THERMAL INFLUENCE OF SURFACE DISPOSAL OF HOT GEOTHERMAL WASTEWATER ON AQUATIC ECOSYSTEMS: WITH EXAMPLES FROM ICELAND

Gabriel N. Wetang'ula[1, 2, 3] and Sigurdur S. Snorrason[1]
[1]*Faculty of Life and Environmental Science, University of Iceland*
[2]*United Nations University-Geothermal Training Programme*
[3]*Geothermal Development Company, P. O Box 17700, Nakuru, Kenya*
Emails: gwetangula@gdc.co.ke, ganw@unugtp.is,

ABSTRACT

Disposal of hot wastewater from a standard steam cycle power plant directly into an existing natural waterway inevitably leads to an increase in temperature. This changes various physical–chemical properties of water, such as density, viscosity, surface tension and solubility of gases. The influence of heating on aquatic ecosystems is ambiguous, and at different levels of heating it may be both positive and negative. The most important ecological factor is then to limit excessive heat dumping which will exceed the buffer capacity of the aquatic ecosystem. Of the many environmental factors influencing an ecosystem probably none exerts a more profound influence than temperature. Nesjavellir geothermal co-generation power plant in SW-Iceland utilizes high temperature geothermal fluid for production of electricity and hot water for district heating. The plant wastewater is either pumped into shallow drill holes or disposed off in a stream, which finds its way into a freshwater Lake. Result of water temperature measurements done to determine the extent of thermal influence show that large volume of geothermal effluent (40.9°C - 84.0°C) disposed of has caused a rise in both summer and winter temperature at lake shoreline outflow sites. Summer temperature was in the range of 11.7°C - 27.3°C with definite outflow sites temperature being in the range 23.4-27.3°C. During winter temperature at Varmagja varied from 0.6°C on the ice edge to 26°C at the mouth. To minimize local effects deep reinjection of geothermal wastewater and further cooling of the condensed steam was recommended.

INTRODUCTION

Aquatic ecosystems are composed of the biological community (producers, consumers and decomposers), the physical and chemical (abiotic) components and their interactions. Within aquatic ecosystems, a complex interaction of physical and biochemical cycles exist, and changes do not occur in isolation. Aquatic ecosystems thus undergo constant change. However ecosystems have developed over a long period of time and organisms become adapted to their environment. In addition, ecosystems have an inherent capacity to

withstand and assimilate stress based on their unique physical, chemical, and biological properties. Nonetheless, systems may become unbalanced by natural factors, which include drastic changes in climatic variations or by factors due to human activities. Any changes especially rapid ones, could have detrimental effects (CCME, 2001).

Adverse effects due to human activities, such as release of toxic chemicals in industrial effluents, may affect many components of aquatic ecosystem, the magnitude of which will depend on both biotic and abiotic site-specific characteristics. In evaluation aquatic ecosystems are always viewed as whole units, not in terms of isolated organisms affected by one or few pollutants (CCME, 2001). As effluents are released into the environment through natural processes or human activities, they may enter aquatic ecosystems and partition into particulate phase. These particles may remain in the water.

Heated wastewater discharge effects on aquatic communities

Thermal pollution has been directly associated with the development of the heat and nuclear power engineering, whose operating objects discharge large volumes of warmed water into water reservoir (Beznosov and Suzdaleva, 2001).

If hot wastewater from a standard steam cycle power plant is released directly into an existing natural waterway it inevitably leads to an increase in temperature. This changes various physical–chemical properties of water, such as density, viscosity, surface tension and solubility of gases. The influence of heating on aquatic ecosystems is ambiguous, and at different levels of heating it may be both positive and negative. The most important ecological factor is then to limit excessive heat dumping which will exceed the buffer capacity of the aquatic ecosystem. Of the many environmental factors influencing an ecosystem probably none exerts a more profound influence than temperature.

Due to its pivotal role in biological activity (development, growth and reproduction) temperature has long been recognized as an important environmental factor in both terrestrial and aquatic ecosystems. Seasonal temperature differences, characteristic of higher latitudes, strongly influence the biological activity of aquatic organisms and establish cyclical patterns that often mediate the scope of each activity. Over the long-term, changes to the thermal regime of the surrounding environment can effect the evolutionary, physiological and behavioural responses of individual organisms (Begon et al., 1990).

Temperature directly influences the metabolic rates, physiology, and life-history traits of aquatic species and helps to determine the rates of important community processes such as nutrient recycling and productivity (Allen, 1995). Thermal loads can cause negative processes in local areas of aquatic environment, such as over growth of blue-green algae deteriorating the water quality, change in the composition of plankton and dynamics of its numbers, disruption of fish and other aquatic communities. Fluctuation in water temperature induces behavioural and physiological responses in aquatic organisms. Permanent shifts in temperature regimes can render formerly suitable habitat unusable by native species.

Because of ecological importance of lake temperature, preventing or mitigating anthropogenic thermal degradation is a common concern for resource managers (Poole and Berman, 2001). In serious cases a permanent increase in water temperature levels can result in a complete change of the community whereby high temperature tolerant species take over. In milder cases water temperatures variations among sites may create differences in the physiological and behavioural advantages among aquatic organisms hence influencing their competitive ability and distribution as indicated by the study of Taniguchi et al. (1998) showing that changes in competitive ability (measured as food consumption and aggression) could be temperature mediated.

Many studies have shown the effects of thermal discharges on aquatic communities. Squires et al. (1979) study of water temperature increases caused by thermal discharges in the Provo River in Utah, USA found a unique algal community which was attributed to this thermal discharge. Flora displayed an overall similarity in specific composition but with zonation related to local environmental conditions.

Esterly (1975) study of thermal effluent effects on the benthos of Thomas Hill Reservoir, Missouri, USA found maximum surface water temperature was 37 ºC while bottom muds varied between 8-29 ºC. Numerical abundance and biomass of benthos were greater in the control Arm than in the hot water Arm but heated water had no apparent deleterious effects on the benthos.

Hickman and Klarer (1975) showed that thermal discharges caused an increase in the standing crop size of the epiphyton associated with sedges, *Scripus validus* and the mean primary productivity also increased. Thermal discharges were also found to cause changes in species composition and dominance in algal communities.

Klarer and Hickman (1975) monitored water temperature, dissolved oxygen and water chemistry in a lake receiving heated water and found no large variations in these parameters except for water temperature and dissolved oxygen levels among the stations.

Phytoplankton species have also an optimum temperature where growth rate is maximal. The growth rate of phytoplankton generally increases with temperature only within a certain temperature range, and the temperature dependency of the growth rate differs among species. Species found growing at a higher temperature usually have a higher optimum temperature (Suzuki and Takahashi, 1995).

A study at Madras Atomic Power Station, India showed that thermal discharge affects benthic communities in three ways; reduction in composition of the assemblages; increased abundance of the so-called opportunistic or ephemeral species and alteration of population dynamics of the most abundant species. Death of almost all the macrofauna and flora species was observed during the hot season in an area impacted by the heated effluents. Much of the area that showed consistent thermal effects on benthic community structures (Suresh et al., 1993).

The response of freshwater algae to temperature change have also been summarized by DeNicola (1996) and include a variety of effects that have been studied at the cellular, population and community level. Individual responses are highly dependent upon the variability in the physicochemical environment and spatio-temporal pattern in species distribution. Physiological responses to temperature include changes in concentrations of photosynthetic and respiratory enzymes, changes in cell quota and nutrient uptake, as well as alterations in fatty acids and proteins. Individual populations have been shown to exhibit minimum, maximum and optimal temperatures for growth that contribute to species composition and diversity and eventually lead to seasonal succession.

Temperature changes beyond threshold levels can also have variable effects on aquatic insect communities diapause induction as a function of endocrine processes; hatching success which decreases at low or high extremes; larval growth, adult size and fecundity for which temperature has influence on the rate of feeding, assimilation and respiration, food conversion efficiencies and enzymatic kinetics; voltinism[3] ; and timing of

[3] Number of generations per year based on larval growth rate.

adult emergence which may be premature or delayed depending on temperature increase or decrease (Sweeney and Vannote 1981).

High but sub-lethal temperature can affect fish in a number of ways. The effects may reflect metabolic inefficiencies, susceptibility to disease and toxic effects of pollutants, changes in behavioural patterns, intra- and inter-specific competition, predator-prey relationships, community composition and parasite-host relationships (Dickerson and Vinyard 1999).

A study of ecological effects of hot water discharge of a steam electric generating plant in Crystal River, Florida on fishes found that species abundance was higher at non-affected sites than affected station (Grimes and Mountain, 1971).

Carr and Giesel (1975) found that both the numbers and biomass of juvenile fish in the thermally affected creeks were 3-10 fold smaller than those obtained from the creek at ambient temperature.

A study of the thermal effluent effects on the community structure and nursery function of fish in an estuary showed decreasing numbers of species with decreasing distance from the thermal outfall (Jones et al., 1996). The thermal effluent only affected the species compositions in the inner estuary, and estuary-opportunistic species. During winter/spring months, thermal effluent attracted some fish species to the warmer waters of the inner estuary. The extended growth season for such species and significantly higher growth rates promoted premature movement out of the inner estuary. The latter effects were postulated to lead to alteration of the population structures of the species by increasing their vulnerability to heavy localized fishing intensity, aggregation of natural predators and point-source pollution.

In a study Mosquitofish from thermally affected stations (28 to 40ºC) and unaffected sites (12 to 29ºC) for reproductive activity, sex ratios, size at sexual maturity, percentage of fat, and size structure. Bennett and Goodyear (1978) showed that mean brood size of populations from thermally affected areas generally varied inversely with water temperature.

Stauffer et al. (1974) studied the distribution of fish in two rivers in relation to thermal discharges from a fossil fuel power plant. They noted a slight decrease in diversity indices for stations located in the thermal discharge. The results showed that while a number of species were not affected; others avoided high temperatures but others were attracted to high temperatures.

Exposure to thermal effluents can possibly compromise gametogenesis in fish (Luksiene et al., 2000). High temperature in Swedish and Lithuanian thermal effluent areas influenced gametogenesis of female perch *Perca fluviatilis*, roach *Rutilus rutilus* and pike *Esox lucius* negatively, indicating reduced reproductive capacity.

In the mitigation of effects arising from heated water discharge on aquatic communities, the most important ecological factor will then be to limit excessive heat dumping that might exceed the buffer capacity of the aquatic ecosystem as a way of eliminating the profound influence of temperature on such communities.

1.2 Nesjavellir co-generation power plant and Lake Thingvallavatn

Nesjavellir co-generation power plant is located in the Nesjavellir geothermal field, a high enthalpy geothermal system within the Hengill Central Volcano in south-western Iceland, on the south of Lake Thingvallavatn (Fig. 1). Thingvallavatn is a rift lake of high conservational value (Jónasson, 1992), fed 90% by underground springs with main springs entering in the north at a temperature of 2.8-3.5°C. Warmer groundwater enters the lake in the southwest from the Hengill geothermal area (Ólafsson, 1992). Geothermal investigations at Nesjavellir commenced in 1946, however, it was not until 1986 that a decision was made to harness the geothermal heat for district heating in Reykjavík (Gunnarsson *et al*. 1992). By 1990, 14 production boreholes had been drilled, and all except one were successful. That year the Nesjavellir power plant was commissioned, generating about 100 MW_t, by producing about 560 l/s of 82°C hot water for district heating. In 1995 the capacity was expanded to 150 MW_t and in 1998 to 200 MW_t and the production of 60 MW_e of electricity commenced (co-generation plant).

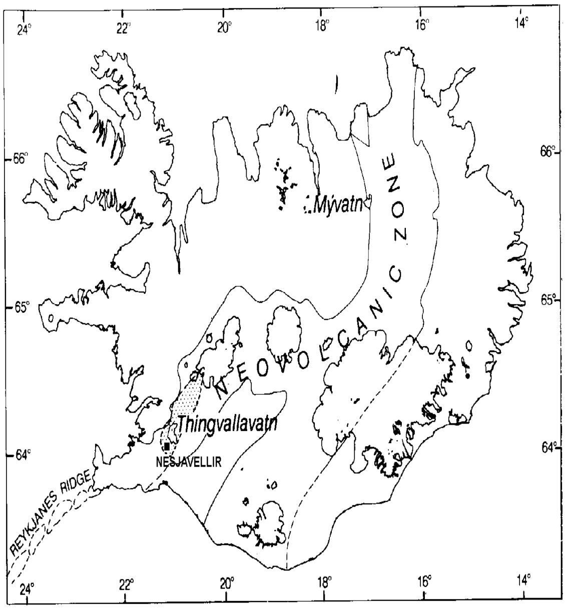

Figure 1. Location of Nesjavellir geothermal co-generation plant and Lake Thingvallavatn

The co-generation power plant has two functions. The first is to produce electricity with the geothermal steam. The second is to heat cold groundwater for district heating. Figure 2 shows the general design of the plant. The electricity production phase is a steam cycle design currently generated by three steam turbines, each 30 MW. The steam is condensed in a tubular condenser and cooled to approximately 55°C with cold groundwater. The condensate is disposed of in shallow boreholes in the nearby lava field. The cooling water is pumped from a shallow fresh-water aquifer (Gramelur) in the lava field 6 km away from the power plant. The temperature of the cooling water is 5-7°C. The cooling water is heated to about 55°C in the condensers, and then piped through heat exchangers, for final heating to 87°C, using the 192°C hot geothermal water from the separators. In the heat exchangers the geothermal water is cooled to 55°C (Gislason, 2000). Used and unused brine at flow rate of 115-143 kg/s at 46 - 100°C are discharged in the nearby Nesjavellir stream that disappears into Nesjahraun lava at Lækjarhvarf. About 126-140 kg/s of condensate at 48-68°C and 343-1776 l/s of cooling water at 49-69°C is also discharged into shallow drillholes that connects to surface groundwater (Wetang'ula and Snorrason, 2003). This mixes with groundwater, which flows some 3.8 km to the lake Thingvallavatn. Present installed capacity is 90 MW_e and 200 MW_t. The project aim was to evaluate the thermal effects of geothermal wastewater disposal on Lake Thingvallavatn water temperature at the out flow points.

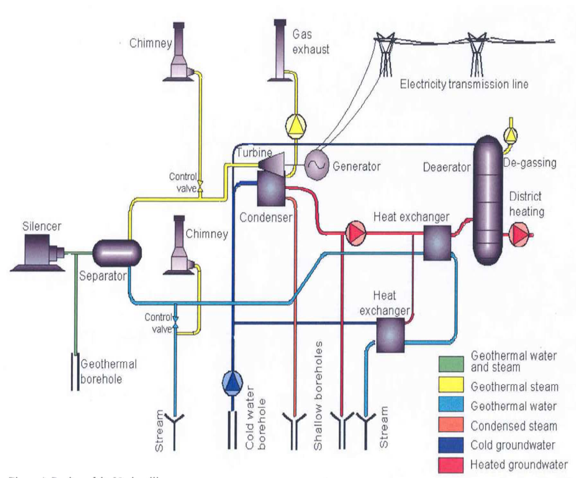

Figure 2. Nesjavellir geothermal co-generation power plant flow diagram.

METHODOLOGY

Beginning in June 2003 water sampling was initiated to describe spatial variability in the water quality at various study sites along the shore of Lake Thingvallavatn, Iceland influenced by geothermal outflow. Temperature mapping was carried out on the southern shoreline of the lake (Fig. 3) to determine geothermal water outflow sites by use of digital thermometer (Cole Palmer).

Approximately ten sites were verified as definite outflow points of warm wastewater into Lake Thingvallavatn. The sites represented a gradient of the influence of geothermal wastewater on Lake Thingvallavatn water quality.

Temperature and conductivity transect measurements

During transect mapping, a YSI 650 Multiparameter Display System logger (YSI Environmental) was used to measure temperature (accuracy ±0.15, resolution 0.01°C), specific conductivity (accuracy ±0.5% of reading +0.001 mS/cm, resolution 0.001 or 0,1 mS/cm), dissolved oxygen – mg/L (accuracy 0 to 20 mg/L: ±2% of reading or 0.2 mg/L, whichever is greater, 20 to 50 mg/L: ±6% of reading, resolution 0.01 mg/L), pH (accuracy ±0.2 unit, resolution 0.01 unit) and depth (accuracy ±0.02 m). The parameters were logged along three sections of three different transects at both Varmagja and Eldvik starting from the mouth.

RESULTS

Water temperature and conductivity

The results for summer 2003 water temperature measurements at definite outflow sites along the shoreline of Lake Thingvallavatn from Markagjà to Gràmelur are as shown in figure 3. The lowest and highest outflow sites water temperature was 16.8 and 27.2 ºC at sites 1 and 2 respectively. Water temperature at other outflow sites sampled was within a temperature range of 23.4-25 ºC.

Conductivity of water at the outflow sites was lowest at site 1 (210µs) and highest at site 8 (322 µs) with a spatial increase in conductivity from site 1 through site 10 (Table 1). Conductivity at sites 7-10 was much higher compared to sites 1-6 (Fig. 4).

Variation in conductivity and water temperature with depth at two sites; Varmagja and Eldvik based on summer 2003 transect measurements show a general trend of conductivity and water temperature decrease with increasing depth. Temperature profiles taken at 10 m, 25 m, 50 m and 75m mark along three different transect (Va T1, Va T2 and Va T3) from the mouth of Varmagja (Transect Va T2, Fig. 5) show a decrease in water temperature as one moves further away from the mouth. At 10 m from the mouth, there is no pattern in water temperature with depth with the water temperature being in the range 14-25 ºC (Fig. 5a).

Water temperature decreases with increasing depth and distance from mouth of Varmagja at the profile points for transects. This was also true with the temperature profile of other Varmagja transects Va T3 and Va T1.

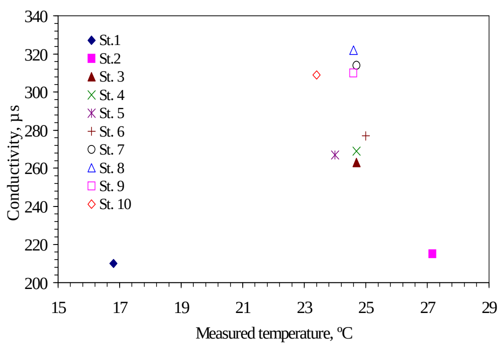

Figure 4: Relationship between conductivity and water temperature at major outflow sites

Table 1: Conductivity and water temperature at various major geothermal water outflow sites (July 2003)

Point	Conductivity (µs)	Temperature (°C)
Site 1	210	16.8
Site 2	215	27.2
Site 3	263	24.7
Site 4	269	24.7
Site 5	267	24
Site 6	277	25
Site 7	314	24.7
Site 8	322	24.6
Site 9	310	24.6
Site 10	309	23.4

The winter temperature profiles at Varmagja also decrease with increasing depth and distance from the mouth. For example point V2 which is just close to the mouth had a surface (30 m depth) temperature in the range of 5-26ºC. At profile points V4, V5 and V6 a layer of warm water is floating on cold water as indicated by drop in temperature with increasing depth. Points V3 and V7 which were closer to the ice edge had lower temperature of < 1ºC at a depth of 2 m which however increased to 3.5-4.0 ºC at 3-3.5 m depth (Fig. 7). Winter surface water temperature around Varmagja were high at the mouth but decreased with decreasing distance to the ice sheet (see Fig. 6**)**. The temperature range at Varmagja was 0.6 ºC near the ice edge to 26 ºC at the mouth. Water temperature at Varmagja outflow site was 27.92 ºC. All points previously measured in the summer were ice free despite most part of the lake having frozen.

DISCUSSION

Variation in water temperature and conductivity at outflow sites

From the temperature measurements at the various sites along southern shoreline of Lake Thingvallavatn, it is evident that the inflow of warm water has elevated the springs temperature in relation to the overall lake temperature which is usually varies between 6-11 °C in summer and 0°C in winter reading. At most outflow sites, the water temperature have increased more than two folds the average lake temperature. Results from the temperature profile transects taken at both Varmagja and Eldvik show a similar trend in water temperature increase. A few meters from outflow sites into the lake, there is a drop in water temperature from top to bottom showing that the warm geothermal wastewater is floating atop the cold lake water. The volume increase in warm wastewater disposal from the power plant is seen in elevated water temperatures at the thermally affected springs from Varmagjá towards Eldvík. This was emphasizes by the fact that during winter when most parts of the lake had frozen forming a thick ice sheet, most section around Varmagja and Eldvik were ice free. There surface water temperature decreased with decreasing distance for the mouth of the outflow sites to the ice edge. Judging by elevated temperatures in drill holes (Hafstað, 2001) at the edges of the warm water tounge, the elevated summer and winter water temperatures at outflow sites further to the south of Eldvík is not a surprise.

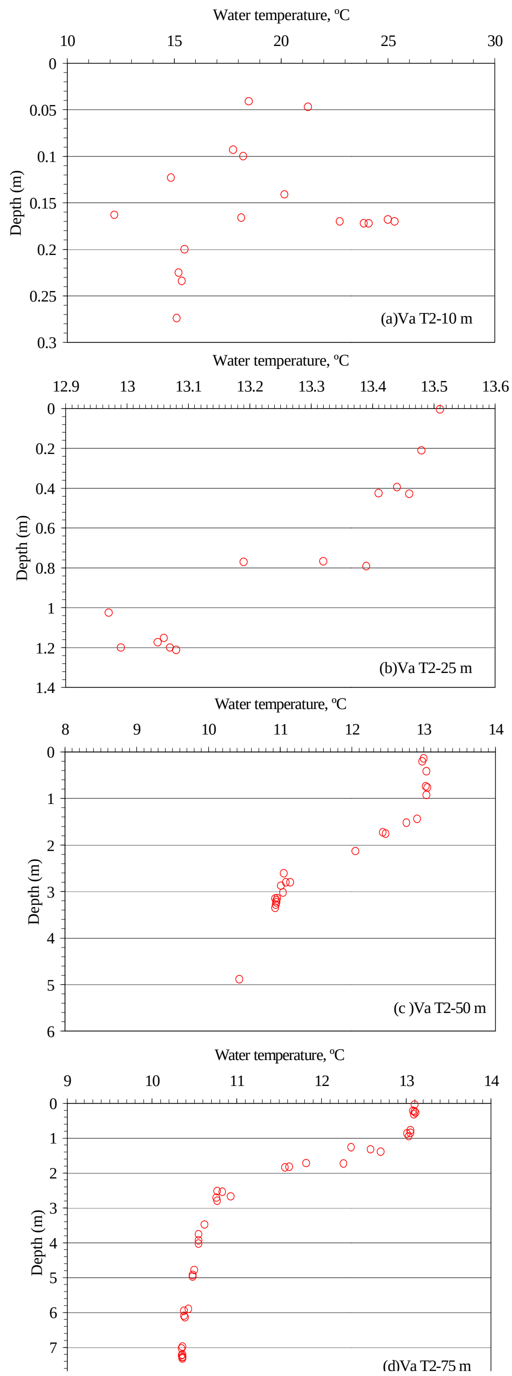

Figure 5. Summer (2003) temperature profiles on transect 2 at Varmagjá. Profiles were situated at 10, 25, 50 and 75 m distance from the outflow sites.

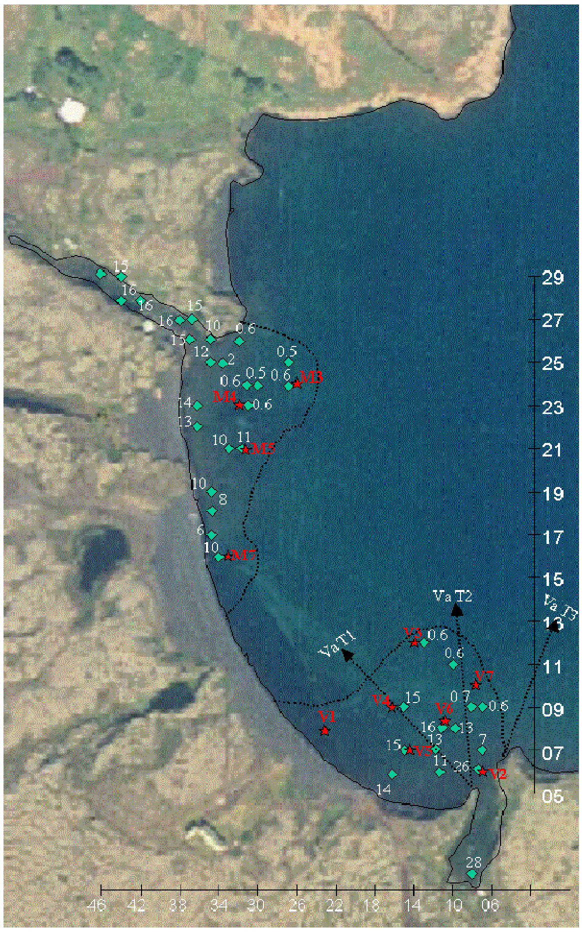

Figure 6. Water temperature measurements at Varmagja and Markagjà. Diamonds = surface temperature in winter 2004, stars = winter 2004 temperature profile points, Va T1 = temperature profile measurements along a transect in summer 2003.

The effects of elevated outflow sites temperatures on Thingvallavatn will only be on a local scale (see Fig. 5). In calm weather tongues of warm water floating on the surface may form temporarily. Such layering is likely to break down quickly due to wave action when the wind picks up. Any large scale effects of elevated spring temperature on the Thingvallavatn ecosystem are not expected. Efficient water mixing (Snorrason, 1982) causes temperature drop to the normal lake temperature a few meters away from sites of outflow. Hence, the normal cold water adapted benthic algal communities will not be affected (Jónsson, 1992). However, changes can be expected to the benthic communities of plants and animals in the nearest neighbourhood of the outflow sites, particularly in Varmagjá, which, due to it's isolation from the lake, is somewhat sheltered from wave action.

Water conductivity of at both Varmagja and Eldvik also decreases with an increase in depth. Electrical conductivity of water being a measure of total dissolved solids (TDS) in water implies that the higher conductivity of the upper water layer is indicative of its TDS content. This high TDS content could be attributed to the geothermal outflow input which also concurs with the earlier supposition that the geothermal wastewater is floating on the cold lake water. There is also a general increase in water conductivity with an increase in water temperature. Apart from wastewater being a major source of ions that have increased the water conductivity of the lake, rock composition (geology) will also determine the chemistry of the watershed soil and ultimately the lake.

Atmospheric input of ions in this case will be relatively minor except if the lake was near a coastal zone where ocean water may increase the salt load of dry aerosol and wet deposition.

CONCLUSION AND RECOMMENDATIONS

After the start of electricity generation at the Nesjavellir Power Plant increased discharge of hot water has lead to a marked temperature rise, - from 11.7 – 27.3°C, of geothermally affected lakeside springs.

Efficient, wind driven mixing of spring water with lake water (Snorrason, 1982) precludes any large-scale effects of elevated temperature and chemical concentrations in affected springs. Hence, any biological effects are expected to be strictly localized. Despite of this, the high conservational value of Thingvallavatn and its surroundings calls for stringent wastewater management. The amount, temperature and chemical composition of wastewater and potentially affected lakeside springs should be closely monitored. The local biota at spring sites should be assessed for effects of increased temperature and chemical effects. To minimize local effects deep reinjection of geothermal wastewater and further cooling of the condensed steam was recommended.

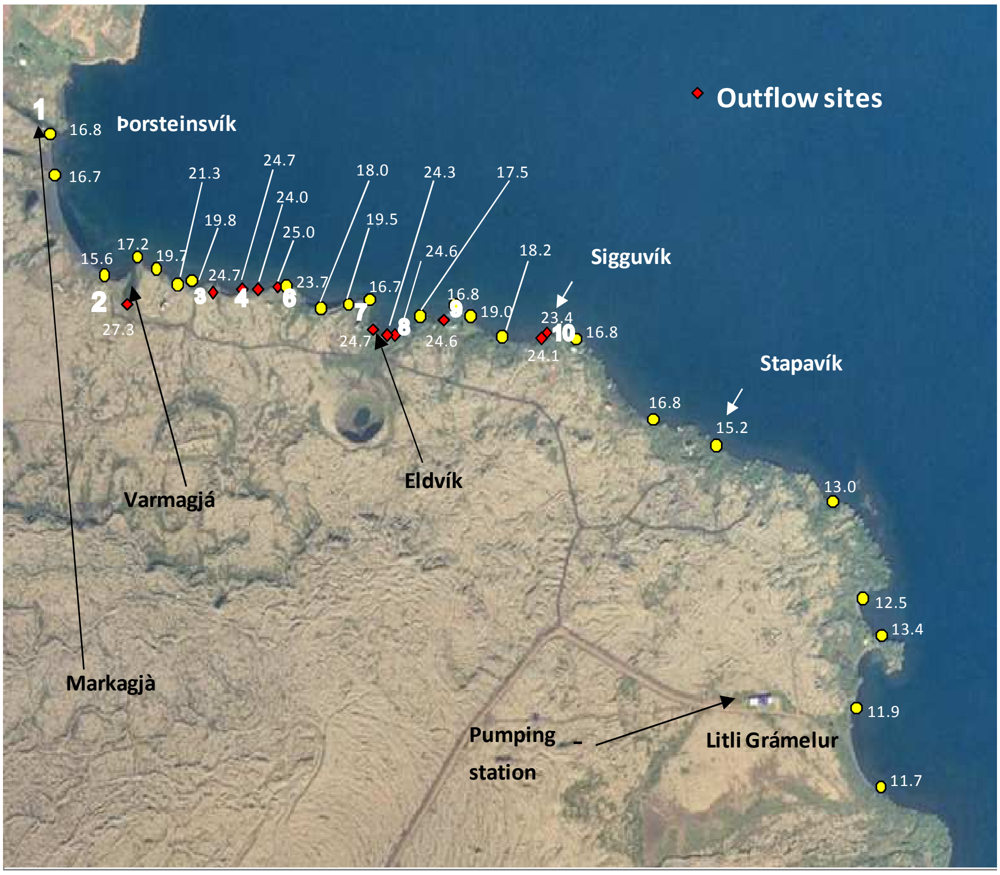

Figure 3. Spatial variations in water temperature along the southern shoreline of Lake Thingvallavatn. Red diamonds = Visible geothermal outflow sites, Yellow dots = Points with no visible outflow flows

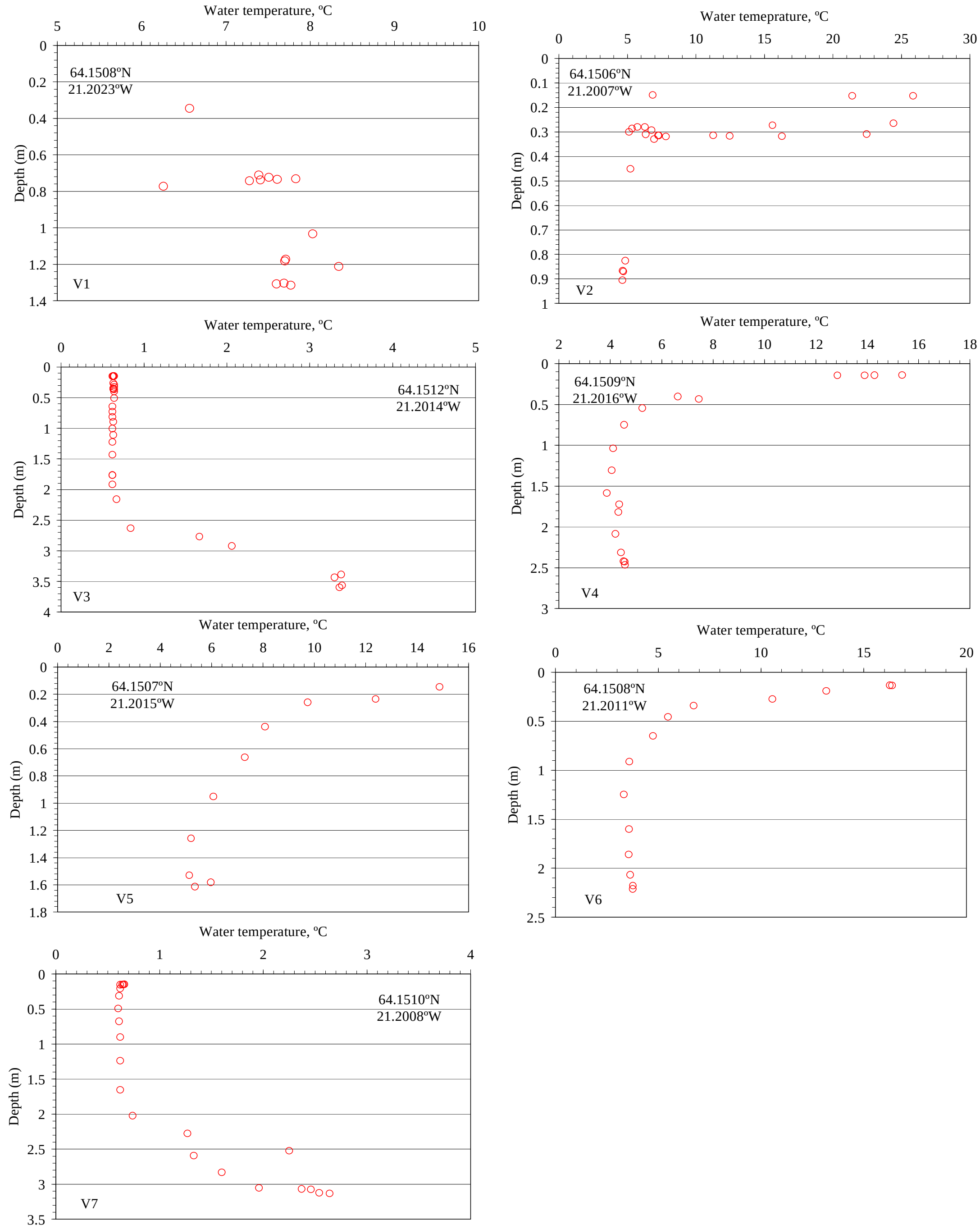

Figure 7. Winter (2004) temperature profiles at Varmagjá. Refer to Figure 6 for the locations.

REFERENCE

Allen, J.D. (1995). Stream ecology: structure and function of running water. Chapman & Hall, New York, 388pp.

Begon, M., J. L. Harper and C. R. Townsend. (1990). Ecology: individuals, populations and communities. Blackwell Scientific Publications, Cambridge, MA. 945 p.

Bennett, D.H, Goodyear, C.P (1978). Response of Mosquitofish to Thermal Effluent Energy and Environmental Stress in Aquatic Systems, Selected Papers from a Symposium, held at Augusta, Georgia November 2-4, 1977. CONF-771114. p 498-510, DOE EY-76C-09-0819.

Beznosov, V. N. and A. L. Suzdaleva (2001) Temperature Decrease in the Surface Water Layer of a Reservoir as an Example of Environmental Thermal Pollution. Water Resources 28(4),396-398.

Carr, W.E.S and Giesel, J. T (1975). Impact of thermal effluents from steam electric station on a marshland nursery area during the hot season. *Fishery Bulletin* Vol. 73, No. 1, 67-80.

CCME (Canadian Council of Ministers of the Environment). (1999). Canadian environmental quality guidelines, Winnipeg. Updated 2002.

DeNicola, D. M. (1996). Periphyton responses to temperature at different ecological levels. Pages 150-183 *in* R. J. Stevenson, M. L. Bothwell and R. L. Lowe (eds.) Algal ecology. Academic Press, New York.

Dickerson, B. R. and G. L. Vinyard. (1999). Effects of high chronic temperatures and diel temperature cycles on the survival and growth of Lahontan cutthroat trout. *Trans. Am. Fish. Soc*.128, 516-521.

Esterly, C.W (1975). The Effect of a Thermal Effluent on the Benthos of Thomas Hill Reservoir, Missouri. National Technical Information Service, Springfield VA 22161 as PB-264 835,ofiche. M.S. Thesis, 63 p,. OWRT B-039-MO(5), 14-31-0001-3296.

Gislason, G., (2000). Nesjavellir co-generation plant, Iceland. Flow of geothermal steam and non-condensable gases. *Proceedings of World Geothermal Congress 2000, Kyushu-Tohoku, Japan, 585-590.*

Gunnarsson, A. Steingrimsson, B.S., Gunnlaugsson, E., Magnusson, J. and Maack, R., (1992). Nesjavellir Geothermal Co-Generation Power Plant. *Geothermics*,21 (4), 559-583.

Hafstad, H. T. (2001). Nesjavellir: Temperature measurement in wastewater run-off area. Orkustofnun, report ÞHH-2001-13 (in Icelandic) 18pp.

Hickman, M and Klarer, D. M. (1975) The Effect of the Discharge of Thermal Effluent from a Power Station on the Primary Productivity of an Epiphytic Algal Community. *Br. phycol. J*. 10, 81-91.

Jónasson, P.M., ed. (1992). Ecolology of oligotrphic, subarctic Thingvallavatn, Iceland. *Oikos*.

Jones, G.K., Baker, J.L., Edyvane, K., Wright, G.J (1996). Nearshore fish community of the Port River-Barker Inlet Estuary, South Australia. 1. Effect of thermal effluent on the fish community structure, and distribution and growth of economically important fish species. *Marine & Freshwater Research* , vol. 47, no. 6, pp. 785-799.

Jónsson, G.S (1992). Photosynthesis and production of epilithic algal communities in Thingvallavatn. *Oikos, 64,* 222-240.

Klarer, D. M., Hickman, M. (1975) The effect of the thermal effluent upon the standing crop of an epiphytic algal community. *Hydrobiol*. Vol. 60, no. 1, pp. 17-62.

Luksiene, D., Sandstrom, O., Lounasheimo, L., and Andersson, J. (2000). The effects of thermal effluent exposure on the gametogenesis of female fish. *Journal of Fish Biology* 56, 37-50.

Ólafsson, J. (1992). Chemical characteristics and trace elements of Thingvallavatn. *Oikos, 64,* 151-161.

Poole, G. C. and Berman, C.H. (2001). An ecological perspective on in-stream temperature:Natural heat dynamics and mechanisms of human-caused thermal degradation. *Environmental Management* 27 (6), 787-802.

Snorrasson, S. (1982). *The littoral ecosystem and the ecology of* Lymnaea peregra *in lake Thingvallavatn, Iceland*..University of Liverpool, Ph.D thesis, Liverpool, 429pp.

Squires, L.E; Rushforth, S.R; Brotherson, J.D (1979). Algal Response to a Thermal Effluent: Study of a Power Station on the Provo River, Utah, USA. *Hydrobiologia* 63, (1), 17-32.

Stauffer, J.R., Dickson, K.L., Cairns, J (1974). A field evaluation of the effects of heated discharges on fish distribution. Water Resources Bulletin, Vol. 10, No. 5, 860-876.

Suresh, K., Ahamed, M. S., Durairaj, G. and Nair, K. V. K. (1993) Impact of power plant heated effluent on the abundance of sedentary organism, of Kalpakkam, east coast of India. *Hydrobiologia* 268, 109-114.

Suzuki, Y. and Takahashi, M. (1995). Growth responses of various diatoms isolated from various environments to temperature. *J.Phycol*. 31, 880-888.

Sweeney, B. W. and R. L. Vannote. (1981). *Ephemerella* mayflies of White Clay Creek: bioenergetic and ecological relationships among six coexisting species. *Ecology* 62, 1353-1369.

Taniguchi, Y., Rahel, F.J., Novinger, D.C. and Gerow, K.G., (1998). Temperature mediation of competitive interactions among three fish species that replace each other along longitudinal stream gradients. *Canadian Journal of Fisheries and Aquatic Sciences, 55,* 1894-1901.

Wetang'ula, G.M.N and Snorrason, S.S (2003). Ecological risk assessment of Nesjavellir co-generation plant wastewater disposal on Lake Thingvallavant, SW-Iceland. *Proceedings of International Geothermal Conference 14th – 17th September 2003, Reykjavik, Iceland.*