provided these releases are consistent with needs for flood control or power generation. In the summer, for example, there may be extremes in formation of cold water layers at the reservoir bottom; such times would be adverse for cold water release impacts downstream.

Regulation

Some countries and even individual states and provinces require limits on discharges that lead to thermal pollution of receiving waters. although this aspect of water pollution has proven to be more elusive than conventional chemical discharge. In many cases regulation has come about through judicial application of the United States Clean Water Act and other statutes.[10] For example, in a state statute challenge the court found that anticipated thermal pollution impacts were sufficient grounds to reverse approval of construction of two nuclear power plants.[11] Regulation may take very different approaches; in some laws, a best practice is required, such as the use of cooling ponds or cooling towers for waste heat discharge. In other cases, a numerical limit on acceptable temperature increase in the receiving waters is applied. For example, the World Bank standard provides a maximum increase of three degrees Celsius at the margin of the mixing zone.[12]

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