BARD

FINAL REPORT

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Sediment-Water Processes as a Management Tool for Water Quality Control in Impoundments

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ABSTRACT

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The present work dealt with several aspects of sediment - water interactions.

a) Use of algae-clay coflocculation for the clearing of turbid water bodies: It was found in field and in model experiments that stimulation of algal growth by controlled fertilizer addition leads usually to the clarification of the water. However, the efficiency of the process depends on the algal species.

b) The methodology of algal culturing in turbid suspensions and that of the measurement of particle sizes has been improved.

c) Mixture of algal rich water with clay was found to be an important cause of irrigation systems clogging. It is important to prevent mixing of clay by scouring or mixing of water sources.

d) The changes of soil to aquatic sediment is leading to an enrichment in organic components and an orders of magnitude increase in ammonium. Nutrient fluxes in the newly constructed Maaleh Hakishon reclaimed effluents reservoir were measured and computed. A model for the accumulation of organic materials in the sediment is showing that the reservoir is already very close to its steady state.

e) A model describing the combined effect of nutrient uptake and release on biological processes was developed. It is shown that systems having an uptake capacity higher than the release potential are stable, even at high nutrient inputs. The opposite case leads to instability (eutrophication).

f) The increase in total phosphorus found in Lake Kinneret may be due to the increased resuspension of sediments due to the decrease in the salinity of the lake.

OBJECTIVES

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The general objective of the proposed research was to broaden our understanding of the interaction of sediment with water and to use this information to develop a water quality management scheme.

- a. To study the mechanisms of algal-clay flocculation and the resultant sedimentation.
- b. To utilize this flocculation reaction as a practical means to control water quality in lakes.
- c. To study the carbon, nitrogen, and phosphorus exchange with sediments in man-made lakes varying in their degree of productivity.
- d. To develop practical means to limit nutrient supply from the sediment to the overlying water in farm ponds and impoundments.
- e. To develop optimal technologies for management of man-made lakes; irrigation water or municipal consumption reservoirs, reclaimed sewage effluents reservoirs, fish ponds or lakes used for recreation.

SUMMARY

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The work presented here deals with the interaction of water with sediments, either dispersed or at the bottom of the water body. The report is presented as a collection of 14 chapters divided into 3 groups. The central topic in our research proposal and in this work is the coflocculation of clay and algae, both as related to the study of the phenomenon as well as to its use as a method to clear turbid impoundments.

In the first chapter of this report we present a reprint of two manuscripts describing the work that was done before the start of the present project, a work that served as a basis for the planning of the present work. The first paper in the series describe the laboratory experiments demonstrating the fact that admixture of algae and clay leads to the formation of flocs created by the interaction of the two types of suspended particles. It was the first time that that type of interaction was reported in the scientific literature (even though some indirect evidence for the phenomenon were reported). Since, a number of publications, some based upon our work have been published. Moreover, the importance of the topic has been widely recognized. One of the observations in that work was that among the algal species tested (*Anabaena*, *Chlorella*, *Clamidomonas* and *Euglena*, the first three induced flocculation while the last did not. The same phenomenon was found later in field trials.

The second work in that chapter represents our first trial to test the applicability of this phenomenon to clear turbid water bodies. Clay-induced turbidity is common worldwide and is one of the main surface water quality problems in places where soft and non-saline water are dominant. The clearing of such lakes through the enhancement of algal growth is described. It was found that in two cases studied it was possible to reduce the turbidity through the application of low levels of nitrogen and phosphorus. Results of additional field trials are presented in Chapter 2.

Fertilizer applications were calculated to provide from 0.28 to 8 mg of phosphorus per g of suspended clay, with a nitrogen/phosphorus ratio of 10/1. Chlorophyll concentrations generally increased and suspended solids decreased after fertilization with more than 1.4 mg of phosphorus per g of clay. Settling of the clay occurred when Chlorella and Anabaena were abundant. Trachelomonas and Euglena were ineffective in settling clay even at higher rates of fertilizer application.

A parallel study was conducted in tanks, where more control of the process could be applied (chapter 3).

We performed a 2-factor experiment in four 600 liter tanks to determine whether addition of inorganic nutrients (NH_4NO_3 and $(\text{NH}_4)_2\text{HPO}_4$) to turbid water could stimulate algal growth and subsequent settling of algae-clay flocs to clarify the turbid water. The 2 factors were exposure to light and addition of nutrients. All of the sediment initially in suspension was deposited after 23 days in the treatment receiving light and nutrient addition, compared to only 18-34 percent in the other treatments. Oxygen production rates in the treatments receiving light confirmed that algal photosynthesis was possible in the turbid water, and that growth was stimulated by addition of nutrients. Sediment deposition rates in the dark treatments confirmed that enhanced deposition rates upon addition of nutrients was not due to chemical flocculation of the clay. The experiment was repeated with only one factor, addition of nutrients, in two 72 m³ (2.7 m deep) tanks. Light scattering properties of suspended sediment restricted light penetration to the upper half meter and resulted in strong diurnal heating and formation of a temporary thermocline. This heating suppressed vertical turbulence permitting motile algae to grow in spite of reduced light penetration. Algal growth was again stimulated and species composition altered by nutrient addition; after 7 weeks, 90 percent of the sediment was deposited in the fertilized tank, compared to only 35 percent in the control. Diffuse attenuation coefficient of photon scalar irradiance was linearly related to the concentration of suspended sediment; the regression can be used to estimate critical depth in turbid water as a function of season and concentration of suspended sediment. The relationship should be useful for setting limitations on the size of

water as a function of season and concentration of suspended sediment. The relationship should be useful for setting limitations on the size of system in which the process can be expected to occur, since turbid natural waters should be mixed more deeply due to a larger wind fetch.

An additional set of pond trials (Chapter 4) was conducted in 1985 when 3 turbid ponds and one clear pond, located in the Brian country OK were tested. This experiment demonstrated that coflocculation of clay with algae is not a dependable result of fertilizing turbid ponds. The early spring application of fertilizer resulted in some clearing, and the active algae were *Chlorella* and *Chlamydomonas* which have previously been shown to promote flocculation. However, the early summer and early fall applications did not give any clearing. Factors that may have contributed to the failure were the unusually heavy rainfall and runoff, the absence of proper algal species, and the relatively low concentrations of suspended solids in these ponds. The clear pond differed from the turbid ponds in this study by having slightly higher concentrations of nutrients.

A trial to control the coflocculation process was conducted in an experiment where both nutrients and algal inoculum were added to limnocorrals placed in a turbid pond (Chapter 5).

The experiments showed that inoculation with viable laboratory cultures and addition of nitrogen and phosphorus are not sufficient to establish *Anabaena* or *Chlorella* populations in turbid ponds, even when the water temperature appears to favor their growth. Other species of algae grew well and utilized the added nutrients. The algal growth was associated with a reduced concentration of suspended solids in only a few cases. The results indicate the need for a better understanding of competitive relationships between algal species in turbid water. In addition, the applicability of limnocorrals as reliable simulation of processes in large water bodies is questioned.

It may be concluded that, as expected, the addition of fertilizers and the resultant growth of algae leads, in most cases, to the coflocculation of clay and algae, and to the clearing of the turbid impoundment. Yet, at

least in the short range, the development of algae that do not induce flocculation (Euglenoids) may occur. Under such conditions, the desired water clarification is not found. A better understanding of the pond ecology is needed for a better control of the system. In addition, it is anticipated that in the long run a low nutrient application will lead to the development of flocculating algae, since their formation and sedimentation leads to a practically irreversible removal of the nutrients from the water.

A second part of the project dealt with related technical topics or other aspects of the algal-clay coflocculation.

The first chapter in this group, (Chap.6) deals with the development of a method to measure particle size using a Photon Correlation Spectroscopy (PCS).

Photon correlation spectroscopy (PCS) is a technique for determining size distributions of submicron-sized particles. Particle diffusion coefficient, which is dependent on particle diameter, is determined from measurements of the autocorrelation function of the intensity fluctuations of light scattered from a laser beam passing through a suspension of particles. We demonstrate the applicability of the technique to particles likely to be found in runoff or turbid impoundments using soil fractions prepared to have a known size distribution. Mean particle diameters of all soil fractions determined by PCS fell within the expected range. Particle-size distributions of natural water samples were reproducible when analyzed within minutes of collection. The effects of sample storage varied between water bodies. Particles from a turbid creek began to coagulate within 2.5-6 h, whereas particles from a perennially turbid impoundment remained stable for 10 d. Addition of sodium hexametaphosphate improved the reproducibility of the particle size distribution with prolonged storage. Applications of the technique include determination of coagulation rates and critical coagulation concentrations of electrolytes and calculation of settling velocity distributions of submicron particles in turbid natural waters.

In a second work (chap 7), the growth of algae in turbid clay suspensions was tested. Algal growth was found in the rather dense clay suspensions. Flocculation of the clay occurred in cases with and without the algae, possibly due to clay-bacteria interactions.

Different ponds located in southern Oklahoma are turbid all year around, clear or turbid in the early spring and clear toward the summer. The different traits of those ponds were studied. A total of 19 ponds were sampled along a year time. The suspended matter in the turbid ponds was mostly inorganic, with a greater proportion of organic material in the clear ponds. The mean size of particles in the turbid ponds was smaller (368 nm) than those in the clear ponds (436 nm). Calcium and electrolyte concentrations in the clear ponds were not high enough to induce flocculation.

A different effect of the algal-clay coflucculation is demonstrated in Chapter 9. It is demonstrated that if this process occurs in the irrigation pipelines, or close to it, it can lead to a clogging of the system. A case study demonstrating the occurrence of major drip irrigation clogging as a result of mixing clay and algae containing water sources is presented. Practical conclusions are drawn.

In the third part of the report we present a number of works related to more general aspects of sediment water interactions.

The release of nutrients from aerobically and anaerobically incubated fishpond sediments was studied (Chap 10), demonstrating the reduction of phosphorus release by iron and aerobic conditions.

A major effort was devoted to the study of Maaleh Hakishon reclaimed effluents reservoir. This reservoir was constructed recently, enabling to follow the transition of the soil from its terrestrial origin to an aquatic sediment. Along a period of 2 years since the flooding of the soil, there was an increase of about 10 in organic carbon and a 100-fold increase in ammonium concentrations in the sediment.

Chapter 11 deals with the measurement of nutrient balances and fluxes in the reservoir. The extensive measurement of nutrient inputs and outflow, sediment trapping and sediment coring enabled to calculate accumulation at the sediment, as well as decomposition processes in the water body and in the sediment. A flow sheet for organic carbon, total nitrogen and phosphorus is presented.

One of the main problems regarding Maaleh Hakishon as well as similar reservoirs is the possible deterioration of the system, mainly due to organic matter accumulation in the sediment. This question is dealt with in Chapter 12.

Aging of reservoirs is related to the accumulation of organic matter in the sediments. The accumulation is considered to be a function of sedimentation rate, B, and a first order kinetics decomposition rate, (KC, where K is the rate constant and C is the concentration of the organic component). Both processes are assumed, as a first approximation, to be time-independent. The equation describing the process is accordingly:

$$dC/dT = B - K \cdot C \dots \dots \dots (1)$$

and upon integration:

$$C = \frac{B}{K} - \frac{B - K C_0}{K} e^{-KT} \dots \dots \dots (2)$$

The organic matter level approaches a constant level of $C = B/K$ with time. Organic matter concentration in the sediments of the newly constructed Maaleh Hakishon reservoir were measured through a series of sediment corings. The annual sedimentation of organic components was computed from input-output budgets and from sediment traps data. The decomposition rate constants for organic carbon and nitrogen, computed from Eq. 2 through successive approximations were 0.42 and 0.35 Yr^{-1} , respectively.

Using the proposed model and the derived parameters it is possible to predict the approach of the reservoir sediments to a steady state and its properties at that point. It is predicted that a 90% achievement of the

steady state situation will occur 3.7 years after construction of the reservoir, i.e., at the end of 1987. At that point, the organic carbon concentration in the sediment will be 0.75 g carbon/m² and the sediment oxygen demand will be 0.6 Kg O₂/m² per year.

A different model for the steady state between immobilisation and mineralization processes is given in Chapter 13.

The steady state situation of microbially mediated decomposition processes is defined through the equality of the decomposition process supplying soluble nutrients and the biological uptake of these nutrients. Both reactions were described using the Michaelis-Menten kinetics. The uptake reaction may obey a second order Michaelis-Menten kinetics if both population size and specific uptake rates are dependent on a given nutrient supply.

As steady state is established, the concentration of the soluble product considered is a linear function of the Michaelis-Menten constant of the uptake compartment, i.e., the concentration increases with a decrease of uptake efficiency.

Stability of the ecological systems considered could be defined through a term, R , the ratio of maximal decomposition rate to maximal uptake rate. Systems having ratios of less than unity are stable, i.e., when the substrate loading in the decomposition compartment is increasing, the concentration of soluble products is buffered and is approaching a limiting value. On the other hand, systems that are typified by a limited uptake potential ($R > 1$) are unable to maintain the steady state balance when substrate load is increased. Eutrophic systems may possibly be defined as systems where the steady state balance is disturbed due to high loading and limited buffering capacity.

Last, a study relating the increase in phosphorus concentrations in Lake Kinneret with sediment resuspension and flocculation is presented in Chapter 14.

An increase in total phosphorus found to occur in Lake Kinneret along the last 2 decades may be related to a concomitant decrease in salt concentration in the Lake.

The effects of sodium and calcium addition on sediments suspended in H_2O and in filtered lake water was evaluated. It was found that addition of 1 meq/l $CaCl_2$ to Lake Kinneret water led to a 5-fold increase in the median settling velocity of the suspended sediments. It is concluded that the salt concentration of the Lake is a close to the flocculation value of the sediment particles.

The changes in salt concentrations along the last 3 decades, and the seasonal changes of calcium concentration may explain an increased resuspension of sediments and thus an increase in the supply of particular phosphorus to the Lake.

COOPERATION

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The first stages of this research were done at the USDA-SEA Watershed Management and Water Quality Research Laboratory in Durant, OK., during the Sabbatical stay of Y. Avnimelech. The research plans were developed jointly during that time. Following that period we had more opportunities to discuss the problems and the achievements, during the visit of R.G. Menzel in Israel and that of Y. Avnimelech in Durant.

CONTRIBUTION TO AGRICULTURE

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a) A major effort was devoted to the development of a method to treat turbid impoundments with fertilizers, to stimulate some algal growth and thus lead to the flocculation of the clay and to the clearing of the water body. The proposed treatment was found effective in most cases where this method is the least expensive of all available methods (flocculation with alum, gypsum or organic coagulants). In some trials, fertilizer addition led to development of algae that are not effective as clay flocculants (Euglenoids), and no immediate response was found. Yet, based upon surveys of ponds and lakes and on theoretical considerations, we conclude that in the long run, addition of the recommended limited fertilizer applications leads to the clarification of muddy reservoirs and lakes.

b) Algal clay coflocculation seems to be one of the main reasons for the clogging of drip irrigation systems. Such clogging can be prevented by the blocking the contact of the algal and clay suspensions. This conclusion has implication as to the planning of water supply systems as well as to the operation of reservoirs.

c) In the research proposal we have presented, as one of the possible uses of the anticipated results, the example of the Maaleh Hakishon reservoir:

"One example as to the importance of the problem and the expected contribution of this research is the newly constructed Kishon Reservoir in Israel. The Kishon Reservoir is designed to store large quantities of reclaimed sewage for irrigation. It is the first large-scale project of its type. Other similar projects are to follow. One of the main unknowns related to this project as defined by the Water Commissioner Planning Committee and by a special sub-committee is how long will the reservoir act as planned. It is quite probable that sometime in the future, the bottom sediments will be enriched and the lake will be eutrophied. It is not known when this process will occur, it is not known if the water pretreatment, before the inlet to the lake, is wasteful, since water will be polluted in the lake in any case. Moreover, though it is accepted that the proper operation of the lake depends on the reactions in the sediment,

no possible treatment of the sediment is suggested."

Presently we can predict that the reservoir is now very close to the steady state level. It is anticipated that the changes of its properties in the future will be slow. In addition we have surveyed the lake sediments and it was found that a large fraction of the organic matter accumulates in a rather small fraction of the reservoir bottom, thus sediment treatment can be done rather easily.

The information obtained in that reservoir can be applied in other reservoirs.

d) The probable relationship between salinity reduction, sediments colloids resuspensibility and phosphorus concentration is an important guide as to the needed, or unnecessary watershed management operations.

PUBLICATIONS

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