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Chemical methods of P-elimination in the tributaries of reservoirs and lakes

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ABSTRACT

Based on experiences which have been gained at Wahnbachreservoir the success of chemical P-elimination in tributaries is described with regard to oligotrophication and subsequent improvement of the conditions for drinking water treatment.

The method of controlling eutrophication by phosphorus elimination in the main tributary has for the first time been applied at the Wahnbach Reservoir. This method has been selected because the phosphorus input originates mainly from diffused sources. The fact that in the case of Wahnbach Reservoir diffused sources prevail, is due to the structure of the catchment area as can be obtained from figure 1. The bed rock in the catchment area consists mainly of devonic slate. Soil formed by withering of this type of rock consists of a fine grained loam. With the exception of the slopes of the steep narrow valleys, the catchment area is mainly used as arable land. Due to the soil type precipitation runs off very quickly, and soil erosion is of great importance. It has been estimated, that about 60 to 70% of the yearly incoming phosphorus originates from agricultural areas [1]. The settlement of the catchment area consists mainly of single farm-houses and small hamlets and there is only one mayor village with a sewage treatment plant. Since the importance of point sources is negligible, the application of tertiary treatment would have been of almost no use and thus phosphorus elimination from the main tributary was stringent. Figure 2 shows an operation scheme of the phosphorus elimination plant. This system has been developed in the course of more than 15 years of research. The technical details have been described elsewhere [2]. It should only be mentioned here that the elimination plant is very flexible in following the extreme variation of the flood pattern of the main tributary. The pre-reservoir with the volume of 500,000 m^3 acts as a buffer which at least can store minor floods. The filtration velocity of the phosphorus elimination plant can amount up to 15 m per hour. The maximal throughput amounts to 5 m^3 per second. This is five times as much as the average flow rate of the main tributary. Depending of the occurrence of soil particles or planctonic algae respectively, the flocculant dosage

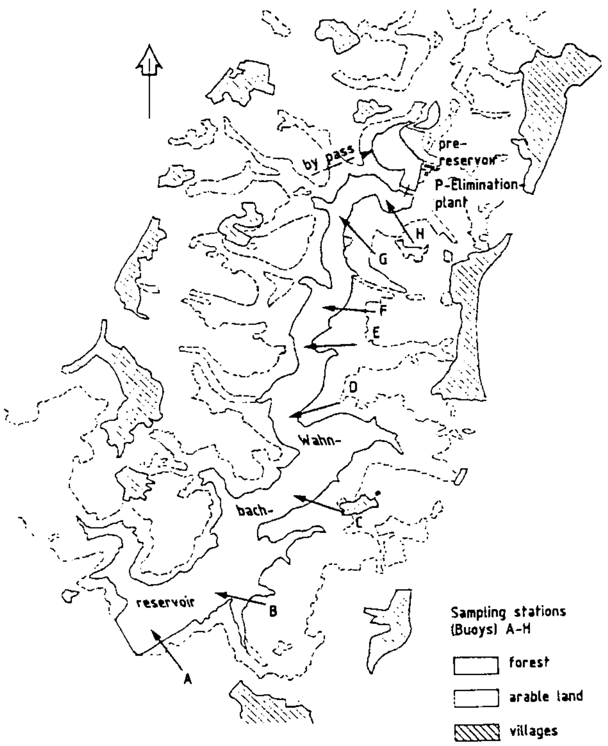


Figure 1. Map of the Wahnbach reservoir showing the structure of catchment area and the position of the sampling stations, the pre-reservoir and the P elimination plant (PEP).

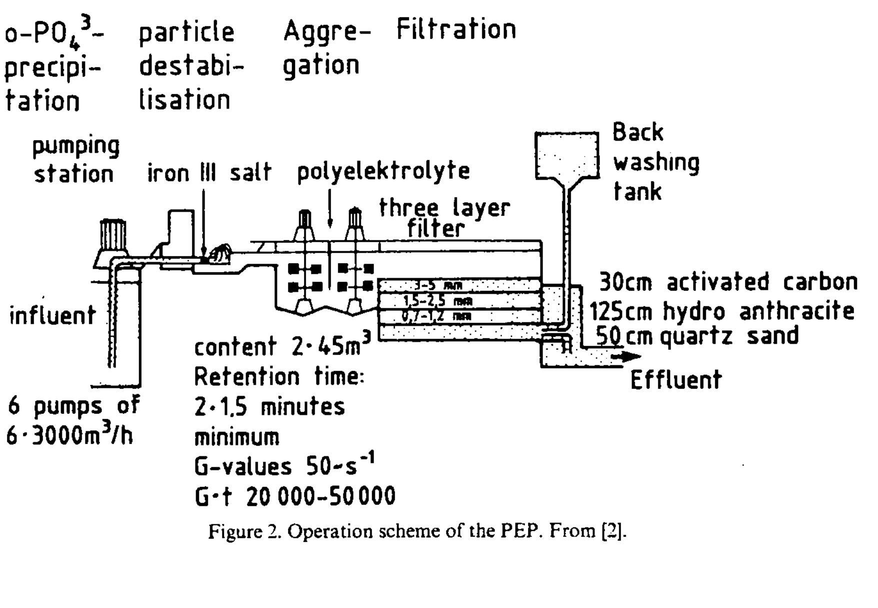
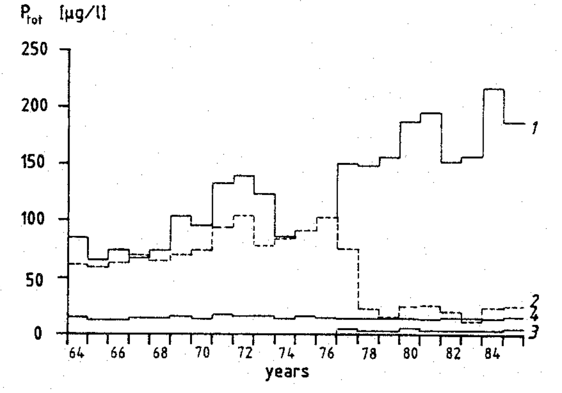


Figure 2. Operation scheme of the PEP. From [2].

amounts to 4 to 10 mg/l of ferric iron. By means of this treatment not only phosphorus is removed but also turbidity, algal and bacterial cells and to some extent DOC [3].
The phosphorus elimination plant at the Wahnbach Reservoir went into operation in late 1977. Since then two similar plants have been built in Berlin. These plants, however, have to cope with much higher phosphorus concentrations. Therefore in these plants it was necessary to apply a sedimentation step prior to filtration. Due to the high concentration of organic phosphorus, the rest P concentration amounts to 30 µg/l P_{tot} whereas at the Wahnbach Reservoir the elimination results in a concentration of only 5 µg/l P_{tot}. The operational details of the Berlin plants and the reaction of the Berlin lakes on the elimination of phosphorus may be obtained from the literature [4,5].
Before the reaction of Wahnbach Reservoir on the reduction of phosphorus input will be described, more details are to be given about the phosphorus input into Wahnbach Reservoir prior to and during the operation of the phosphorus elimination plant. This can be obtained from figure 3. Line No. 1 is a calculated figure which shows the potential yearly phosphorus input into the reservoir. This number has been calculated by summing up the phosphorus loads of the main tributary, the minor tributaries and precipitation and deviding this figure by the sum of the water input of these three sources. From figure 3 one can obtain that in the course of the past 20 years a considerable rise of the phosphorus concentration took place. Within this time the potential phosphorus input was almost doubled. The same is also true for the nitrogen concentration. The reasons for this considerable rise are not yet quite clear. There is, however, much evidence, that this is due to a change of the agricultural methods. One reason for the increased phosphorus run-off seems to be the fact that in the last years maize has become a more and more important crop. Maize can be much heavier fertilized than other cereals. Since the distance between the single maize plants is much wider than e.g. the distance between the plants of a wheat field and since the soil between the maize plants is strictly kept free from weeds, soil erosion seems to be of greater importance in maize fields. A further reason for



1 = sum of all tributaries and precipitation *without* P-elimination
2 = sum of all tributaries and precipitation *with* P-elimination
3 = PEP effluent
4 = Tolerable for oligotrophic condition (Vollenweider)

Figure 3. Yearly means of P concentrations in the tributaries of the Wahnbach reservoir with and without P elimination compared with the P concentration which would be tolerable for oligotrophic condition.

the increase of the phosphorus load seems to be the change in the way of applying manure. Originally manure was mainly applied in a solid form. In more recent years nearly all manure is applied in a liquid form.

Line No. 2 shows the real phosphorus input into the reservoir. For the time before the phosphorus elimination plant went into operation, this figure has been calculated by summing up the phosphorus output of the pre-reservoir, of precipitation and of minor tributaries. In most years the values represented by line No. 2 are lower than those of line No. 1. This is due to the fact that a natural phosphorus elimination has taken place in the pre-reservoir. The phosphorus elimination in pre-reservoirs has also been observed in other places [6] and has been worked out as a sophisticated system for phosphorus elimination [7]. After 1977 the difference between line No. 1 and line No. 2 is by far greater than in the years before. This is due to the operation of the phosphorus elimination plant. The values which are representing line No. 2 are, however, higher than the phosphorus output concentration of the phosphorus elimination plant which is shown in line No. 3. This is due to the fact that there is not only a phosphorus input from the phosphorus elimination plant but also from precipitation and minor tributaries. Furthermore in some years so high floods occur that they cannot be totally treated in the treatment plant, which means that the yearly P input into the reservoir is increased. Nevertheless the phosphorus input concentration of the Wahnbach Reservoir is sufficiently low for our demands since 1978, which can be derived from the fact, that this concentration is very close to the limit concentration for oligotrophic lakes. This limit concentration calculated for the Wahnbach Reservoir, is shown in line No. 4. Because the importance of the minor tributaries has increased since the phosphorus elimination plant went into operation, great efforts have to be made to reduce the phosphorus input from these minor tributaries, at least in the worst cases. Up to the present this has been done with two tributaries. One stream which is heavily loaded by domestic sewage, was diverted by a bypass-pipeline towards to pre-reservoir (fig. 1). Another stream, the one closest to the dam of the

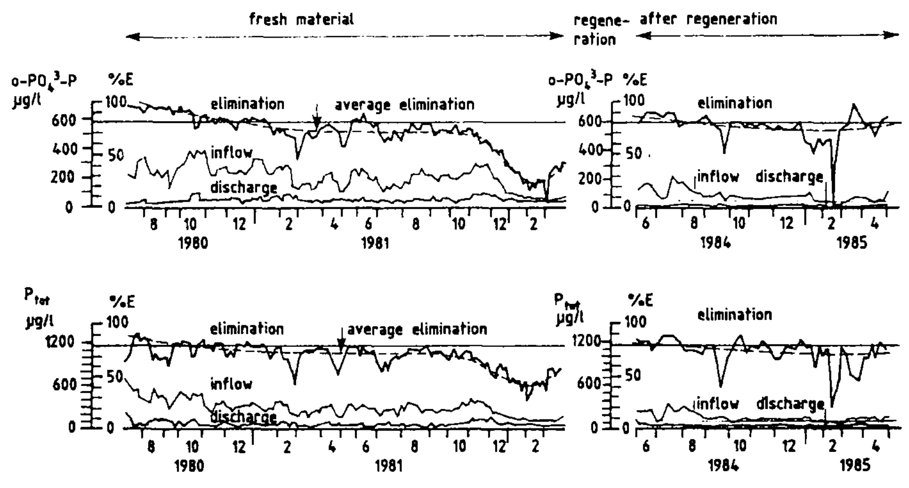


Figure 4. Results of P elimination using activated alumina filters. P concentration of in- and outflow of the pond for the period June 1980 to March 1982 with new filter material and from May 1984 to 1985 with regenerated material.

reservoir, is heavily loaded with phosphorus and ammonia from a fish farm. Here a pilot plant has been built, which removes the phosphorus by means of filters which are filled with alumina grains. The results can be obtained from figure 4. The main advantage of this system is that it can be operated in a very simple way. A regeneration of the alumina grains is possible [8].

The phosphorus concentration of the reservoir is shown in figure 5 (upper graph). The upper line shows the concentration of the total phosphorus, the lower line of the soluble

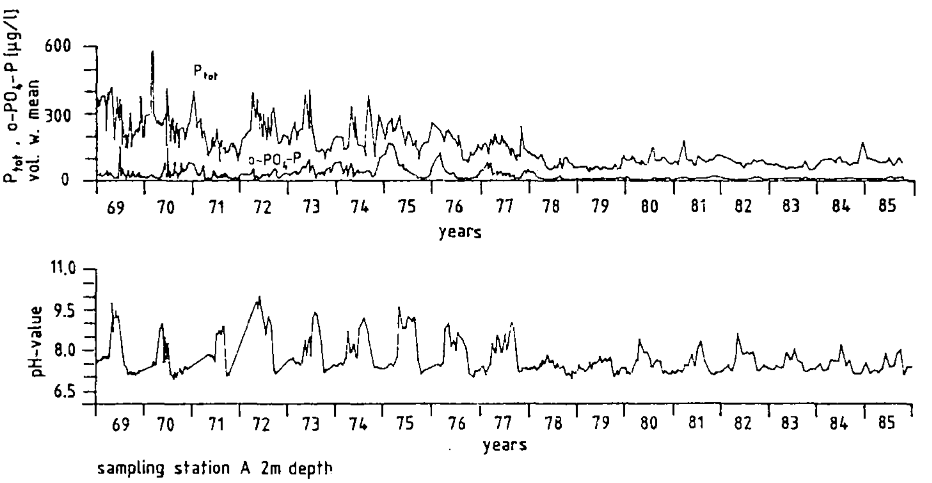


Figure 5. P concentration (volume weighted means) and pH of Wahnbach reservoir. P elimination started in late 77.

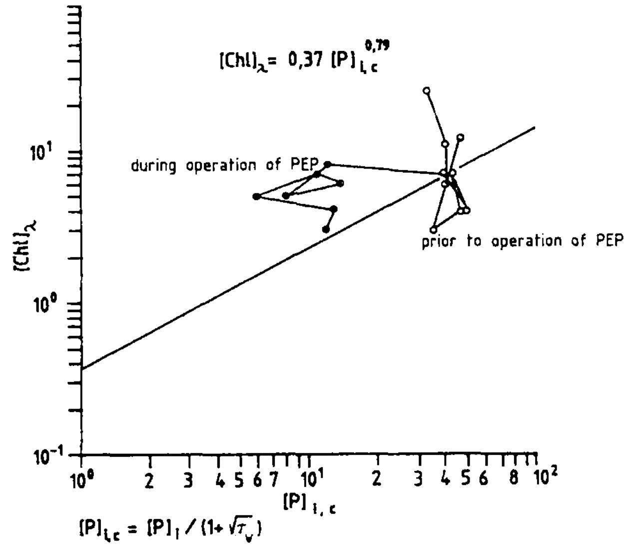


Figure 6. Chlorophyll-a concentration of Wahnbach reservoir versus P concentration of its tributaries. Comparison with the OECD regression [9].

reactive phosphorus. Both lines have been constructed by calculating volume weighted means. As stated above the phosphorus elimination plant went into operation in the autumn of 1977. It can be obtained from figure 5 that in the course of only half a year the phosphorus concentration in the reservoir dropped considerably after the phosphorus elimination plant went into operation. Since the phosphorus elimination plant has been run, the concentration of soluble reactive phosphorus in the Wahnbach Reservoir is almost always below the limit of detection. In figure 6 the annual volume weighted means of the chlorophyll concentration have been plotted against the retention time corrected input concentration of phosphorus, and they are compared with the regression line which originates from the OECD study [9]. The dots have been combined with a line which follows the course of time. Dots which are representative for the time prior to phosphorus elimination, are marked in a different manner to separate them from those which are representative for the years with phosphorus elimination. Generally speaking, the variation of the chlorophyll concentration is much greater than the variation of the phosphorus concentration. Whereas the dots which are representative for the years prior to phosphorus elimination are scattering around the OECD line, the dots which are representative for the time with phosphorus elimination are all above this regression line. This means that the chlorophyll concentration, compared to the phosphorus input, has been rather high during the time of phosphorus elimination. It seems, however, that there is a trend towards the OECD line. Further observations in the coming years will show, whether this trend goes on. Another way of evaluating the phosphorus and chlorophyll concentrations in the reservoir, is the construction of sum of frequency curves. For the construction of these curves not the yearly averages have been taken, but the single values of volume weighted means. Additionally a separation has been made between the station A, which is situated close to the dam and the sampling station E, which is situated close to the main tributary. Figure 7 shows the frequency of phosphorus concentration at sam-

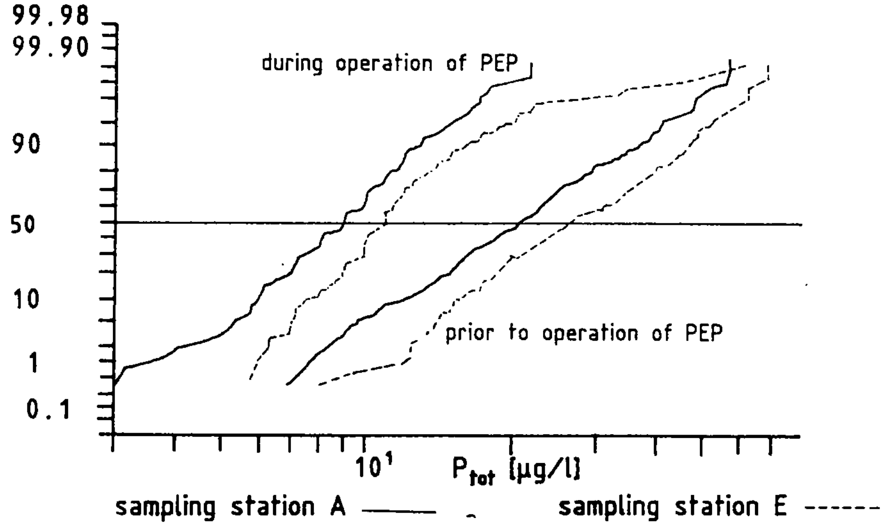


Figure 7. Sum of frequency of P concentrations of Wahnbach reservoir prior to and during P elimination. Comparison of results from sampling stations A and E (see fig. 1).

pling station A prior to and during elimination. The dramatic shift of the concentration from higher to lower values is evident at both sampling stations. The comparison of sampling stations A and E reveals that the phosphorus concentrations at sampling station A are always lower than the phosphorus concentrations at sampling station E. It is remarkable that this is not only the case before the phosphorus elimination plant went into operation, but also during the time of phosphorus elimination. This means that during the operation of the phosphorus elimination plant, higher phosphorus concentrations occur in sampling station E, although this point is closer to the outlet of the phosphorus elimination plant than sampling station A. This shows that a considerable decrease of the phosphorus concentration takes place along the main axis of the reservoir. The net settling rate of phosphorus seems to be higher in the deeper part of the reservoir close to the dam (sampling station A). Figure 8 has been constructed for chlorophyll. Also here a shift of the chlorophyll concentration towards lower values due to the phosphorus elimination is evident, although not as striking as in the case of the phosphorus concentration. Not only the phosphorus but also the chlorophyll concentrations are higher in the shallower parts of the reservoir. Figure 9 show the frequency distribution of the Secchi disc readings. Whereas in the case of phosphorus and chlorophyll a normal distribution could be obtained by using a logarithmic scale, a linear scale had to be applied for the Secchi disc readings. This is due to the fact, that the Secchi disc readings per se are a sort of logarithmic values, since they represent the light attenuation in the water. From figure 9 one can obtain that the Secchi disc readings have increased considerably since the phosphorus elimination plant went into operation. Even for the Secchi depth the difference between the sampling station A and E is remarkable.

In the case of Secchi depth values not only from two sampling stations are available so that it is possible to construct longitudinal sections along the main axis of the reservoir,

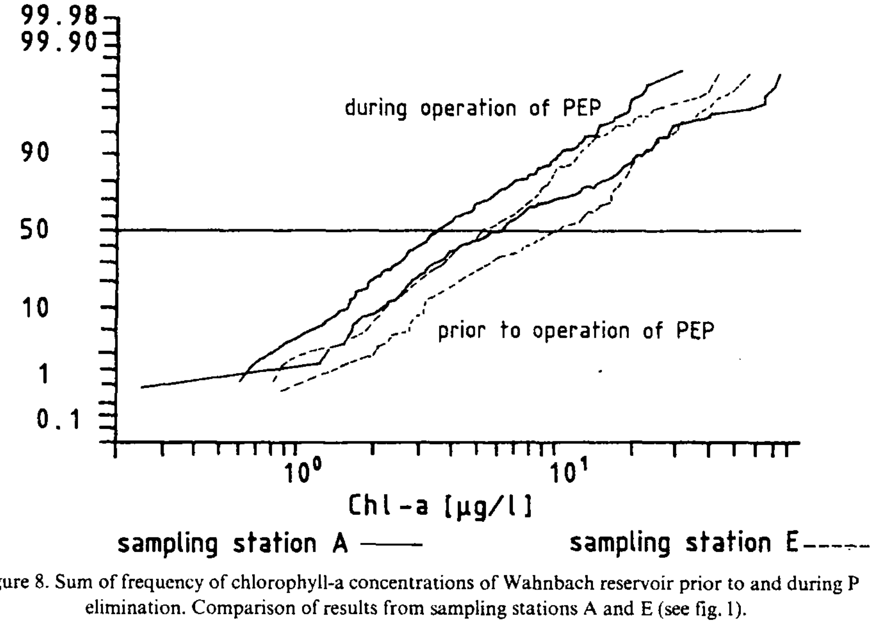


Figure 8. Sum of frequency of chlorophyll-a concentrations of Wahnbach reservoir prior to and during P elimination. Comparison of results from sampling stations A and E (see fig. 1).

which show the increase of the Secchi disc readings from the upper (sampling station G) to the lower end (sampling station A) of the reservoir (fig. 10). This difference is best visible in summer and autumn when the water input is usually low. All results seem to point out, that the trophic state of the reservoir is at a higher level in its shallower part. This might be due to the fact, that in the shallower part the internal load of phosphorus is of greater importance than in the deeper part of the reservoir. The influence of the sediment of the shallower parts on the quality of water have been described elsewhere [10].

Not only the phosphorus and chlorophyll concentration and the Secchi disc readings show a dramatic change which is due to phosphorus elimination, but also the composition of the algal flora. Of the many results which are available, there is only one example shown in this paper. The occurrence of three selected species of planctonic algae is presented in figure 11. In the upper graph the occurrence of *Oscillatoria rubescens* is

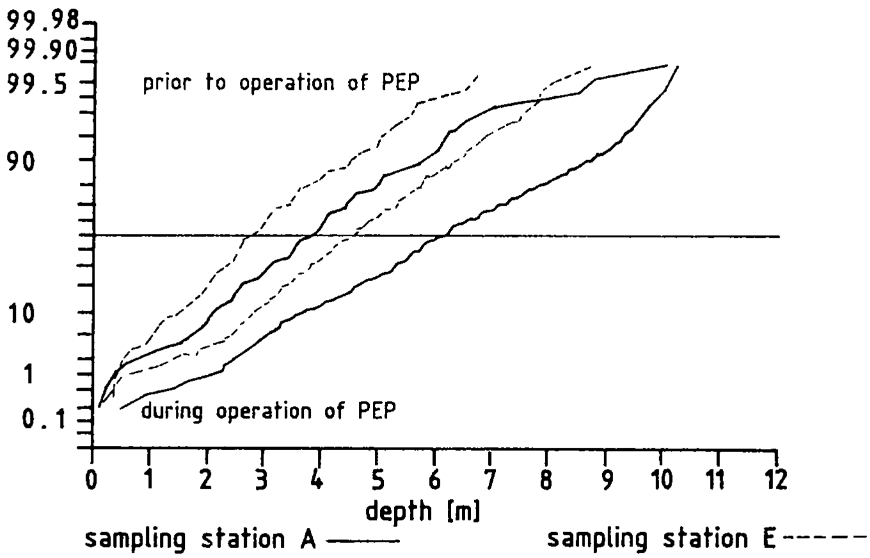


Figure 9. Sum of frequency of Secchi disc readings of Wahnbach reservoir prior to and during P elimination. Comparison of results from sampling station A and E (see fig. 1).

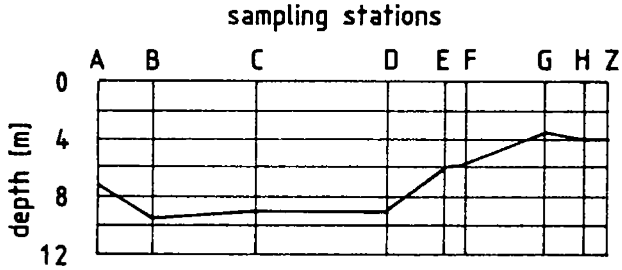


Figure 10. Secchi depths along the main axis of the Wahnbach reservoir from sampling station A to sampling station Z (at the mouth of the main tributary during a period of low water input (September 1985).

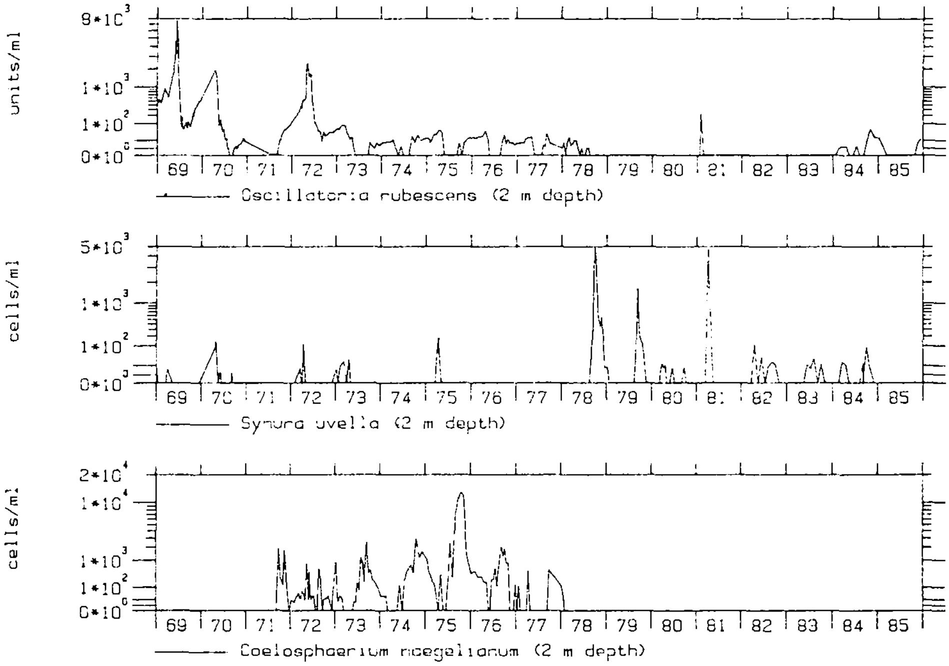


Figure 11. Occurrence of selected algal species in the Wahnbach reservoir prior to and during (since autumn 1977) operation of PEP.

shown. Formerly this species formed blooms in the reservoir [11]. Since 1973 the frequency of this alga was rather low. After phosphorus elimination went into operation it disappeared for several years but reoccurred in relatively low numbers in the most recent years. Heavy blooms, however, have never again been observed. The occurrence of *Oscillatoria rubescens* is of great importance for the operation of the drinking water treatment plant since fragments of the filaments may penetrate the filters. The same is due to single cells of another blue-green alga, *Coelosphaerium*, the occurrence of which is also shown in figure 11. This alga appeared for the frist time in 1971 and disappeared after the phosphorus elimination plant went into operation. It has never reoccurred again. Of special interest is the chrysophyte *Synura*. This alga was rather infrequent before the phosphorus elimination plant went into operation. In the first three years after the phosphorus elimination plant went into operation, tremendous blooms of this alga occurred mainly in the shallower parts of the reservoir. In recent years the frequency of this species has decreased more and more. It is remarkable that *Synura* has a very high chlorophyll content compared to its phosphorus content. Thus it is mainly due to the occurrence of this species that the chlorophyll concentrations compared to the phosphorus concentrations have been relatively high in the first years after the phosphorus elimination went into operation (compare fig. 6).

Not only a shift in the composition of the flora, but a decrease of primary production seems to be have taken place as well. This can be derived from the pH values in the epilimnion which are shown in figure 5 (lower graph). Since an overturn of water takes

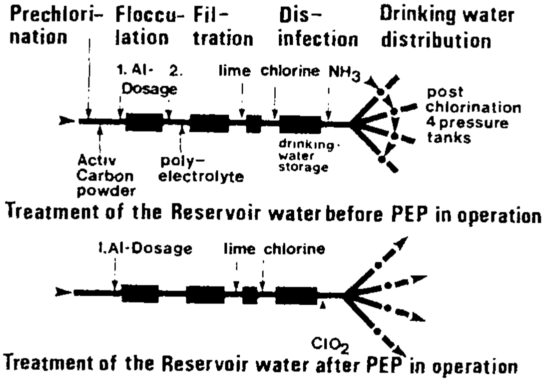


Figure 12. Treatment of reservoir water before and after PEP in operation.

place in winter, during that time a replenishment of CO_2 takes place so that the pH remains close to 7. In summer, however, when inorganic carbon is consumed by the algae faster than it can be replenished from the atmosphere and from the tributaries, a considerable rise of the pH takes place. Therefore this rise of pH can be regarded as a measure of primary production. Figure 5 shows very clearly that the summerly rise of pH and thus the primary production was much higher before the phosphorus elimination plant went into operation. One could argue, however, that the pH of the inflowing water is lowered by one unit due to the dosage of ferric salts in the phosphorus elimination plant. But this seems to be of almost no influence on the pH in the reservoir. Otherwise winter values, which at present occur in the reservoir, should be lower than the winter values which occurred prior to phosphorus elimination.

The changes which took place in the reservoir, influenced dramatically the operation of the drinking water treatment plant as well.

Not only P_{tot} and chlorophyll-a but also DOC decreased considerably after the phosphorus treatment plant went into operation. This decrease is partly due to the elimination of DOC in the phosphorus elimination plant, but also to the decrease of primary production. The decrease of DOC is of utmost importance for the operation of the drinking water treatment plant since such organic compounds can be regarded as precursors for the formation of trihalogenmethanes. The schemes which are shown in figure 12 clearly prove that the production of potable water at the Wahnbach Reservoir has become much more simple and safe since the P-elimination plant went into operation. This mean that the aims of this plant have been fully achieved.

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