Эту закономерность целесообразно использовать в практических целях при проектировании и строительстве различных подземных объектов ЯТЦ, в которых предполагается размещение экологически опасных технологий и материалов, в том числе при захоронении радиоактивных отходов [4], строительстве подземных атомных станций и т.д.

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PHYSICO–CHEMICAL FEATURES OF WATERS AND BIOCOENOSIS OF A MEROMICTIC RESERVOIR IN THE YEARS 1981–1998 IN THE LEKNICA REGION (WESTERN POLAND)

ŪDEŅU FIZIKĀLI ĶĪMISKĀS ĪPAŠĪBAS UN MEROMIKTISKAS ŪDENSTILPES BIOCENOZE 1981. – 1998.GADOS LEKNICAS REĢIONĀ

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Abstract. *The research concerned the biggest, the deepest and the youngest (25 years old) acidotrophic reservoir located 4 km south–east from Łęknica. It was created as a result of brown–coal mining and opencast method. The present pyrite was the cause of significant acidifying and salinity of waters.*

17 years of physico–chemical examinations of waters showed a progressive difference between mixo– and monimolimnion that is increase or decrease of such indicators as pH, redox potential, total iron, sulphate and others. First symptoms of ageing of the reservoir were visible.

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Key words: *post–mining water reservoirs, meromixis, acidotrophic lakes.*

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1. Introduction

Meromixis is a rare phenomenon however widely common on our globe (Hutchinson, 1957; Walker, 1974).

In the „anthropogenic lake district" three meromictic reservoirs were found (Fig. 1). These are the only described cases representing this phenomenon in Poland (Matejczuk, 1986; Solski, Jędrczak, 1991a). Meromixis in its sharpest form was found in the biggest, the deepest and the youngest reservoir at the some time (25 years old). It was created in 1973 as a result of brown coal mining and the opencast method. It is located among pine–tree forests on depression land with its high and steep banks covered with deep furrows (water and wind erosion).

It is devoided of providing water and outlets. This reservoir has been examined many times in the years 1981–1998 (Matejczuk, 1986; Solski, Jędrczak, 1990; Solski, Jędrczak, 1991a, b; Jędrczak, 1992; Najbar, Jędrczak, 1998). It has been recognized as a particularily interesting object especially because of its extreme acidifying and salinity, presence of monimolimnion, bio–chemical processes taking place there (Jędrczak, 1992) and because of visible changes of their physico–chemical conversions in a short period of time.

2. Methods

2.1. Physico–chemical investigations

The reservoir was examined four times during the summer stagnation (VIII. 1987, VII. 1988, VIII. 1993, VIII. 1997) and twice during the autumn circulation (XI. 1981, IX. 1998).

The water samples were taken with a Ruttner sampler in vertical profile at the depth of: 0, 1, 3, 5 and then every two meters and 1 m above the bottom. The analysis contained over 20 physico–chemical indicators, whereas only 9 of them were analised and interpreted: temperature, pH, redox potential, oxygen, total iron, sulphate, ammonium, nitrates and phosphates, were determinated by the methodes described by Hermanowicz *et al.* (1976).

2.2. Biological examinations

The samples to indicate chlorophyll a contents were taken in quantities of 30–50 litres at the same depth as for chemical analysis. The chlorophyll a concentration was indicated according to SCOR–UNESCO method. (Ausgewählte Methoden 1970). Measurements on primary production were taken according to the oxygen method by Vinberg (1960). Bottles of water taken at a proper depth were exposed from dawn to dusk after which the oxygen contents were marked according to the Winklers method (Hermanowicz, 1976).

The samples of waters to indicate the phyto– and zooplankton were taken with help of a Ruttner sampler at the depts of: 0, 1, 3, 5 and then every two meters and 1 meter above the bottom. The samples were strained and preserved according to Starmach (1955). To indicate individual systematic groups of phyto– and zooplankton proper keys were used: *Protozoa* – Kahl (1931, 1932, 1935), *Bacillariophyceae* – Siemińska (1964), *Cyanophyta* – Starmach (1966), *Euglenophyta* – Popova (1966), *Chlorophyta* – Starmach (1972).

Organisms of littoral sphere represented by only few species were taken with help of a dredge and a nett. The contents were washed with water and the rest was preserved with formalin. To indicate organisms of this zone as well as benthos following keys were used: *Heteroptera*– Jaczewski, Wróblewski (1978), *Coleoptera* – Galewski and Tranda (1978), *Diptera* – Romaniszyn (1958).

3. Results

3.1. Temperature

Examination of temperature in vertical profile distinguished two layers: mixo– and monimolimnion. During the summer stagnation three typical layers of this period: epi–, meta– and hypolimnion were distinguished in mixolimnion. The lowest temperature (ca 6°C) appeared at the

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border line between mixo– and monimolimnion (9–11 meters) and then rose to ca 9.5°C (16–18 m). The border line of the lowest temperature was not stable and relocated vertically in years as a result of physical factors (convection stream, winds) (Fig. 2A). Examining temperature changes of waters in the distinguished meromictic reservoir in the years 1987–1997, the temperature rose in both mixo– and monimolimnion (Fig. 2A).

3.2. Oxygen

Changes of oxygen contents in waters of meromictic reservoirs were typical for strongly eutrophied reservoirs. Sufficient oxygenation in mixolimnion and total luck of oxygen in monimolimnion were found. Division of mixolimnion into three layers (epi–, meta– and hypolimnion) on the basis of temperature measurements, receded in case of oxygen and didn't return either in case of other indicators.

The oxyclin shows steadily grawing worse oxygen conditions through out years in the examined reservoirs. The top border line for waters devoided of oxygen was moving steadily towards the surface of reservoir (Fig. 2B).

3.3. Hydrogen– ion concentration

The reservoir was characterized with steady process of changes in pH of vertical profile of mixolimnion between 3.20 pH (VIII. 1997) and 4.38 pH (IX. 1998) and its rising in monimolimnion to 5.4 pH (IX. 1998) (Fig. 3A). The slighly growing pH in monimolimnion in relation to water leyers located above (mixolimnion) in November 1981 is worth mentioning. The growing pH in monimolimnion took place as a result of reduction process leading to using hydrogen– ion, whose intensity seems to have grown lately. Significant growth of pH in mixo–and monimolimnion was found in September 1998 (Fig. 3A).

3.4. Redox potential

The vertical distribution of redox potential in the reservoirs was in some way a revers vertical distribution of pH (Fig. 3B). The highest redox potential was found in mixolimnion: from ca 798 mV (VIII. 1993) to ca 818 mV (IX. 1998). At the depth of 9–10 m redox potential was decreasing in monimolimnion from ca 639 mV (VII. 1998) to ca 405 mV (VIII. 1993). The above results of examinations showed different to the results of 1981 (620–745 mV) (Fig. 3B).

3.5. Total iron

The concentration of iron in the vertical profile of mixolimnion was even and ranged between ca 60 mg $Fe \cdot dm^{-3}$ and ca 200 mg $Fe \cdot dm^{-3}$. Exceptions were found only during examinations carried out in August 1992, when the contents of iron rose to over 1000 mg $Fe \cdot dm^{-3}$ at the depth of 10 m. The concentration of iron below 10 meters rose steadily in the 1980s and reached the level of 800–900 mg $Fe \cdot dm^{-3}$ at the bottom. An intensive increase of total iron was found in August 1993 especially in monimolimnion where its concentration reached ca 1000 mg $Fe \cdot dm^{-3}$ (Fig. 4A).

3.6. Sulphates

The concentration of sulphates in vertical profiles of mixolimnion was balanced and ranged between ca 1400 and ca 1500 mg $SO_4 \cdot dm^{-3}$ in February and November 1981. It rose steadily below 10 meters in monimolimnion and reached ca 2750 and 2990 mg $SO_4 \cdot dm^{-3}$ above the bottom. The concentration of sulphates in mixolimnion decreased slightly between 1987–1997 whereas in monimolimnion in relation to 1981 increased considerably and reached 3850 mg $SO_4 \cdot dm^{-3}$ at the bottom in July 1988. The results of the 1993 examination were characterised with an increase of sulphates concentration already at the depth of 7 meters and kept the same in the monimolimnion, reaching 3935 mg $SO_4 \cdot dm^{-3}$ at the bottom (19 m) (Fig. 4B).

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3.7. Ammonium

Contents of ammonium salts in vertical profile of mixolimnion were aproximate and did not exceed 5 mg N·dm^{-3} (except August 1993). The difference in their concentration was found in monimolimnion and increased according to the depth. The ammonium salt's contents ranged between 7.6 mg N·dm^{-3} (XI. 1981) and 88.9 mg N·dm^{-3} (VIII. 1993), above the bottom (Fig. 5A).

3.8. Nitrates

The highest concentration of nitrates was observed in vertical profile of mixolimnion in 1981 and ranged between 3.30 and 3.60 mg N·dm^{-3}. They tendet to decrease as the depth increased. The nitrates disapeared in monimolimnion. They appeared in mixo– and monimolimnion in 1993 and their concentration ranged between 0.286 and 0.727 mg N·dm^{-3}. A hard to understand process of nitrates concentration in vertical profile was observed in 1998 when the lowest concentration (over 0.10 mg N·dm^{-3}), was shown already at the depth of 9 meters and slowly decreased to the depth of 17 m. Otherwise only a slight concentration of this anion was observed. It took place in the top layer of mixolimnion and did not exceed 0.05 mg N·dm^{-3} (Fig. 5B).

3.9. Phosphates

There were no phosphates observed according to accesable methods, in mixolimnion in November 1981. This anion appeared at the depth of 13 m, and reached concentration not exceeding 0.001 mg PO_4·dm^{-3} whereas it increased at the bottom and ranged between 0.002 and 0.003 mg PO_4·dm^{-3}. In mixolimnion phosphates reached 0.10 mg PO_4·dm^{-3} in the years 1987–1988. The concentration of this ion was lower in monimolimnion and did not exceed 0.010 mg PO_4·dm^{-3}. The lowest concentration of phosphates was observed at the depth of 5 meters in August 1993 (ca 0.013 mg PO_4·dm^{-3}) and even lower concentration of this anion took place in monimolimnion (Fig. 6A).

3.10. Development of biocoenosis

The moving banks, lack of vascular plants and lack of typicaly created littoral these are the main obstacles for the examined reservoir to be settled in by water organisms. Whereas lack of oxygen in monimolimnion limited the benthos penetrating the profundal below isobath of 9–10 m, reducing their living area. For these reasons number of the selected systematic individuals and particular species of plankton and benthos was poor over 18 years. Only 12 units of classification were observed between 1980–1995 whereas 6 new species have been found in the last two years (1997–1998) (Table I).

4. Discussion

Meromixis is a phenomenon, which was obserwed in the examined reservoir as well as in three other reservoirs of the „antropogenic lake district" and it shows its own complicated genesis as the ektogenic and endogenic meromixis (Walker, Likens, 1975). The phenomenon was created in very fovourable morphometry of their excavation (high value of the relative depth 0.0788–0.0533) and the surrounding land (piled heaps, low location of the basin, the forests) (Solski, Jedrczak, 1991).

Pyrite accompanying the coal mines went through a very complicated process of decomposition (Backer, Wilshire, 1970); Walsh, Mitschell, 1972) causing creation of sulphuric acid and its results:

- acidifying of waters to the extend limiting development of biological life,
- creation of conditions favourable for degradation of rocks,

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- gathering of sulphuric acid salts at the bottom of waters in quantities leading to creation of monimolimnion,
- appearance of sulphate type water in reservoirs.

Iron and sulphur played the main role in creation of monimolimnion (Kjensmo, 1967; Carignan 1988; Forsberg, Morling, 1988). There is a question of whether or not there has been any progress in the process of eutrophication of the examined reservoir.

In the opinion of Solski and Jedrczak (1991) the intensity of reductive processes in monimolimnion are measure for aging of meromictic reservoirs expressed in redox potential. Examination of meromictic reservoirs in the 1980s proved that the redox potential of monimolimnion waters was equal or higher than 400 mV showing at the same time lack of any desulphatisation processes. At the same time in two other (older) meromictic reservoirs redox potential reached from 300 mV to 212 mV which proves of advanced reductive processes of sulphates (Solski, Jedrczak, 1991). Reduction of redox potential in the monimolimnion of the in July 1988 and August 1992 examined reservoir to the level of 398 mV and 390 mV proved that reservoir is getting old. What was discovered that within 17 years (1981-1998) proceeding differences between the mixo- and monimolimnion took place, consisting in increasing or decreasing concentration of the following physico-chemical indicators: pH (Fig. 3A), redox potential (Fig. 3B), iron (Fig. 4A), sulphates (Fig. 4B), ammonium (Fig. 5A). As a result of water acidifying with sulphuric acid, the ion composition of those waters went through transformation processes and sulphate waters appeared.

Chemolitoautotrophic bacteries such as *Thiobacillus* mainly species of *Thiobacillus ferrooxidans* were considered to be the pionier organisms of acidotrophic waters of post-mining or sinkhole origin. Those bacteries oxygenate the bivalent iron in acidic conditions. Further in the row there are bacteries oxygenating sulphur as well as typical acidobionts and acidophils (Berg, Petersen, 1958; Popova, 1966; Langworthy, 1978) among which there are *Eunotia exiqua* (*Bacillariophyceae*) and *Euglena mutabilis* (*Euglenophyta*).

When in waters with its pH close to neutral the number of *E. mutabilis* did not excee 2.4% of all found organisms, so in case of 2.41-3.89 pH their number reaches up to 90-100% of all organisms among *Euglenophyta.* Apart from *E. mutabilis*, *E. exiqua* is another dominant living in the most (inaccessable) acidotrophic reservoirs of the examined „antropogenic lake district", deciding together with the bacteries about their productivity. *E. exiqua* was found to have been dominating species in waters of the described meromictic reservoir (2.4 pH) in the years 1993-1998 and made between 90% up to 100% of all organisms of phytoplankton found. Yoshimura (1933) found the *Eunotia* species in more acidic enviroment (1.4 pH). It must be stressed that such strong water acidifying can be critical for *E. exiqua.* A large percentage of *E. exiqua* armours taken from the examined meromictic reservoir showed deformation of armours which indicates difficult living conditions. Matejczuk (1992) considered 3.1 pH as an optimal hydrogen- ion concentration for *E. exiqua* to live. Diatoma *E. exiqua* was accompanied by similar species of *Eunotia tenella* which some times is considered as indicating organism for acidic waters. Quantity of this diatoma in meromictic reservoirs in the years 1993-1995 ranged between 0.5-4.2%. Another interesting species found in this reservoir is *Lyngbia ochracea* building visible agglomerations in quiet shallow and warm waters of the reservoir.

Among other organisms appearing in the waters of this reservoir there were: *Ciliata* and *Flagellata apochromatica, Sialis sp.* (*Megaloptera*), *Chironomus* (*Tendipes*) *plumosus* (*Diptera*), and recently *Heteroptera* (*Corixidae*) and *Coleoptera* (*Dytiscidae* and *Gyrinidae*) (Table I).

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Among „pionier" vascular plants appearing in the bank area of acid and salty reservoirs in the region of Łęknica there were: *Juncus bulbosus* L. and *Phragmites communis* Tr. In Matejczuk's opinion (1992) *Sphagnum sp.*, can also be considered as „pionier" species, whereas Heym (1971) proves that it could be *Sphagnum cuspidatum* Schimp. Pietsch (1965) howewer thinks, that the speed of acidotrophic reservoirs to become populated depends on fine rush (*J. bulbosus*), which grows at the bottom of a reservoir even at the depth of 30 meters. There were not any cases of phytocenosis in the bank area or in the water within 25 years.

Populating the post–mining acidotrophic reservoirs by both animals and plants of different species depends mainly on their pH and iron concentration (Riley, 1960; Parsons, 1964; Puchalski, 1985) and further on other physico–chemical feature of the water enviroment.

Presence of individual flora nad fauna representatives is not finally and exclusivly determined by chemism of reservoir waters. Two of them located in Leknica region, close to each other are worth mentioning as they show similar genesis, age and pH, but different biocoenosis. In one of them (the described meromictic reservoir above) only few representatives of bacterioplankton, fungis, a few species of phyto– and zooplankton and lately insects were found whereas in the second reservois apart from the above mentioned groups of plants and animals: *Chlorophyta* (*Binuclearia tectorum*), *Rotatoria* (*Ascomorpha sp.* and *Asplanchna sp.*), *Odonata* (*Aeschna sp.*, *Anax sp.*, *Cenagrion sp.*), *Macrophyta* (*J. bulbosus* L., *J. compresus* L., *J. effusus* L.) and even *Amphibia* (*Rana lessonae* Camerano) appeared few years ago (Najbar, 1996).

A great contribution to a luxuriant development of plants and bigger number of animal species have brought creation of quiet forests protected from winds shallow bays which enable plants to root and to grow. Their close surrounding makes it possible to create ecological niches, which use microorganisms and built basis for further succesion.

The majority of the representatives of the above mentioned which were found in bigger number of the examined reservoirs showed better adaptative abilities and their presence falls on particular ecological collective body. Some of them are species common in Poland but they belonged to the rare in the examined reservoirs.

It has been proved that for the biocoenosis to develop and to populate the reservoirs with representatives of various groups of plants and animals, apart from the ground composition on which they were created, also the biotopic conditions are of importance. Shallow reservoirs with high banks or shallow back waters with low located bays surrounded with forest, protected from winds, become populated by macrohydrophytes and living close to them phyto–, zooplankton and numerous arthropoden much faster.

Reservoirs with steep, moving banks covered with drift, where it is difficult even to differentiate the proper littoral sphere give incomparably less chance for the „pionier" plants to settle permanently.

A good example of a reservoir shoving similar composition of it bank line is the meromictic reservoir described above and located near Leknica (Fig. 1). So shaped bank line together with disadvantageous geomorphological conditions, open exposed to strong winds water level of 18,8 ha and considerable depth (over 20 m) makes it difficult for every species to settle and can be extended in time and then the processes of the reservoirs getting older is hardly visible.

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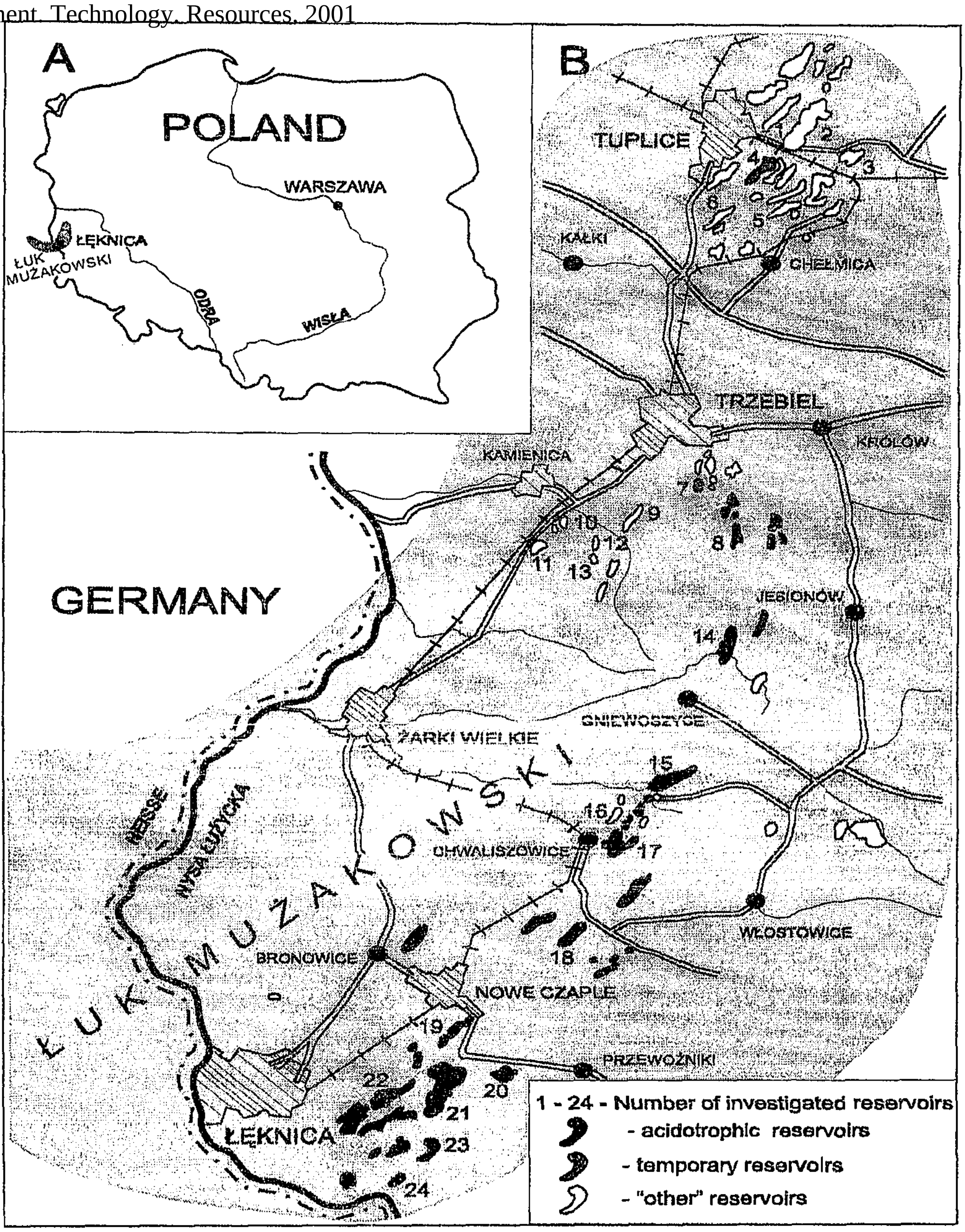

Fig. 1 *Łuk Mużakowski (Western Poland) A - general location, B - investigated region.*

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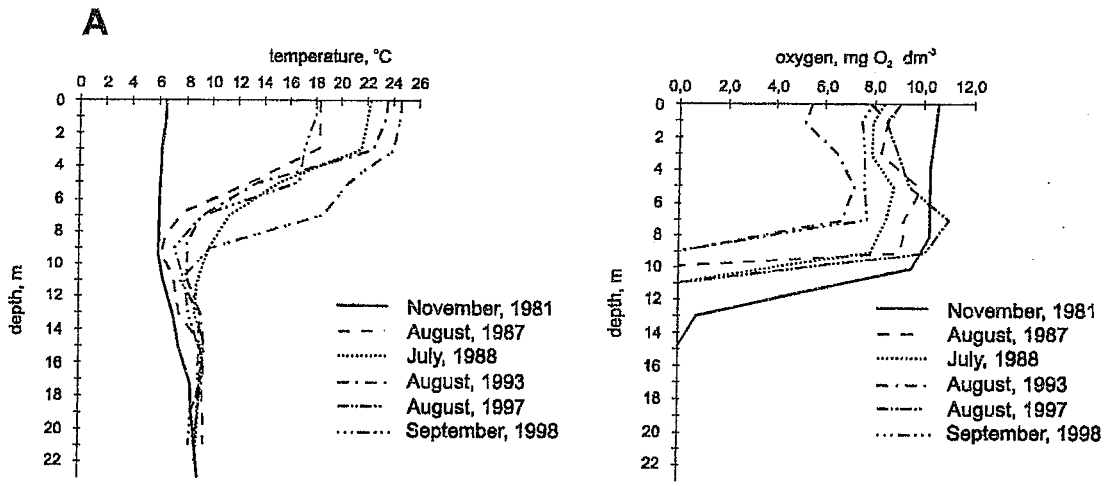

Fig. 2 *Vertical distribution of temperature (A), oxygen (B) in the meromictic reservoir, 1981-98.*

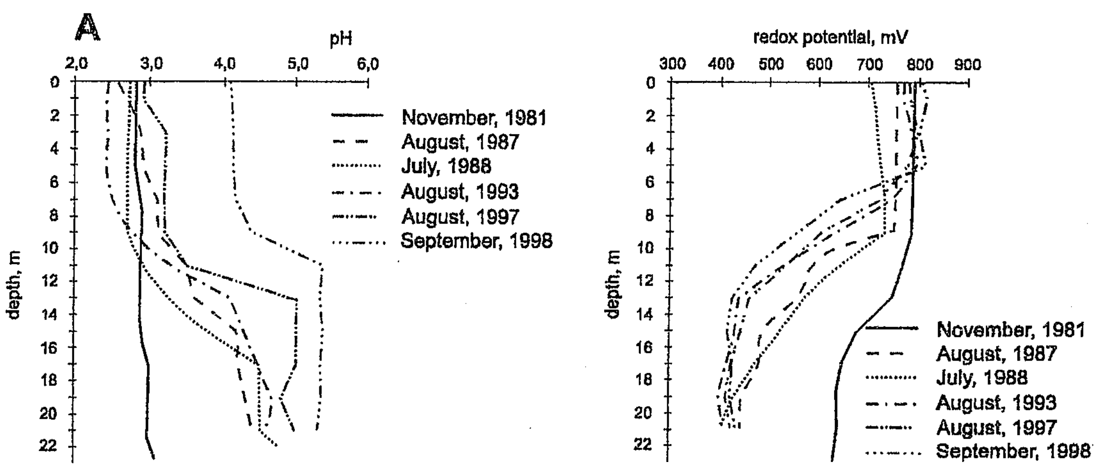

Fig. 3 *Vertical distribution of pH (A), redox potential (B) in the meromictic reservoir, 1981-98.*

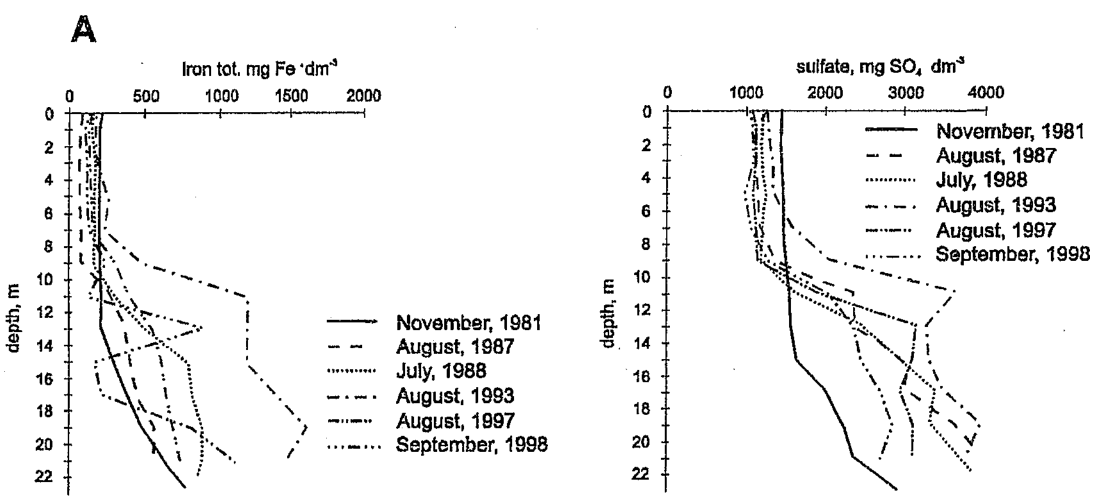

Fig. 4 *Vertical distribution of iron (A), sulfate (B) in the meromictic reservoir, 1981-98.*

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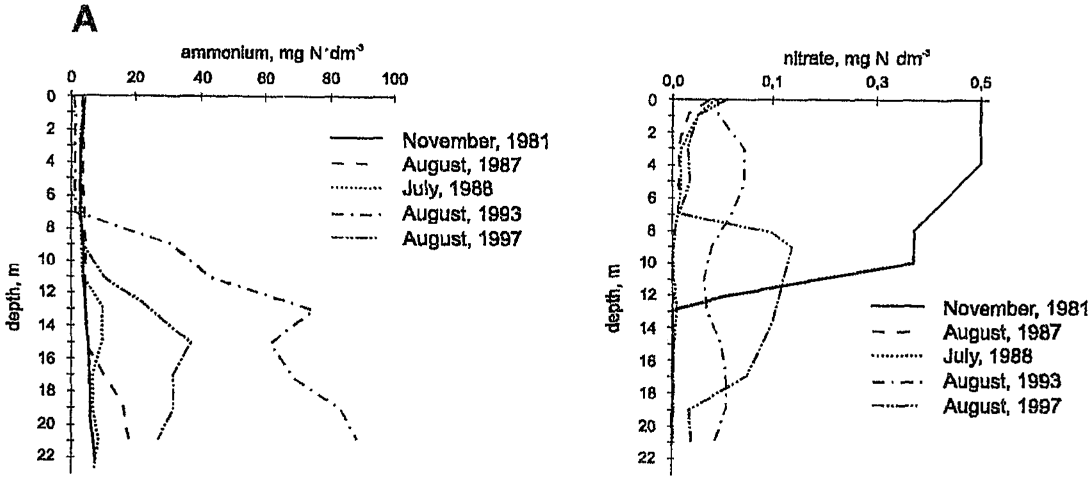

Fig. 5 *Vertical distribution of ammonium (A), nitrate (B) in the meromictic reservoir, 1981-97.*

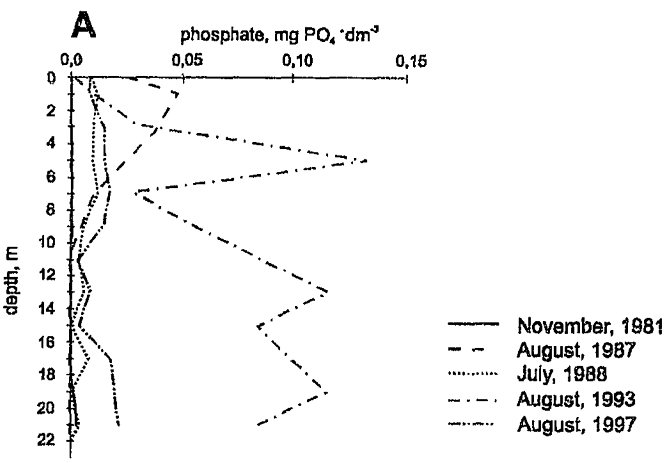

Fig. 6 *Vertical distribution of phosphate (A) in the meromictic reservoir, 1981-97.*

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