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RESEARCH CENTER  
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Bulletin 40  
WATER RESOURCES RESEARCH IN VIRGINIA -  
ANNUAL REPORT for FISCAL YEAR 1970

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WATER RESOURCES RESEARCH IN VIRGINIA  
ANNUAL REPORT for FISCAL YEAR 1970  
(Public Law 88-379)

Submitted to the Director  
Office of Water Resources Research  
U. S. Department of the Interior  
Washington, D. C. 20240

Water Resources Research Center  
Virginia Polytechnic Institute  
and State University  
Blacksburg, Virginia 24061

## PREFACE

The Water Resources Research Act of 1964, Public Law 88-379, July 17, 1964, as amended by Public Law 89-404, April 19, 1966, authorized the establishment of State Water Resources Research Institutes or Centers in each of the 50 states plus Puerto Rico. The purpose was to stimulate, sponsor, provide for, and supplement present programs for the conduct of research, investigations, experiments, and the training of scientists in the fields of water and of resources which affect water so as to assist in assuring the nation at all times of a supply of water sufficient in quantity and quality to meet the requirements of its expanding population.

The Act authorizes appropriations every year (continuing indefinitely) to assist each participating state in establishing and carrying out the responsibilities of a competent, qualified Water Resources Research Institute or Center at one university in each state. It also provides for annual matching funds for the centers, and authorizes annual grants, contracts, matching or other arrangements with educational institutions including the center universities, foundations, private firms, individuals, and local, state, and federal government agencies to undertake research into any aspect of water problems related to the mission of the Department of the Interior which may be deemed desirable and are not otherwise being studied.

In August 1964, Governor Harrison, by letter to President T. Marshall Hahn, designated the Virginia Polytechnic Institute and State University as the center for Water Resources Research in the Commonwealth of Virginia. The Center was established to plan and conduct competent research, investigations, and experiments of either a basic or practical nature, or both, in relation to water resources and to provide for the training of scientists through such research, investigations, and experiments. It also provides the mechanism for cooperation in water resources research with other institutions of higher learning, private research groups, and action agencies throughout the state.

This is a summary of the sixth Annual Report submitted to the Office of Water Resources Research, Department of the Interior, in compliance with Section 506.1 of the Rules and Regulations Pursuant to the Water Resources Act of 1964 (Federal Register, December 3, 1964).

William R. Walker  
Director

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## DIRECTOR'S REPORT

An examination of the various water resources problems of the State reveals that no one dominant problem is common to all sections of the State. Yet individual water problems for a given region may be quite severe, and some hold the potential for becoming acute in the immediate future. Under these circumstances it is inappropriate to concentrate the limited budget of the Center on the problems of any one section of the State to the exclusion of equally important problems in other geographic areas. Therefore, the Center has sought to focus on the critical elements of a variety of problems hoping that this approach will provide a large return for each research dollar expended and will be of some assistance to the several areas of the State.

Southeastern Virginia is experiencing a severe lowering of water tables due to excessive pumping. The area badly needs a water management plan for the conjunctive use of surface and ground water. The formulation of any workable plan requires a good estimate of the location and availability of ground-water resources. However, the costs associated with the extensive test drilling and the time required to complete such a program suggest that another alternative be found. The Center has sponsored a project (A-023) to determine whether the measurement of tides in wells can, with appropriate calculations, be used to inventory aquifer storage. The research results confirmed that a good approximation of aquifer storage can be obtained efficiently from wells displaying tidal fluctuation. This tool holds considerable promise for approximating the specific storage of confined aquifers which is information that must be available for the formulation of a meaningful water management plan for Southeastern Virginia.

The establishment of water quality standards for the streams of the State pursuant to the Water Quality Act of 1965 has had a significant impact on all sections of the State. Development in some northern Virginia communities has been slowed because additional wastewater hookups have been enjoined until treatment facilities are modified or improved for increasing the removal of phosphorus and nitrogen. These nutrients are thought to be the key elements in the eutrophication process.

Project A-024 has developed improved operating parameters for increasing phosphorus removal in the conventional activated sludge process common to many treatment facilities. Such an increase should reduce by 30 to 40 percent the cost of phosphorus removal by chemical methods now being applied to wastewater streams from these facilities.

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Project A-025 consists of basic research concerning the modification of surfactant molecules which are a large source of phosphorus in detergents. The results of this research hold promise of increasing the operating efficiency of activated sludge treatment by decreasing the oxygen costs an estimated 20 percent.

Most of the treatment facilities in Virginia are of small to medium size since there are only five metropolitan areas in the State. Many of these plants are required to add tertiary treatment to meet water quality standards. Activated carbon is utilized in many of these advance waste treatment processes, but it is very expensive without an economical method of regeneration. Activated carbon can be regenerated by burning, but because of the large capital cost for equipment, it is economically feasible only for large treatment facilities. Project A-032 has demonstrated that activated carbon can be regenerated by an electrochemical process which would be economical for use in small and medium size treatment facilities.

At the present time there is not a nuclear generating facility in the State, but one has been licensed and is scheduled for completion in the near future. The pollution resulting from heated water has the potential of being one of the major problems of the State in the next five years. Project A-031 has inventoried the existing biological and chemical condition of the North Anna River, the proposed site of the nuclear plant. With this information any change in the ecology of the area as the result of this installation can be readily ascertained. The Center has thus assisted in establishing a sound base of information which will enable the State agencies to effectively regulate nuclear installations. Appropriate compromises between preserving the environment and meeting the increased demands for electricity can better be made with an improved understanding of the changes which these new facilities bring about.

Heated water is certain to have a significant effect on the microbial community. The result of project B-017 has been the development of a technique for delivering thermal shock to micro-organisms under laboratory conditions. In addition, a system has been perfected which will simulate the passage of micro-organisms through an electric generating facility and into the variety of conditions likely to be found in a receiving stream or reservoir. These new techniques will assist in gathering data to ensure the intelligent regulation of nuclear installations.

The ability to accurately predict the amount of heat that must be dissipated by a body of water is extremely helpful in evaluating various sites for generating facilities. In project B-021 an analytical relationship was developed for a heat and mass transfer coefficient related to air-water systems. With this information, the thermal loading capacity for a stream or reservoir can be approximated by knowing the amount of energy likely to be transferred to the atmosphere under a variety of conditions and the maximum amount of energy to be dissipated by the water under constrained conditions. Again research has provided a tool which offers a great promise in dealing with a facet of a problem which looms on the immediate horizon for the State.

Other projects in the research program for the Center have made contributions to the solution of large numbers of individual problems. For example, basic research dealing with the absorptive capacity of various polymers (A-026) has shown that waste nylon can be used to remove phenol from water. A small amount of phenol in a drinking water supply can cause a severe taste problem. The cost of removing phenol using conventional methods is quite large. The research results show promise for the removal of this objectionable chemical by utilizing another waste product.

The impact on recreational activity of large drawdowns at multiple purpose water reservoirs is being studied by the investigator for project B-009. The preliminary data contains some of the information necessary for formulating appropriate guidelines for the operation of multipurpose reservoirs. Decisions are now being made on the Blue Ridge project on the New River based on less than adequate information. Data from this research should improve the quality of decisions made at other locations with power, water quality, and recreation as project purposes.

The limited budget for the Center precludes the development of a truly interdisciplinary program designed to deal with the interaction of the social, political, economic, and technical aspects of a problem. Although such an approach is initially expensive, the ability to study the interaction of the various alternatives under a variety of conditions offers the greatest promise for the production of useful information at an ultimate cost much less than the "piecemeal" approach necessitated by restricted funds.

REMOVAL OF TRACE ORGANICS FROM  
WATER BY ADSORPTION ON COAL  
Project A-015-VA

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December 1970

## REMOVAL OF TRACE ORGANICS FROM WATER BY ADSORPTION ON COAL

The purpose of this paper is to give an overview of some of the work which has been done and is now completed at Virginia Polytechnic Institute and State University regarding the use of coal in water and waste treatment. Initial interest in this topic began a little over four years ago, because at that time there was considerable talk about various uses of coal for both water and waste treatment. For years, in water treatment, coal, particularly anthracite, has been one of the components which has been used as a filter media. Even as much as 30 or 40 years ago people were talking about using anthracite coal on top of sand in an effort to achieve higher filtration rates and better operation of a rapid sand filter. This trend has been accentuated in the last few years with the introduction not only of dual media filters, a dual media filter normally using coal and sand, but also what is termed multi-media or sometimes designated mixed-media filtration. In this case, coal is invariably one of the components that is used along with sand. Usually, for a heavier medium, a material called garnet is frequently used. With respect to waste treatment, these mixed-media filters have been used for a variety of purposes, and there has been considerable interest in very recent years in the use of mixed-media filtration as a polishing process in a tertiary waste treatment.

More recently coal has been suggested as a material to use in the filtration of sewage in a variety of different processes. Some of the major equipment companies have talked about the use of coal in a so-called moving bed filter, which is really nothing more than a counter-current operation where the coal is introduced at the top of a filter; it is taken off at the bottom while the waste is introduced at the bottom and travels upward through the filter. The result is a counter-current type of system where the coal that is nearly spent, as far as its adsorptive capacity, comes in contact with the highest concentration of contaminants in the incoming material, and up at the top one has essentially a low concentration of contaminants and fairly fresh coal. This type of system has been proposed, and an FWQA demonstration project on this moving-bed filter operation is now being conducted. The idea is to use coal as a filtering media and also make use of whatever adsorptive capacity the coal has in order to remove materials which are in solution but which are biologically resistant, perhaps even to the point of possible classification as refractory substances. We also explored the question of how much phosphate would be removed in a system of this type.

One of the advantages of using coal in a moving bed filter is that one can essentially remove the spent coal and then employ it in a manner similar to a

## REMOVAL OF TRACE ORGANICS FROM WATER BY ADSORPTION ON COAL

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One of the advantages of using coal in a moving bed filter is that one can essentially remove the spent coal and then employ it in a manner similar to a

normal use of coal. In other words, the coal would be incinerated and its heat value recovered. At the same time some of the solids disposal problem would be solved. This would be a tremendous advantage, if one could do away with a solids treatment process such as anaerobic digestion. The basic question which was asked in formulating this particular work was as to how well coal does as an adsorbent in removing some of the contaminants of concern, specifically phosphates and persistent organic chemicals. For this purpose, we selected several phosphate-containing compounds and pesticides for use in this study. Correlative data using activated carbon as an adsorbent for the same materials was also obtained for comparison purposes. Coal is not nearly as effective for organic matter removal as activated carbon, but the cost difference is great. Depending on the grade of coal, this cost differential may be 20 to 100 times.

In formulating the project several typical coals were selected, including some rather low grade coals. The principal types of experiments which were run were first, studies of the uptake kinetics or the rate of transfer of material from solution onto the adsorbing media; and second, the determination of the actual equilibrium capacity of the various coals for the selected pollutants. The pesticides which were studied included a representative of each of the three major groups of pesticides. Lindane was chosen as a representative of the chlorinated hydrocarbon insecticides. Parathion was used as a typical organic phosphorus insecticide, and chloroisopropyl carbamate as a typical organic herbicide. With respect to the phosphorus, straight orthophosphate, a polyphosphate, and a metaphosphate were utilized. The types of studies which were conducted were of two types. Some batch kinetic and equilibrium studies were completed, and counter-current continuous-flow column type experiments were also conducted. The analytical techniques which were employed for phosphate determinations utilized a Technicon Auto-analyzer. For pesticides, liquid-liquid extraction using hexane as a solvent was followed by a determination of pesticide concentration using electron capture gas chromatography. A Beckman GC-5 gas chromatograph worked well for this particular purpose.

The first series of experiments concerned batch kinetics studies for determining the rate of removal of orthophosphate utilizing various types of coal. One of the principal results of this work was the evident difference in kinetics and ultimate uptake capacity depending on the type of coal utilized. Our purpose in this study was to obtain phosphate removal. An initial phosphate concentration of 20 milligrams per liter was used. This level of phosphate concentration might be expected in conventional domestic sewage. The higher grade coals, the low volatile and the medium volatile, were very

poor in their uptake of phosphorus in this batch system. The high volatile "C" coal, which is a poorer grade, did very well in the removal of the phosphorus from the system. This particular experiment showed that it is possible to do quite well with some coals and very poorly with others. In using a moving-bed filter or similar system to achieve phosphorus removal, some preliminary experiments ought to be conducted to give an indication as to whether that particular coal is good for phosphorus uptake. Considerable work with a high volatile "C" coal was also conducted. The results of a series of experiments where the concentration of coal was varied showed that 1 to 2 hours was sufficient to achieve equilibrium in the system. With 2 grams of coal per 100 ml of sewage, phosphorus concentration was reduced from 20 mg/l down to practically zero. The effect of pH on system performance was also investigated. At pH 3, 4, and 5, the system operated effectively. If the pH dropped below about 3, the phosphorus removal decreased rather markedly. This effect seems to be related to the actual mechanism of phosphorus removal which was postulated to be associated with impurities in the coal. The one impurity which seemed to be most important in this regard was the presence of iron. In other words, in systems that effectively remove phosphorus using coal as an adsorbent, some reaction where a complexing of an iron phosphate type substance is achieved seems to be occurring. It may well be  $\text{FePO}_4$ , but we are not really sure about that. At pH 2.3 most of the iron is in solution and this type of reaction does not occur.

The removal of polyphosphate type compounds was also compared to orthophosphate. Again, 20 milligrams per liter of phosphate substance was initially used. The metaphosphate was removed in about the same manner as the orthophosphate. The pyrophosphate removal was considerably better. This is not surprising because the pyrophosphates are less soluble, hence have more affinity toward the solid phase and, as a result uptake is increased. If considerable phosphate in a form other than orthophosphate exists in a waste there is an additional advantage using coal as an adsorbent for this type of material.

The pesticide experiments were conducted to show the effect of the system on representative persistent organic chemicals. Lindane was selected for several reasons. Probably the first and foremost is that lindane is the most water soluble of the chlorinated hydrocarbon group and thus, concentrations of lindane in wastewater can be expected to be relatively high. Also, lindane tends to leach through soil more than any of the chlorinated hydrocarbon insecticides. Thus, from the standpoint of its potential for pollution, although it is somewhat degradable, it does rank high on the list. Another reason for the selection is that with a considerable amount of chlorine in lindane, it

detects nicely in the electron capture gas chromatography system. For the organic phosphorus insecticides, parathion was selected because of its high toxicity, and while it doesn't contain chlorine, it captures electrons rather well for two reasons. One is the presence of sulphur and the other is the benzene ring contained in the molecule. Parathion has a water solubility of about 50 parts per million whereas lindane is down around 5 to 10 parts per million. Parathion is not as persistent in water as lindane, but is a good representative of the organic phosphorus insecticides. For the herbicides, chloroisopropyl carbamate (CIPC) was selected. Again, largely because of its containing chlorine, it measures well in the analytical system that we had available and it is a fairly good representative of at least one type of the organic herbicides. The experimental data indicate that uptake of lindane by the coal was excellent, parathion adsorption was moderate, and CIPC uptake was relatively poor. In comparing coal with other sorbing media, parathion was selected as a typical organic contaminant. A number of types of materials to which pesticides tend to be sorbed were used including two types of soils, a sandy soil and a high clay soil, an algal species, and activated carbon. Invariably the high clay soil, as one would expect, takes up and sorbs more pesticide than does the sandy soil. There is about a 100-fold increase in the extent of adsorption on the algae as opposed to the soil. We have considerable work that has been done in our laboratory on another project on pesticide uptake by algae. Coal is not quite as favorable at higher concentrations relative to the algae, but another approximate tenfold increase on the average in the extent of uptake of parathion on coal as opposed to algae was noted. The generally preferred method for removal of these substances involved the use of activated carbon. Again, a tenfold increase in uptake capacity was noted. These data have some interesting implications. They certainly tie down at least one aspect as to how pesticides are concentrated through the food chain because of this very decided affinity of the pesticide for uptake on algae. If it is desired to find a material to adsorb or remove these pesticides, then coal is a possibility, but, as we would expect, activated carbon is considerably better.

The major conclusions from this study would be that the uptake of these materials is quite rapid. Phosphorus removal is particularly encouraging if one properly selects the coal that is going to be used in this particular type of process. Phosphorus is generally not removed by adsorption on activated carbon. The adsorption process for organics is also quite selective. Lindane was adsorbed better on coal relative to activated carbon than was chloroisopropyl carbamate on coal as related to activated carbon. The advantages of coal in this system, which are almost entirely cost advantages, vary with the particular contaminants that are being removed. No attempt

was made to obtain any gross measurement of uptake of the type of organic material that is found in normal sewage. There is data that has been published on this particular topic and the Rand Development Corporation has a very thick report in which they show, for example, COD removal in systems of the type that were studied. They show that there is a fairly healthy removal of COD, which is kind of a gross measure of organic pollution. Our purpose was to look at some more specific contaminants. We focused on phosphates and persistent organics because we thought that this would be helpful data which was not available. The future of this type of system is a little hazy at this time. Some of the demonstration plant work that is going on now, which is supported by FWQA, will shed light on whether a moving-bed filter, using coal as a filter media, is feasible for incorporation into many plants. The data obtained in this study will answer some more specific questions about the process.

**TREATMENT OF DYEING BATH WASTE  
STREAMS BY FOAMING AND FLOTATION  
TECHNIQUES**  
Project A-017-VA

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## TREATMENT OF DYEING BATH WASTE STREAMS BY FOAMING AND FLOTATION TECHNIQUES

The effective treatment of waste streams from dyeing operations at minimal costs is taking on significant proportions since the passage of federal legislation requiring the classification of all interstate streams. This investigation studied waste treatment and color removal of dispersed dye bath waste using foaming techniques. The work was to include study of dispersant surfactants using foam fractionation, adsorptive bubble fractionation, and homogeneous ion flotation (complexing). The objectives were intended to achieve:

1. A better understanding of the mechanisms involved.
2. An estimate of the costs using developed techniques in conjunction with traditional means of separation (flocculation).
3. Foaming techniques that would be helpful in the removal of phenol and phenol derivatives.

Considerable effort was made to screen various foaming agents for the removal of COD, color, and turbidity from simulated disperse dye bath wastes. However, the mechanism of study was abandoned after numerous unsuccessful attempts to analyze separately for surfactant and dye. Instead a fundamental study was completed in order to determine the effect of operating parameters on the performance factors. Because of time limitations, no attempt was made to study the removal of phenol and phenol derivatives.

Initial batch foam fractionation tests were conducted using Foron Black "K" powder with Dispersing Agent No. 8. This system contained 400 ppm dye and 200 ppm dispersing agent. A concentration of COD and color was noted in the foamed overhead. But because of fractionation of the dye components, i.e., red dye in the overhead foam, systems containing only a single dye component were chosen for subsequent testing.

Three disperse dye systems, blue, yellow, and brown containing 300 ppm pure dye and about 100 ppm dispersing agent (sodium lignosulfate) were selected for testing. Because of the analytical limitations of COD and turbidity, the brown dye system was selected for most foam fractionation tests.

Foam fractionation of these wastes, as is, and after addition of lime, were unsuccessful with little or no concentration of color and COD in the overhead foam. Various cationic, anionic, and nonionic surfactants were then tested as additives. Only cationic surfactants were successful. Typical results using 50 ppm of lauryl trimethyl ammonium bromide were 52.1 percent removal of the COD, 89.2 percent removal of the color, and 75.3 percent removal of the turbidity with 7.1 percent of the batch feed going overhead as foam product. To treat 1.0 MGD of this concentrated waste, the chemical cost would be about \$210 per day. This cost is high, but the color and turbidity removal of these materials is probably more complete than is possible by biological oxidation alone.

Foam fractionation tests were also conducted using the three different types of polyelectrolytes by themselves. The results using cationic polyelectrolytes were not as good as with cationic surfactants, although the polyelectrolytes might be considered for use as flocculants. Similarly, testing with a combination of cationic polyelectrolytes and cationic surfactants was successful, but would probably be somewhat more costly. Since these results were so encouraging, no attempt was made to expand the work using adsorptive bubble fractionation or homogeneous ion flotation. Neither of these techniques is desirable from a processing or cost standpoint when compared to foam fractionation.

In terms of the fundamentals of foam fractionation, a series of tests was conducted using lauryl trimethyl ammonium bromide to determine the effect of surfactant concentration, air rate, and foam height on performance. COD removal increased from about 10 percent to 45 percent as surfactant concentration increased from 25 to 50 ppm. Higher concentrations of surfactants showed little influence. Similar jumps were noted in color and turbidity removal at the same surfactant concentration levels.

The effect of foam height on performance generally indicated that results were better at low foam heights. However, carry-over or percent overhead was generally higher with high foam heights indicating an operating inconsistency for the runs made.

The effect of air volume on removals was not thoroughly studied, but maximum removal was achieved by operating above an 8:1 ratio air volume to feed volume, and further air addition had essentially no effect on performance.

In an effort to make the results more meaningful, several tests were conducted using a more dilute textile waste (actual) provided by Dan River Mills. The color concentration of this waste was about one tenth of the simulated waste. The fractionation of this more dilute waste, including the addition of 50 ppm of a cationic surfactant, yielded reductions of COD and color that were 30 percent and 10 percent lower than for the more concentrated simulated waste. The foam fractionation performance of the dilute textile waste as a function of cationic surfactant showed a more linear function than with the simulated waste. With 10 ppm surfactant, 35 to 45 percent of the color and turbidity could be removed while at 100 ppm perhaps 75 percent could be removed.

Another study was conducted in which flocculation tests were completed with 100 mg/l of alum. Here the chemical costs for treating the typical mill wastes were \$55 per million gallons, but removals of 70 percent COD, 75 percent color, and 82 percent turbidity were achieved. On the other hand for foam fractionation the chemical costs were \$240 per million gallons for removal of 21 percent COD, 55.4 percent color, and 30 percent turbidity. Thus, costwise the foam fractionation of the dilute textile waste does not look promising unless there is sufficient surfactant concentration in the waste to foam with little (2 to 5 ppm) or no cationic surfactant. Even then the large dilute volumes of waste to be handled and high air flow rates may make such a treatment unattractive.

The following conclusions were reached in this investigation:

1. Simulated disperse dye bath wastes without additives do not respond well to foam fractionation as a waste treatment technique.
2. Of the additives tested, only cationic surfactants significantly improved the performance. Substantial reductions of chemical oxygen demand, color, and turbidity were observed.
3. A removal of 52.1 percent of the COD, 89.2 percent of the color, and 75.3 percent of the turbidity was effected by using 50 ppm of a lauryl trimethyl ammonium bromide surfactant as a foaming agent. The chemical cost for a foam fractionation pretreatment would be about \$210 per day for the treatment of 1.0 MGD of concentrated waste.

4. Cationic surfactant concentration is the most important variable in achieving good foam fractionation results.
5. The behavior of an actual industrial waste was found to coincide with simulated wastes during foam fractionation. The percentages of color and turbidity reduction were similar for both wastes, but the amount of each variable removed was far greater for the simulated wastes. The pretreatment of dilute wastes by foam fractionation is uneconomical unless no cationic surfactant or very little surfactant needs to be added for foaming.
6. The cationic polyelectrolytes were ineffective as foaming agents for concentrated wastes, but were very effective in performing as flocculants for this disperse dye system.

**SIMULATION OF THE HYDROLOGIC CYCLE  
ON SMALL AGRICULTURAL WATERSHEDS BY  
DIGITAL TECHNIQUES**

Project A-018-VA

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## SIMULATION OF THE HYDROLOGIC CYCLE ON SMALL AGRICULTURAL WATERSHEDS BY DIGITAL TECHNIQUES

The rapid development of high-speed digital computers over the past decade has provided the impetus for significant advances in simulation models for the purpose of synthesizing the hydrologic cycle. In the past few years several notable contributions have appeared in the literature, for example, Crawford and Linsley<sup>1</sup>, Dawdy, et al.<sup>2</sup>, Boughton<sup>3</sup>, and Sittner<sup>4</sup>. These models express the physical system or watershed as a collection of mathematical expressions.

Probably the most comprehensive of these is the Stanford Model developed by Crawford and Linsley.<sup>1</sup> It consists of a group of mathematical expressions which establish relationships between the elements of the hydrologic cycle and the interactions between its components. The model is normally operated with known input and output and the different model parameters are optimized until an acceptable fit is achieved. Two major difficulties are encountered in this model and in simulation models in general. One is associated with the placement of appropriate quantitative values on qualitative estimates of the conditions on or in a watershed, and where qualitative estimates are feasible, vast volumes of data not readily attainable or available are usually required.

In the Stanford Model qualitative estimates are achieved through the collective and/or individual use of a large number of coefficients. The values of some are readily attainable from historical records while for others their magnitude must be evaluated through simulations by trial and adjustment.

Because the interaction between the many phases of the hydrologic cycle are so complex, and the exact mathematical formulation(s) combining these integral relationships simply are not well understood, or at least feasible; empirical approximations have been used quite freely in deterministic watershed model development. It is doubtful that this condition will be wholly circumvented in the near future. Since so many approximations are employed, the different model concepts must be tested for different watershed or basin sizes, geographic regions, and physical characteristics, as well as varying climatic and meteorologic conditions.

It was in this context that this study was initiated with two general objectives: (a) to evaluate the effectiveness of the Stanford Watershed Model for synthesizing stream flow records for small agricultural watersheds in

Virginia and (b) to present the different components of the model, their mathematical form and relative sensitivity, in a documentary form that hopefully would allow the unfamiliar to efficiently use the model with a minimum of background preparation.

A Fortran version of the model was obtained from the United States Weather Bureau through the Northeast Hydrologic Research Center of the United States Department of Agriculture, Agricultural Research Service. Through extensive revisions this program was made approximately equivalent to a Fortran translation written by Dr. James of Kentucky and later reviewed by Ligon, et al.<sup>5</sup>

### Procedures

Two agricultural watersheds (Brush Creek and Crab Creek), having areas of approximately 800 acres and located near Blacksburg, Virginia, were selected for the study. These two areas were selected because they consistently reacted quite differently to given rainfall experiences. Recorded discharge from Brush Creek and Crab Creek for the period 1958 to 1968 has averaged approximately 18 inches and 6 inches respectively.

Five years of recorded data were used to "calibrate" the model to each Watershed after which five additional years of streamflow records were generated using the respective model parameters developed for the first period. The generated and recorded data were then evaluated for goodness of fit.

The goodness of fit was evaluated from statistical and visual inspection of plottings of observed versus simulated discharge. Although a visual examination of plotted hydrographs is a highly reliable method of evaluating the accuracy of model output, it is almost completely subjective. As a result, an attempt was made to compute meaningful statistical summaries to complement visual inspection. Unfortunately, no one summary can be considered to be wholly comprehensive; for example, correlation coefficients give a good indication of the response of one value relative to another, but they give no quantitative measure of the result. Three statistical summaries were made with the hope of allowing some additional objective interpretation of the results.

The first involved computation of appropriate correlation coefficients for all summaries. The second tests involved a summary of the events occurring at preselected rates over the period of analysis. In the same context, a measure

of timing of flow events was obtained by summarizing the percentages of time that recorded and simulated flow events occurred at rates less than or equal to selected values. The third test involved the computation of the error in the computed mean daily discharge.

Sensitivity studies were made of all model parameters subject to change. A total of seventeen including potential evapotranspiration were analyzed. The general procedure was to hold all parameters constant, while the variable of interest was varied through a low to high range. This technique does not consider interactions but does provide insight to the hydrologic elements affected and relative magnitude of change.

### Results and Discussion

Typical simulation results are shown in Figure 1. These data represent observed and simulated daily discharge from the Brush Creek Watershed during water year 1958-59. The maximum peak discharge for the interval 1957-70 occurred on September 30, 1959, and the observed and simulated rates for this event were 95 and 99 cfsd respectively.

Water yield estimates from Brush Creek and Crab Creek simulations and summaries of annual and monthly intervals are compared in Figures 2 through 5 for the ten year period, 1958 through 1968. Maximum mean daily peak discharge estimates are summarized in Figures 6 through 9.

The distribution of estimated flows over the ten year period with respect to preselected rates are presented in Figures 10 and 11. The percentage of time that flows occurred at rates less than or equal to preselected values are given in Figures 12 and 13.

In general, relatively good agreement was noted between annual observed and simulated water yield estimates. More variability was observed when the results were compared over shorter time increments. For example, daily variations were greater than monthly estimates and monthly estimates tended to vary more than annual estimates.

The errors in the estimate of annual water yields from Brush Creek from a continuous synthesis over a ten year interval were less than or equal to 11 percent for 9 of 10 years. By comparison, only 6 events were less than 11 percent with the Crab Creek simulations. Percentage errors were somewhat higher from this watershed because of the low yields which required a much lower absolute error to avoid high percentage error estimates. For example,

an error of 1.2 inches was noted in the annual estimate for both watersheds during the 1965-66 water year, but percentage errors were 11 and 35 percent for Brush Creek and Crab Creek respectively. Percentage errors in monthly flow estimates were quite variable. However, when compared to respective annual yields, most errors were less than 3 to 4 percent.

Peak flow estimates exhibited considerable scatter, particularly the monthly estimates. Percentage errors varied considerably, however, the absolute error was usually relatively small. Absolute errors ranged from 0.0 to 30 cfs on Brush Creek and from -3.4 to 19 cfs on Crab Creek. The overall distribution of flow rates and the timing of events was quite good (see Figures 10 to 13).

The model was found to be effective in reproducing within acceptable limits a given hydrograph ignoring all other events during the year. Difficulty was encountered in obtaining a set of values for the model parameters that would give the best fit of water yield and peak discharges. In general, it was found that a sacrifice in peak estimates was required for the best fit of yields and vice versa for the best fit of peaks.

Some typical examples of sensitivity results with the routing coefficient (CSSR), interflow index (CC), and infiltration index (CBI) are shown in Figures 14, 15, and 16. In each example an observed hydrograph, resulting from a runoff producing rainfall event, is plotted versus the simulated hydrographs from using the indicated values for the parameters. As can be readily noted, significant attenuation of the runoff hydrograph is apparent in all examples. Further details on the sensitivity analyses and model evaluation and documentation in general will be published in a forthcoming Water Resources Research Center bulletin.

#### Conclusions

Some general conclusions relative to the model are:

- (a) Considerable familiarity with the model was necessary to arrive at an optimal set of values for those model parameters requiring trial and adjustment.
- (b) For the most part, the model appears to simulate the hydrologic process of a watershed within the accuracy of basic input data.

- (c) By judicious use, insight can be obtained on the effect of specific changes within the system being synthesized.
- (d) The model can provide approximations for the practicing engineer that would be difficult to obtain otherwise.
- (e) The model, like most all current deterministic watershed models, is not an exact formulation of the complex processes within the hydrologic cycle and therefore must be used accordingly.
- (f) Modification of the upper zone storage allocation procedure appears to be necessary in order to obtain an improved simulation of the watershed's response to small storm events and during the early stages of larger events.

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2. Dawdy, David R. and Terence O'Donnell (July 1965) "Mathematical Models of Catchment Behavior"; Proc. ASCE; 91(HY2):123-137.
3. Boughton, W. C. (1969) "A Mathematical Catchment Model for Estimating Runoff"; J. Hydrol. (New Zealand); 75-100.
4. Sittner, W. T., E. C. Schauss and J. C. Munro (1969) "Continuous Hydrograph Synthesis with an API-Type Hydrologic Model"; Water Resources Research; 5:1007-1022.
5. Ligon, James T., Albert G. Law and Donald A. Higgins (Nov. 1969) "Evaluation and Application of a Digital Hydrological Simulation Model"; Report No. 12; Water Resource Research Institute, Clemson University.

FIGURE 1

BRUSH CREEK WATERSHED, FLOYD COUNTY, VIRGINIA.  
COMPARISON OF DAILY OBSERVED AND SIMULATED  
DISCHARGE FOR WATER YEAR 1958-1959.

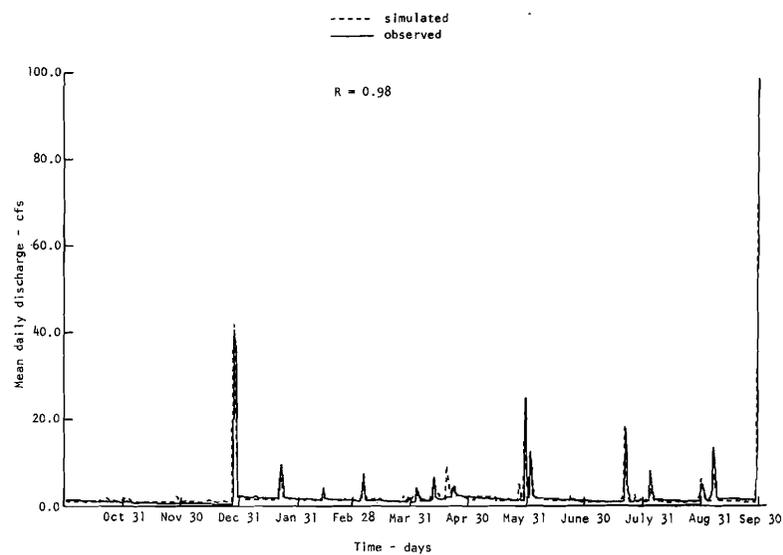


FIGURE 2

BRUSH CREEK WATERSHED, FLOYD COUNTY, VIRGINIA.  
COMPARISON OF OBSERVED AND SIMULATED ANNUAL  
DISCHARGES FROM WATER YEARS 1958-1968.

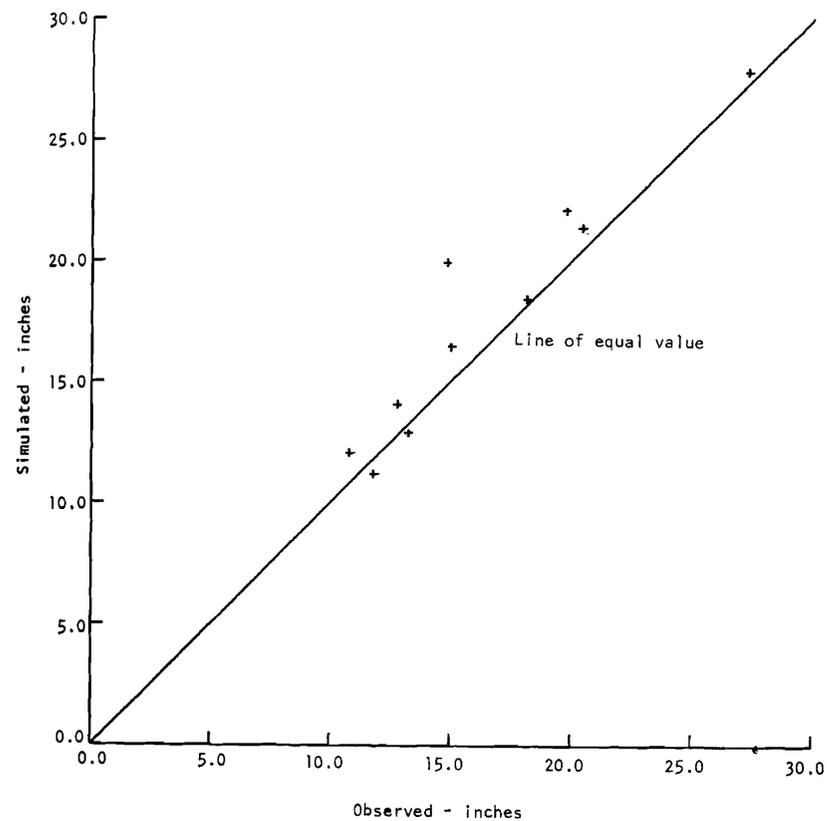


FIGURE 3

CRAB CREEK WATERSHED, MONTGOMERY COUNTY, VIRGINIA.  
COMPARISON OF OBSERVED AND SIMULATED ANNUAL  
DISCHARGES FROM WATER YEARS 1958-1968.

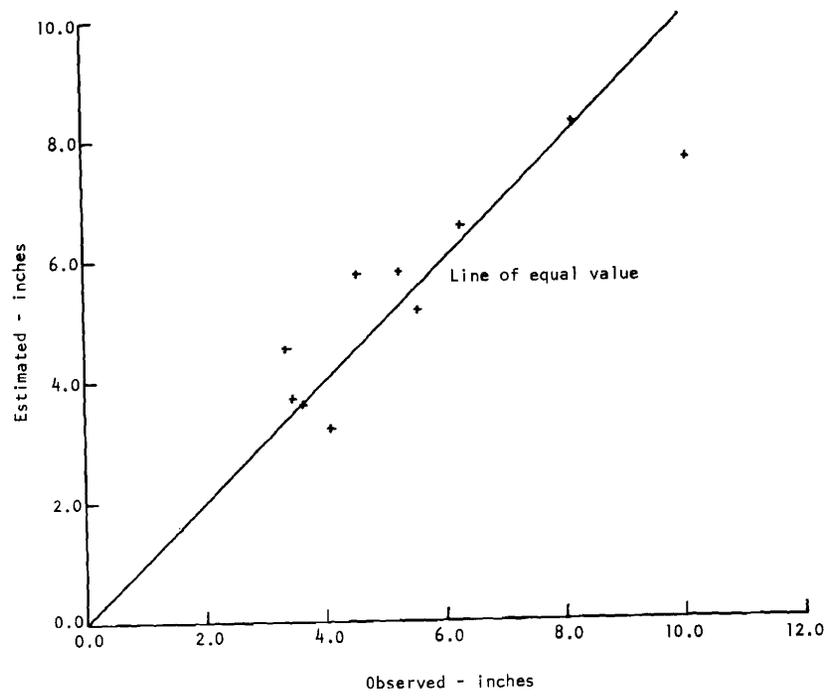


FIGURE 4

BRUSH CREEK WATERSHED, FLOYD COUNTY, VIRGINIA.  
COMPARISON OF OBSERVED AND SIMULATED MONTHLY  
DISCHARGES FROM WATER YEARS 1958-1968.

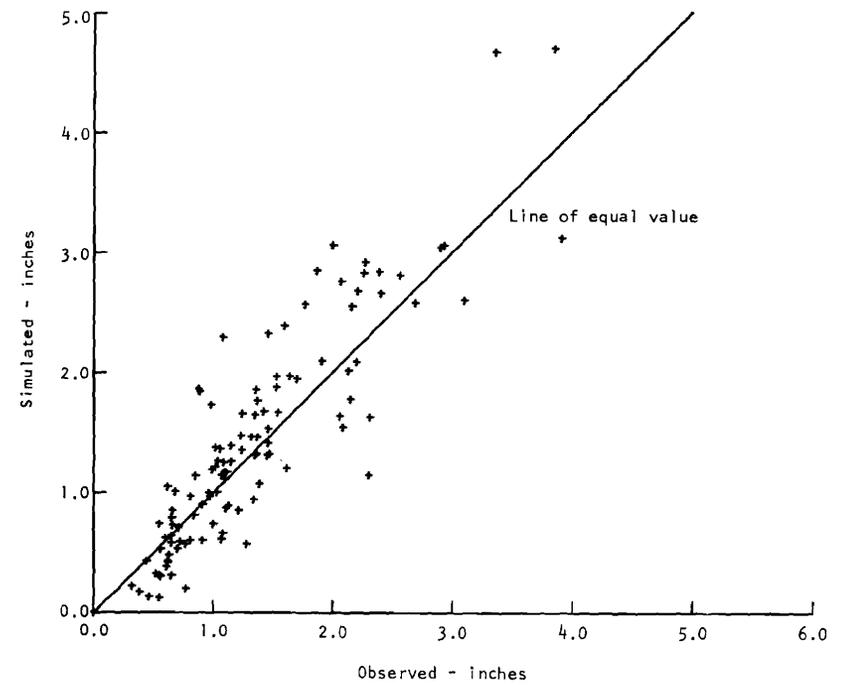


FIGURE 5

CRAB CREEK WATERSHED, MONTGOMERY COUNTY, VIRGINIA.  
COMPARISON OF OBSERVED AND SIMULATED MONTHLY  
DISCHARGES FROM WATER YEARS 1958-1968.

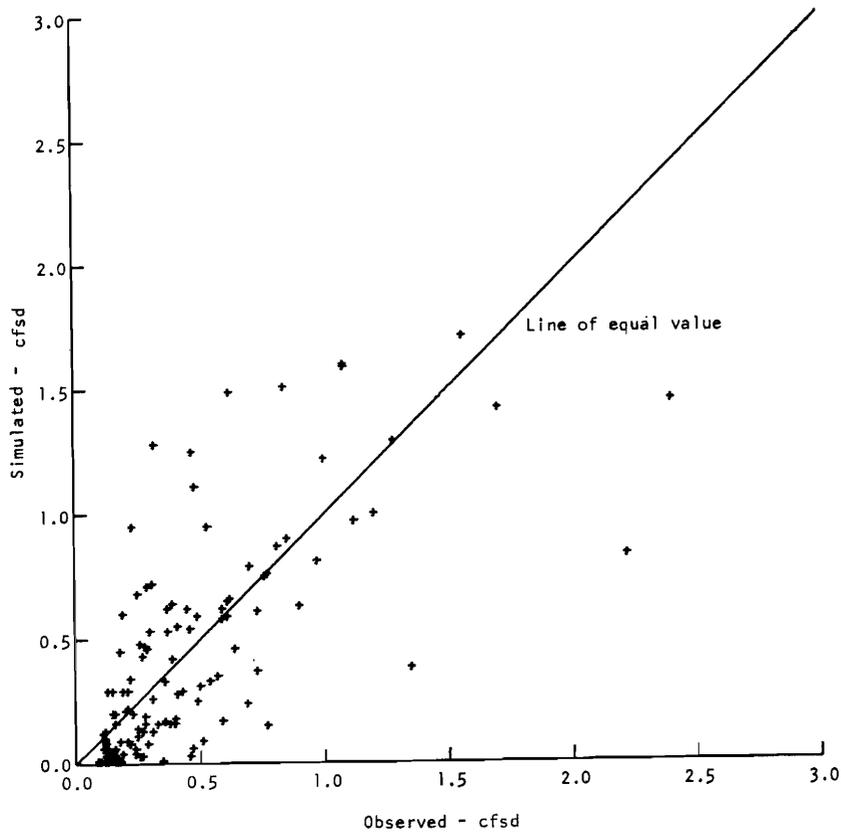


FIGURE 6

BRUSH CREEK WATERSHED, FLOYD COUNTY, VIRGINIA.  
COMPARISON OF OBSERVED AND SIMULATED ANNUAL MAXIMUM  
MEAN DAILY DISCHARGES FROM WATER YEARS 1958-1968.

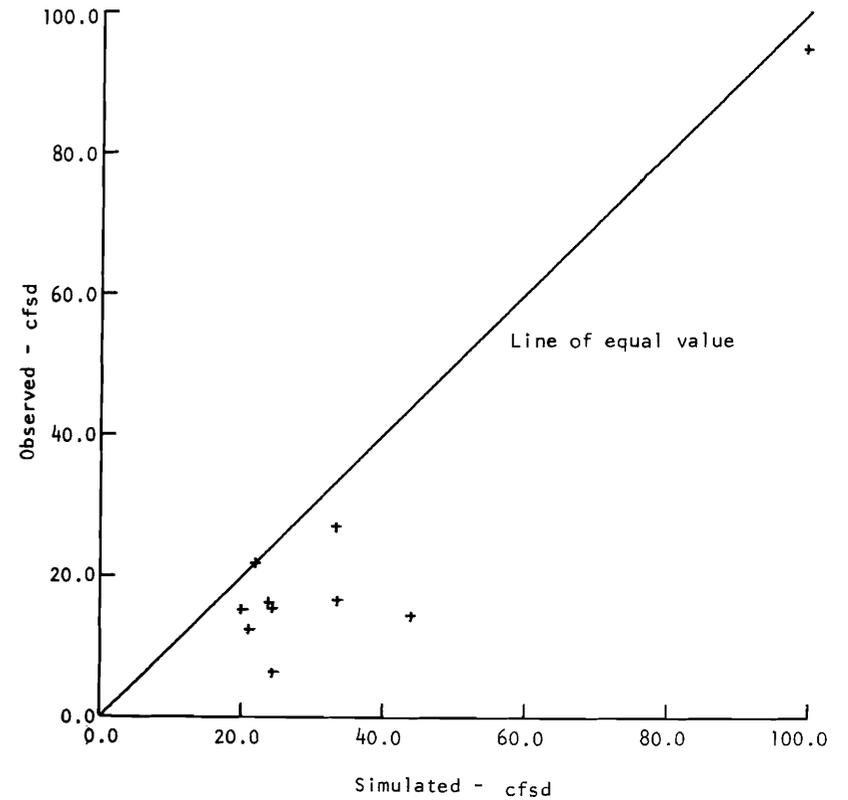


FIGURE 7

CRAB CREEK WATERSHED, MONTGOMERY COUNTY, VIRGINIA.  
COMPARISON OF SIMULATED AND OBSERVED MAXIMUM ANNUAL  
MEAN DAILY DISCHARGES FROM WATER YEARS 1958-1968.

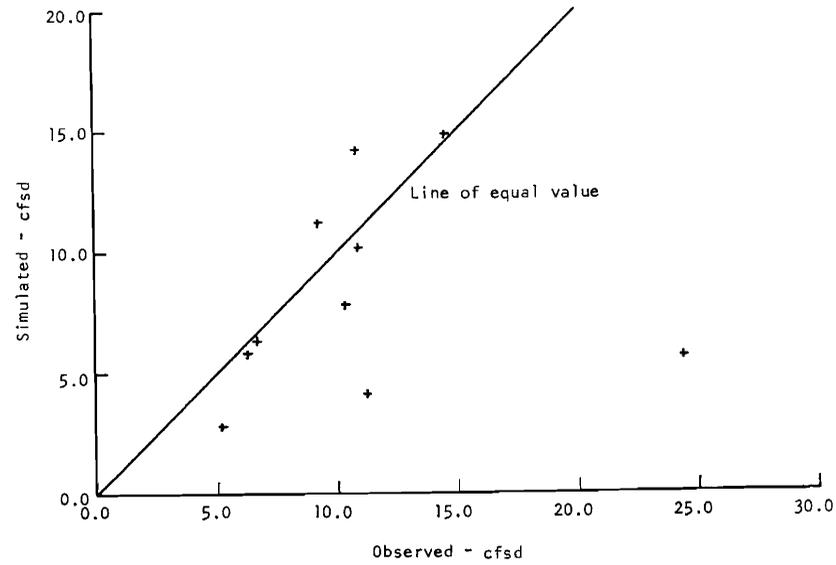


FIGURE 8

BRUSH CREEK WATERSHED, FLOYD COUNTY, VIRGINIA.  
COMPARISON OF SIMULATED AND OBSERVED MAXIMUM MONTHLY  
MEAN DAILY DISCHARGES FROM WATER YEARS 1958-1968.

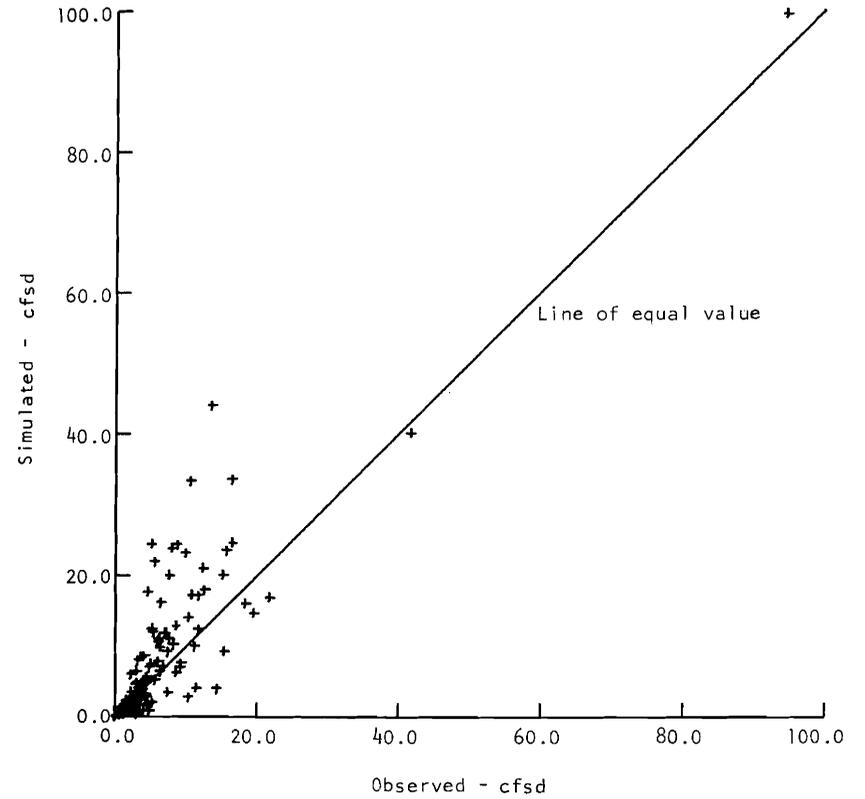


FIGURE 9

CRAB CREEK WATERSHED, MONTGOMERY COUNTY, VIRGINIA.  
COMPARISON OF OBSERVED AND SIMULATED MONTHLY MAXIMUM  
MEAN DAILY DISCHARGES FROM WATER YEARS 1958-1968.

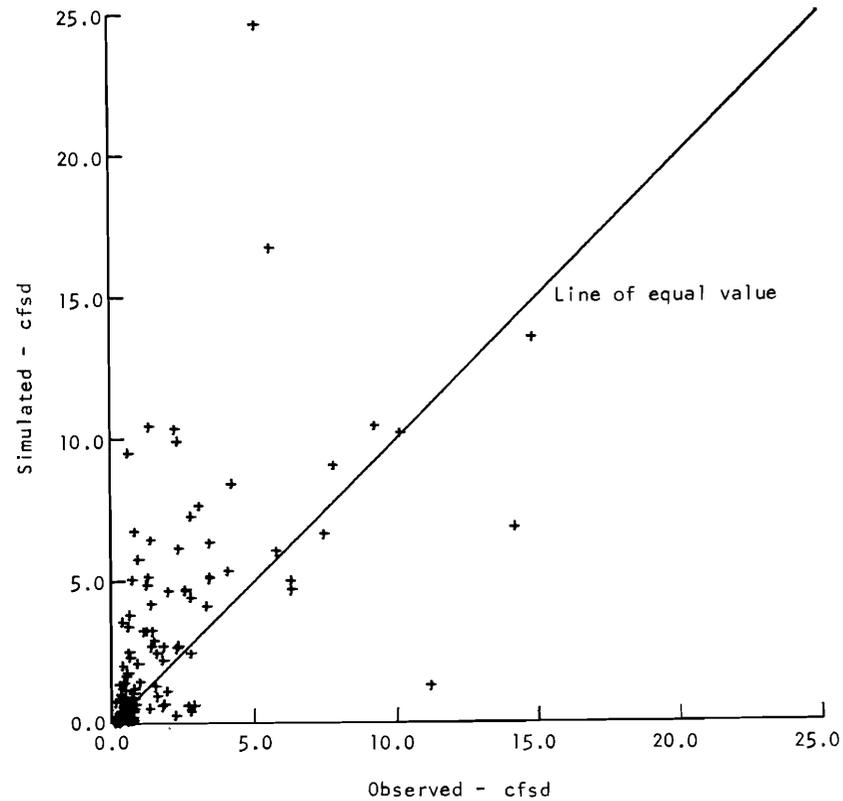


FIGURE 10

BRUSH CREEK WATERSHED, FLOYD COUNTY, VIRGINIA.  
PERCENTAGE OF FLOW THAT OCCURRED AT RATES LESS  
THAN OR EQUAL TO INDICATED VALUES  
FOR THE PERIOD 1958-1968.

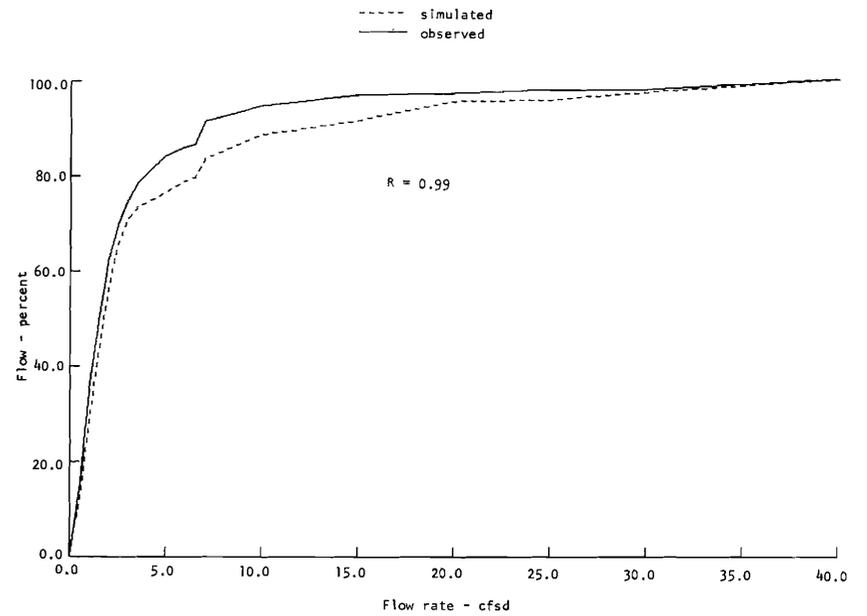


FIGURE 11

CRAB CREEK WATERSHED, MONTGOMERY COUNTY, VIRGINIA.  
PERCENTAGE OF FLOW THAT OCCURRED AT RATES LESS  
THAN OR EQUAL TO INDICATED VALUES  
FOR THE PERIOD 1958-1968.

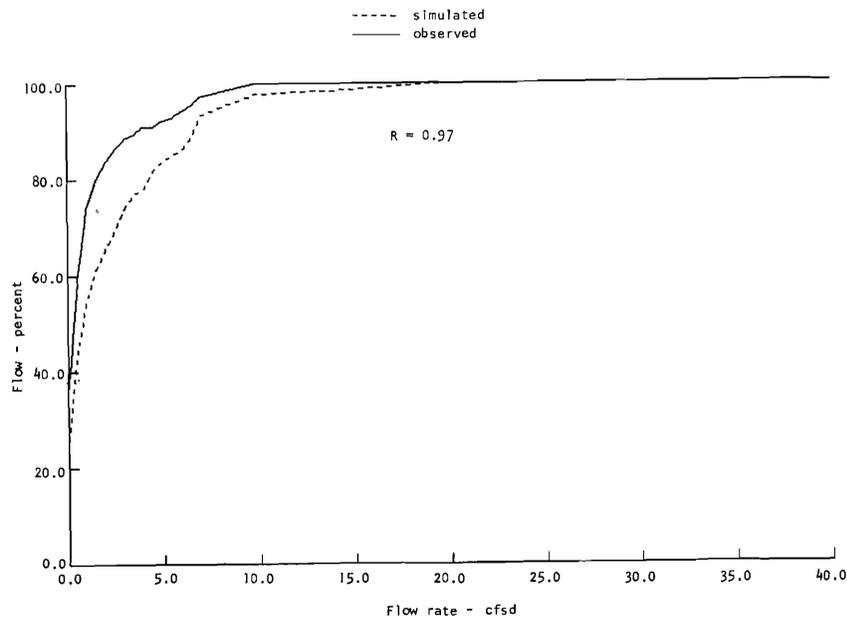


FIGURE 12

BRUSH CREEK WATERSHED, FLOYD COUNTY, VIRGINIA.  
PERCENTAGE OF TIME THAT FLOW OCCURRED AT RATES  
LESS THAN OR EQUAL TO INDICATED VALUES  
FOR THE PERIOD 1958-1968.

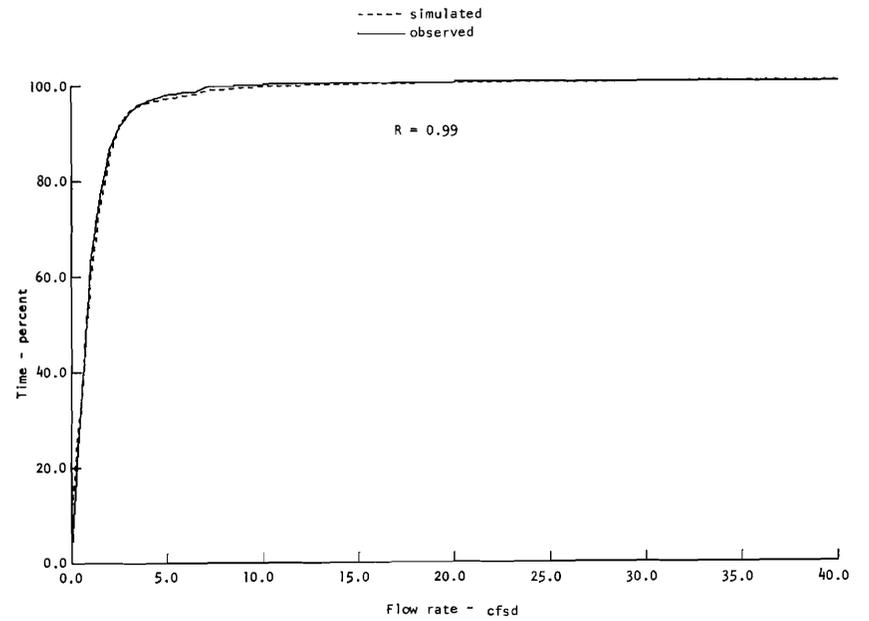


FIGURE 13

CRAB CREEK WATERSHED, MONTGOMERY COUNTY, VIRGINIA.  
PERCENTAGE OF TIME THAT FLOW OCCURRED AT RATES  
LESS THAN OR EQUAL TO INDICATED VALUES  
FOR THE PERIOD 1958-1968.

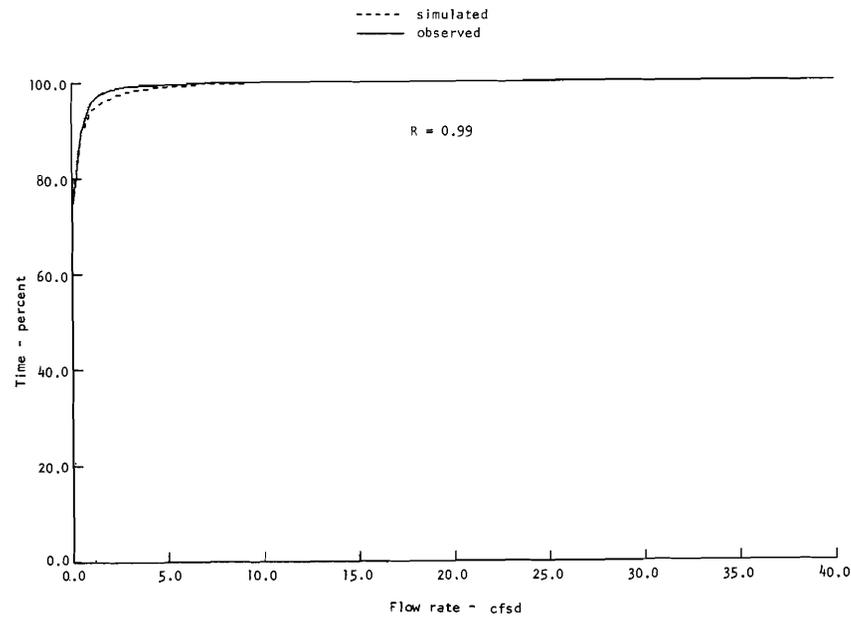


FIGURE 14

BRUSH CREEK WATERSHED, FLOYD COUNTY, VIRGINIA.  
MODEL RESPONSE TO STORM EVENT 1/21-23/59  
FOR INDICATED VALUES OF CSSR.

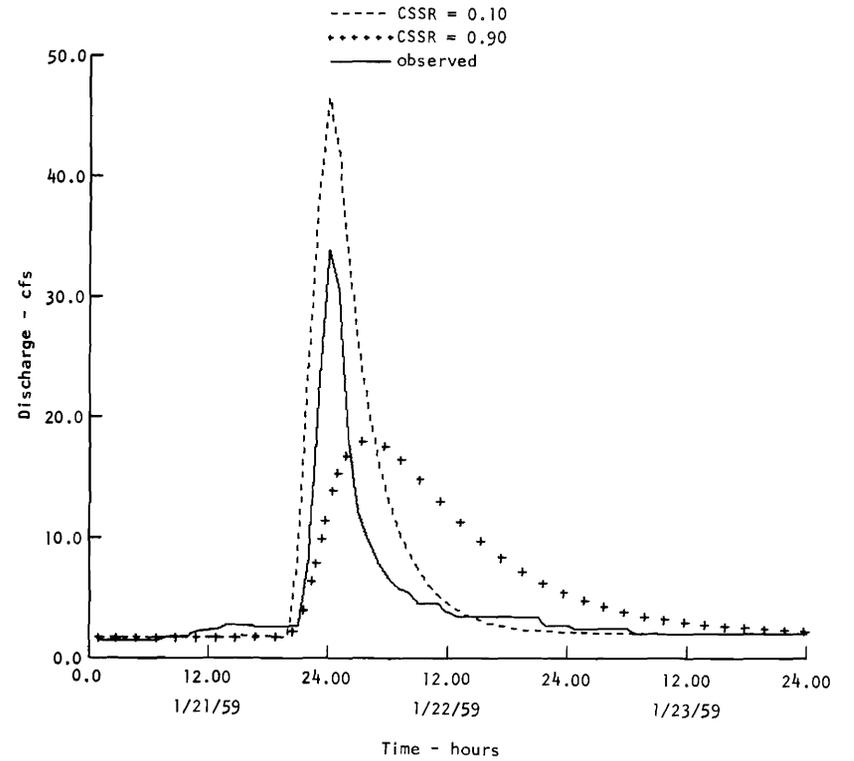


FIGURE 15

BRUSH CREEK WATERSHED, FLOYD COUNTY, VIRGINIA.  
MODEL RESPONSE TO STORM EVENT 1/21-23/59  
FOR INDICATED VALUES OF CC.

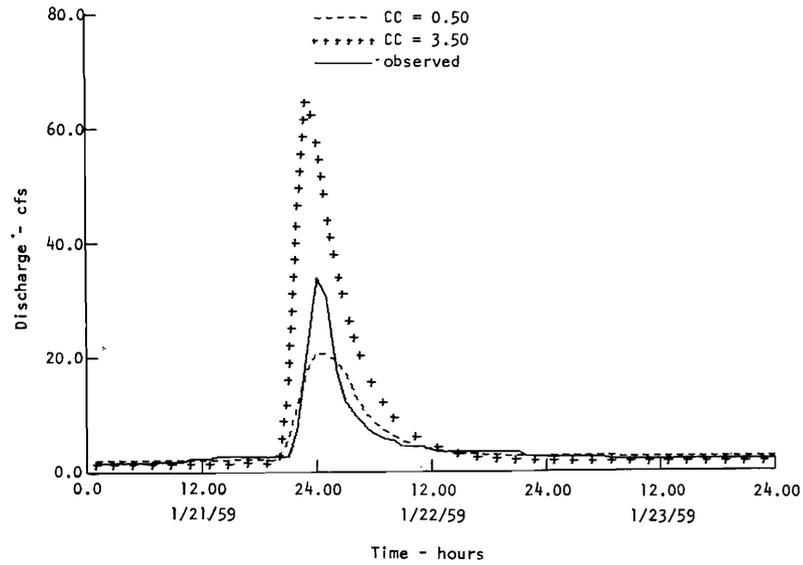
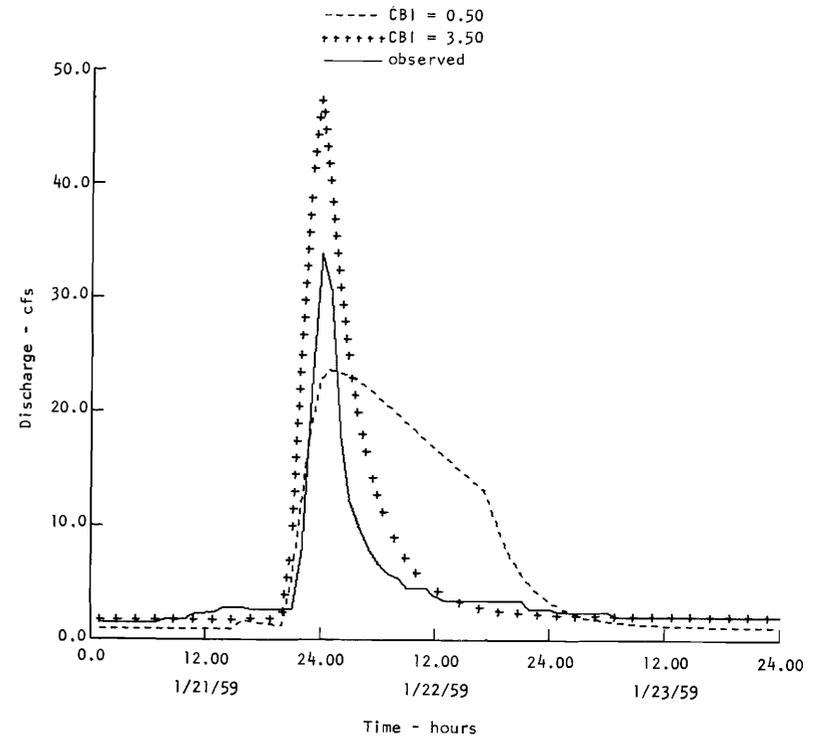


FIGURE 16

BRUSH CREEK WATERSHED, FLOYD COUNTY, VIRGINIA.  
MODEL RESPONSE TO STORM EVENT 1/21-23/59  
FOR INDICATED VALUES OF CBI.



**EFFECTS OF ZOOPLANKTON ON PHOTOSYNTHESIS  
BY ALGAE IN LAKES**  
Project A-022-VA

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December 1970

## EFFECTS OF ZOOPLANKTON ON PHOTOSYNTHESIS BY ALGAE IN LAKES

Small lakes that result from dammed up streams are among the most common bodies of water in Virginia. They serve many uses, but because of the large growths of algae they often develop undesirable features. Blooms of algae may clog filters, create an unsightly appearance, deplete oxygen, and give rise to other unwanted qualities of water. The present study concerned a biological control of algae. The specific objective was to measure the extent to which zooplankton (small, weakly swimming animals) regulated algae in a lake.

Previous studies indicate that feeding by zooplankton may regulate algae. These studies usually follow one of two techniques. The first involves correlations between sizes of populations of zooplankton and algae in nature. The second involves the measurement of feeding by zooplankton under controlled conditions in the laboratory. The first technique is most applicable to field situations, but it relies on large changes in the sizes of the populations. The technique used in our study measured the effects of zooplankton under conditions similar to those in nature. It relied on the nearly ubiquitous behavior of zooplankton to migrate vertically rather than on large changes in the sizes of the populations. Most zooplankton descend during daylight and ascend during the night.

Large aquariums were filled with surface water and natural populations of algae from the lake. They were suspended from the surface and extended to a depth of three feet. Aquariums set out in the day (day aquariums) contained few zooplankton and aquariums set out during the night (night aquariums) contained many zooplankton. Properties of zooplankton and algae within and without the aquariums then were measured over a period of several days.

Westhampton Lake was used as the site for the study as it was readily accessible, on the campus of the University of Richmond, and is a potential site for studies of the effects of urbanization on lakes. It has a drainage basin that is experiencing increased alteration—especially in the loss of top soil.

Figure 1 shows a bathymetric chart of the lake. The surface area is 20 acres and its mean and maximum depths are 1.5 m and 4.0 m. The major tributary, an intermittent stream, enters into the northeast sector.

Figure 2 shows the temperatures and intensities of light at various depths

during the study. The temperature was 29°C at a depth of nine feet. The intensity of light was decreased to 0 percent incident radiation by a depth of six feet.

Figure 3 shows the concentrations of chlorophyll a and rates of photosynthesis at various depths. Chlorophyll a is a pigment in algae and is a rough index of the abundance of algae. Photosynthesis is a measure of growth of the algae. The concentration of chlorophyll a was the same within the upper three feet and reached a maximum at five feet. Photosynthesis was greatest at the surface. About 60 percent of all photosynthesis took place in the upper 1.5 feet.

Figure 4 shows the concentrations of zooplankton at different times of a day. The concentrations without and within the day and night aquariums are indicated by triangles, solid circles, and open circles.

Copepods, both young stages (nauplii) and older stages, underwent descents during the day and ascents during the night. Figure 5 shows the concentrations of two other kinds of zooplankton. The migrations of cladocerans were similar to those of the copepods, but the rotifers exhibited no clear, consistent pattern of migrations.

Figure 6 shows the rates of photosynthesis within and without the aquariums during different times of the summer. The statistical procedures of analysis of variance and covariance indicate that the zooplankton as a whole do not significantly affect photosynthesis or chlorophyll a. Rotifers were the only zooplankton to significantly influence photosynthesis; the average population decreased the rate of photosynthesis by 22 percent per day. They had no effect on chlorophyll a concentrations.

During the analysis of the data, interest arose in changes in photosynthesis during the summer with respect to climatic conditions. The relationship between rates of photosynthesis and rainfall was analyzed according to Kendall's rank correlation technique. The correlations were not significant one to two days after rain, but were significant three to five days after rain. That is, photosynthesis increased three to five days after a rainstorm. Photosynthesis did not correlate with chlorophyll a. The increased photosynthesis, therefore, was not simply due to increased algae, but rather the increased efficiency with which the algae could use chlorophyll a. A probable explanation is that rain washed nutrients into the lake and that the algae stored the nutrients for several days before their photosynthesis increased. Studies by Mr. Peters from VEPCO lend support to this

explanation. They found increased concentrations of certain nutrients in the James River near Westhampton Lake after rainstorms.

FIGURE 1  
BATHYMETRIC CHART OF WESTHAMPTON LAKE

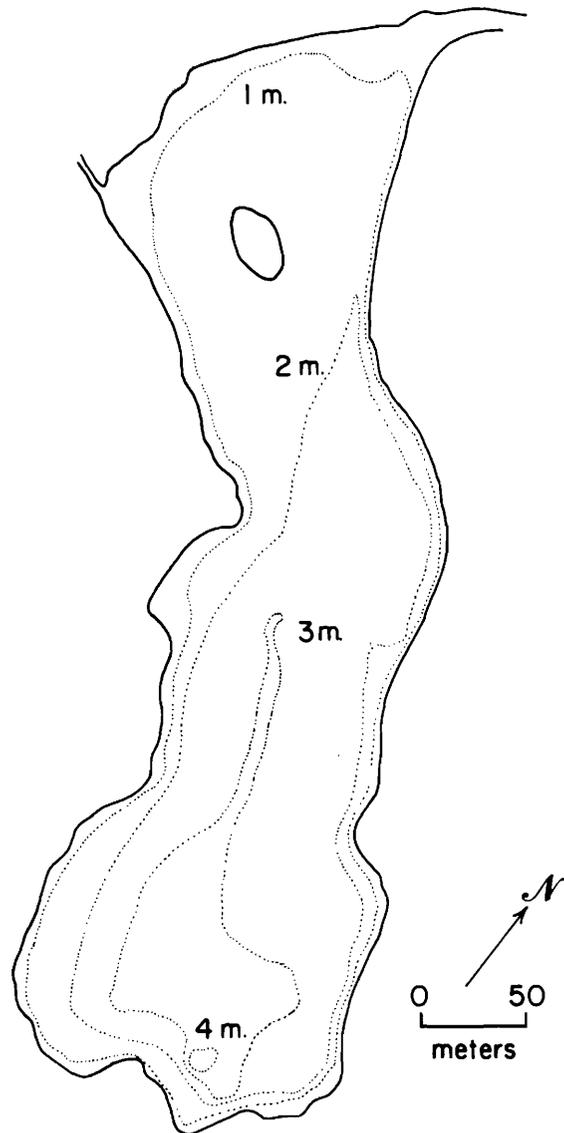


FIGURE 2  
WATER TEMPERATURES AND LIGHT INTENSITIES  
AT VARIOUS DEPTHS

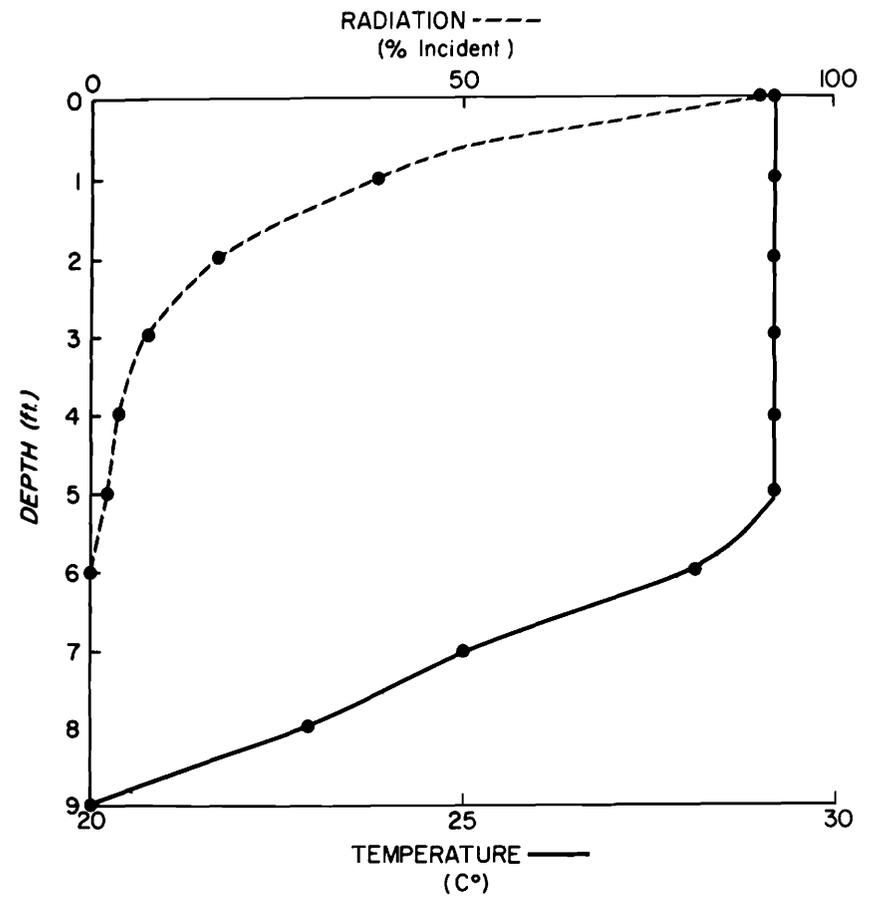


FIGURE 3

CHLOROPHYLL CONCENTRATION AND PHOTOSYNTHESIS RATES AT VARIOUS DEPTHS

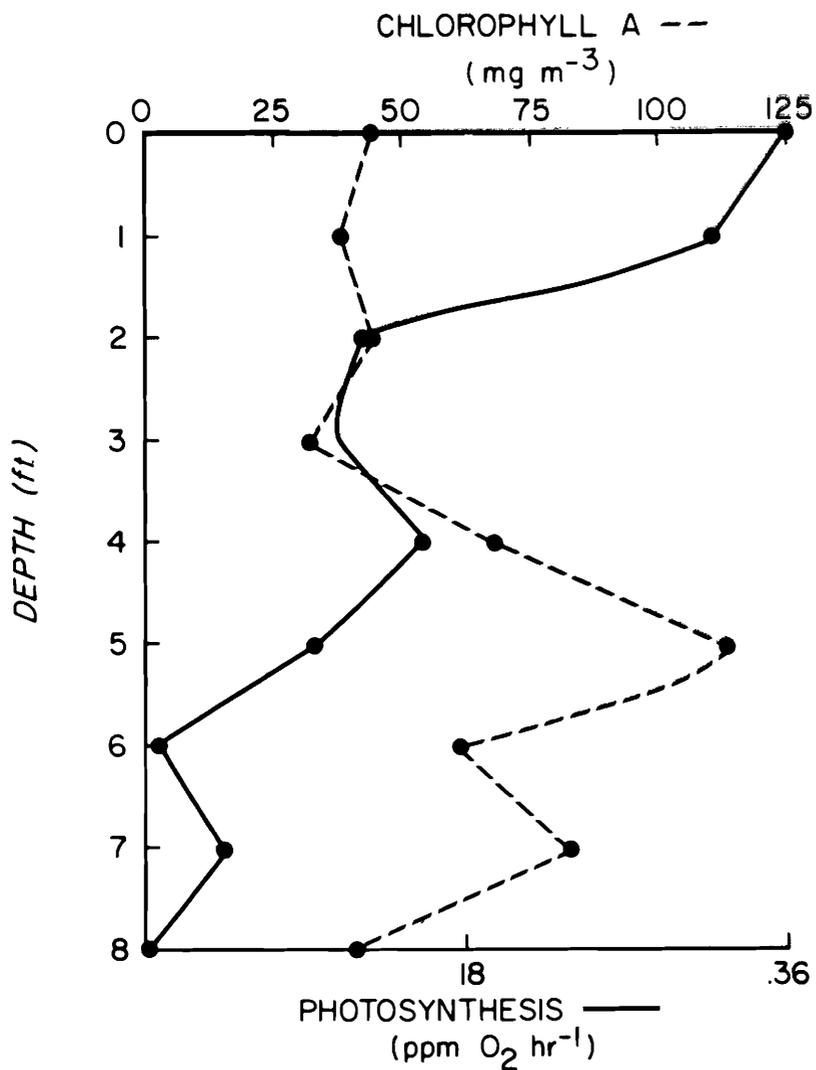


FIGURE 4

ZOOPLANKTON CONCENTRATIONS VS. TIME OF DAY

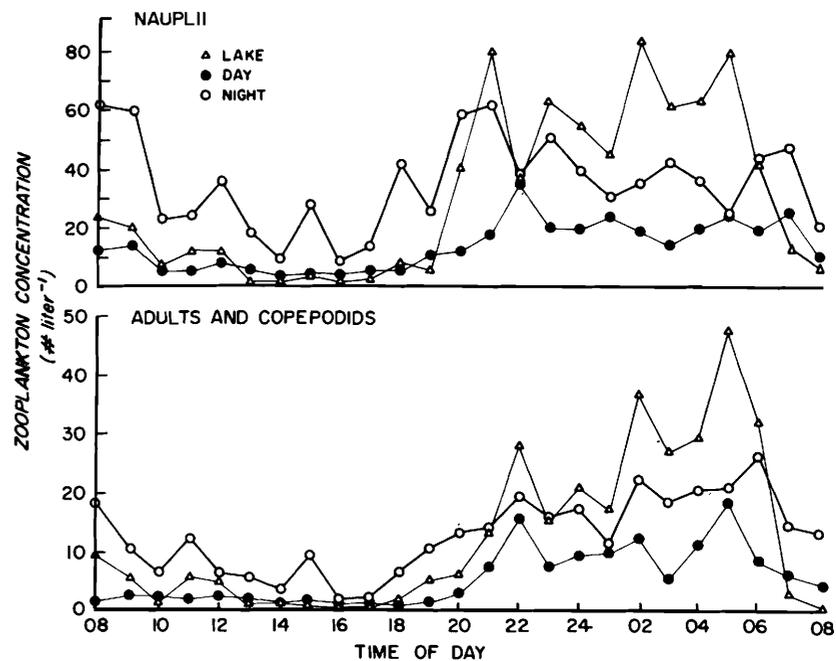


FIGURE 5  
ZOOPLANKTON CONCENTRATIONS

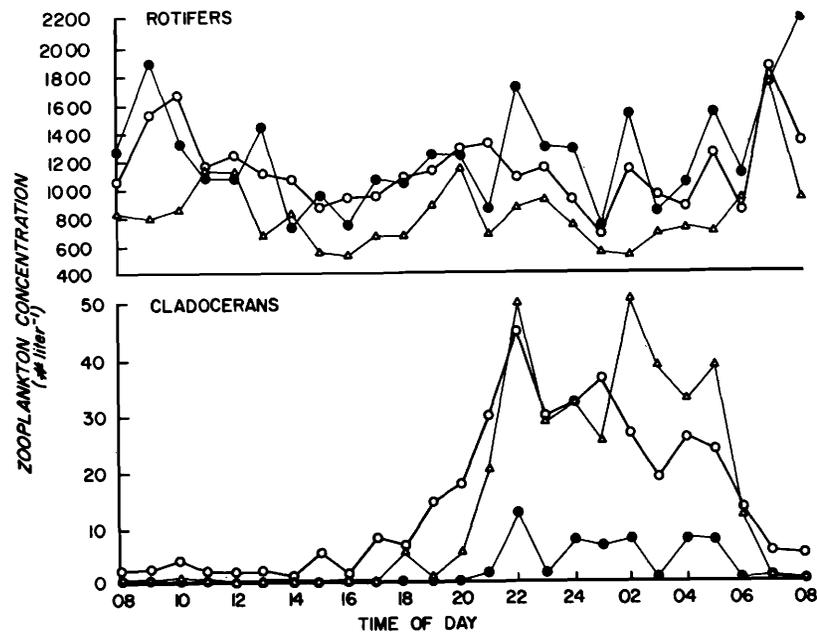
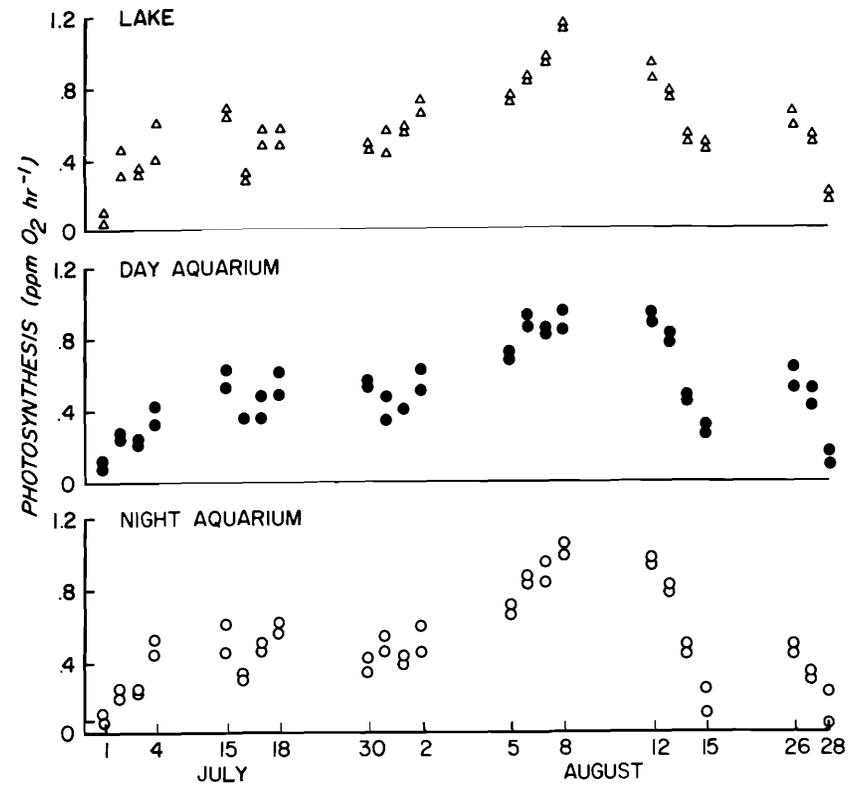


FIGURE 6  
RATES OF PHOTOSYNTHESIS



**GROUND WATER RESERVOIR RESPONSE  
TO EARTH TIDES**  
Project A-023-VA

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December 1970

## GROUND WATER RESERVOIR RESPONSE TO EARTH TIDES

### Introduction

It is well known that lunar and solar tide generating forces can cause periodic water level fluctuations in wells. Melchior (1966) and Bredehoeft (1967) have reviewed the work of earlier investigators who sought to demonstrate qualitatively that observed water level variations in wells and mines were indeed tidal in nature. Bredehoeft (1967) and Bodvarsson (1970) have developed theories which attempt to describe the response of well-aquifer systems to periodic dilatations. Since the response equations relate tidal amplitudes to specific aquifer storage it seems reasonable to attempt to use tidal observations as a means of determining ground water reservoir storage capacity.

A study was undertaken in Virginia to examine tidal water level fluctuations in wells, and to quantitatively relate observed tides and ground water reservoir storage parameters. Data from thirty wells were examined, and tides were identified in twelve of these wells. Quantitatively reasonable relationships between tides and aquifer porosity and bulk modulus were established for seven wells. Data were insufficient to establish good quantitative relationships for three wells, and data from two wells showing well developed tides came to the attention of the writer too late for analysis within the time allotted by OWRR for this study.

In the following discussion the theoretical response of well-aquifer systems is first considered. Then the observed data are examined which provide confirmation of the theory. Finally, an evaluation of the applicability of tidal studies in aquifer investigations is presented.

### Theory

Well-aquifer systems are usually considered as ideally confined or unconfined in studies of relationships between water height in a well and pressure on the aquifer. Bredehoeft (1967) showed that for an unconfined aquifer the thickness of the saturated zone must be great and the porosity very low in order to observe tides. Since the study of Virginia wells involves aquifers of moderate porosity and moderate thicknesses, the following discussion will be restricted to an idealized aquifer confined above and below by impervious materials. Let  $n$  be the aquifer porosity, and  $E_m$  and  $E_w$  represent the bulk

moduli of the aquifer matrix and fluid respectively. The aquifer is penetrated by a well in which water rises to a height,  $h$ , above the aquifer. A dilatation,  $\Delta_A$ , causes a change in water level,  $dh$ .

Since the response of well-aquifer systems of reasonable permeability to tidal dilatations can be considered as a static problem (Bodvarsson, 1970), water level change corresponding to a dilatation will be:

$$-dh = \frac{\Delta_A}{\rho g \left( \frac{1-n}{E_m} + \frac{n}{E_w} \right)} \quad (1)$$

where  $\rho$  is fluid density,  $g$  is gravitational acceleration, and dependence of  $\Delta_A$  on grain binding is ignored.

The dilatation arises from three sources which include solid earth tides, barometric tides, and ocean tides. The solid earth tide is assumed to be in phase with the luni-solar tidal potential,  $W_2$ , but the barometric and ocean tides are generally not in phase with the potential. Although all arise from a common source, they may be viewed as independent in their effects on well-aquifer systems. The time varying aquifer dilatation for a particular harmonic constituent of angular frequency  $\omega$  is:

$$\Delta_A \cos(\omega t + \phi_A) = \Delta_T \cos \omega t + \Delta_B \cos(\omega t + \phi_B) + \Delta_O \cos(\omega t + \phi_O) \quad (2)$$

where  $\Delta_A$ ,  $\phi_A$ ,  $\Delta_B$ ,  $\phi_B$ ,  $\Delta_O$ ,  $\phi_O$  are the total aquifer dilatation and phase angle, barometric dilatation and phase angle, and ocean tide dilatation and phase angle. Phase angles are obtained from harmonic analysis of observable data.  $\Delta_T$  is the earth tidal dilatation.

The earth tidal dilatation is given by:

$$\Delta_T = 0.49 W_2 / ag \quad (3)$$

where  $a$  = earth radius,  $g$  = gravitational acceleration, and  $W_2$  is obtained from equations describing the motions of the earth-moon-sun system (Kuo and Ewing, 1966; Longman, 1959). Equation (3) was obtained by Takeuchi (1950).

The aquifer dilatation caused by barometric tides will be:

$$\Delta_B = B dp_B \left( \frac{1-n}{E_m} + \frac{n}{E_w} \right) \quad (4)$$

where  $B$  is the barometric efficiency of the well-aquifer system, and  $dp_B$  is change in barometric pressure.

The ocean tidal dilatation cannot be independently computed but is assumed to be proportional to the height of the ocean tide,  $H$ .

To relate the tidal water level fluctuations and aquifer storage parameters the value of  $\Delta_A$  must be obtained for use in equation (1). For wells located approximately 100 km. or more from the ocean the ocean tidal dilatation of the aquifer is small, and  $\Delta_O \approx 0$  can be assumed. The aquifer dilatation is then given by the equation:

$$\Delta_A = (\Delta_T + \Delta_B \cos \phi_B) / \cos \phi_A \quad (5)$$

The phase differences  $\phi_B$  and  $\phi_A$  between the luni-solar tidal potential and the barometric and well tides respectively are obtained from harmonic analysis, and  $\Delta_T$  and  $\Delta_B$  are obtained from equations (3) and (4).

For wells located near the ocean at least two tidal harmonic constituents are required if observed tides are to be related to aquifer parameters. For practical purposes the main lunar semi-diurnal and diurnal constituents  $M_2$  and  $o_1$  will be used. Since  $\Delta_O$  cannot be estimated, two equations must be used. Equation (2) is written for  $M_2$  and  $o_1$  separately. Then assuming that:

$$\frac{\Delta_{o_1}}{\Delta_{M_2}} = \frac{H_{o_1}}{H_{M_2}} = R \quad (6)$$

The two equations can be combined to give:

$$\frac{\cos \phi_{oM_2} (P\Delta_{Ao_1} - \Delta_{To_1} - Q\Delta_{Bo_1} \cos \phi_{Bo_1})}{\cos \phi_{oo_1} (\Delta_{AM_2} \cos \phi_{AM_2} - \Delta_{TM_2} - \Delta_{BM_2} \cos \phi_{BM_2})} = R \quad (7)$$

where  $P = dh_{o_1}/dh_{M_2}$  and  $Q = dp_{o_1}/dp_{M_2}$  are obtained from harmonic analysis of well tide and barometric tide records, and  $H_{o_1}$  and  $H_{o_2}$  are obtained from ocean tide records near the area of the well-aquifer system.

### Observations

Water level records showing tidal fluctuations were obtained from ten wells identified in Table 1. These records show aperiodic as well as periodic changes. The data were digitized at hourly intervals and transferred to punch card form for subsequent reduction and analysis.

Non-tidal aperiodic water level changes were removed from the observed data by standard digital filtering methods and by a non-harmonic filtering method which compares the observed record with the luni-solar tidal potential record. In this latter method the potential record crosses zero 2 to 4 times a day. Water level at these times is attributed to aperiodic sources and is used to construct a smoothly varying curve of aperiodic change in water level. This curve is then subtracted from the observed well water level data. In these ways the observed data were reduced to produce records showing only tidal fluctuations.

The tidal fluctuation records were then processed by the least squares harmonic analysis method of Nowroozi, Kuo, and Ewing (1969) to obtain the amplitudes and phase angles of the  $M_2$  and  $o_1$  tidal constituents. Results are given in Table 1.

Ocean tide data from Hampton Roads, Virginia, and barometric records at or near well sites were also processed by the above method of harmonic analysis to obtain the amplitude and phase angle data required by equations (5) and (7).

### Interpretation

In the following discussion values of porosity will be computed for seven of

the ten wells listed in Table 1. For the three wells at Kilmarnock, Lee Hall Reservoir, and Eastern State Hospital tides are very low and can be explained in terms of barometric effects alone. This suggests that the aquifers are not ideally confined.

Four wells located near Blacksburg, Christiansburg, and Cripple Creek, Va., all penetrate aquifers in a sequence of carbonates and shales which comprise a series of low angle thrust faults within the Appalachian mountains. Cambrian rocks are overthrust onto a sequence of middle-Paleozoic sediments. Rocks in the thrust plates are locally brecciated and severely structurally deformed. As a consequence the aquifers are probably of limited extent and characterized by fracture porosity. No two wells penetrate the same aquifer.

Assuming values of  $E_m = 2 \times 10^{11}$  dynes/cm<sup>2</sup> and  $E_w = 2.13 \times 10^{10}$  dynes/cm<sup>2</sup> and the results of harmonic analysis given in Table 1, porosity values were computed for each well using equations (1), (4), and (5). Results are given in Table 2. Reasonable values of porosity were obtained from each well which serves to confirm the equations used. Some discrepancy is seen for the  $M_2$  and  $o_1$  porosity determinations for CC-1. This probably can be attributed to the low amplitude of the  $o_1$  constituent. Equation (1) shows great sensitivity to tidal amplitudes less than 1 cm and small errors can yield large uncertainty in computed porosity.

The three wells located near Camp Perry, Suffolk, and Walkers Dam, Va., all penetrate the main Atlantic coastal plain aquifers. All of these wells probably penetrate the same aquifers. The geologic section consists of a sequence of interbedded sands and clays which are largely uncemented. Porosity varies from well to well depending upon sand grain shape and clay content. The aquifers are not locally recharged and are not hydrologically connected with the ocean.

Assuming the same values of  $E_m$  and  $E_w$  and taking  $R = .2$  the values of porosity given in Table 2 were obtained by combining equations (1), (4), and (7). Again the reasonable values confirm the validity of these equations.

### General Discussion

The tides observed in water wells can be related to the porosity and bulk modulus of an aquifer by means of equations presented earlier in this paper. To establish this relationship one must have water level records, barometric records, and ocean tide records covering at least two weeks and preferably 29 continuous days. Insofar as a well can be made available for tidal observations

for this period of time, tidal analysis may be useful in aquifer evaluation studies. Practical methods could probably be developed which would require only about 2 days of data if ocean tide effects could be neglected. Tidal analysis in aquifer studies is probably more applicable to inland locations.

For purposes of computing aquifer porosity and specific storage it is necessary to know the bulk modulus of the aquifer matrix material. It is reasonable to expect the bulk modulus to fall in the range of  $1 \times 10^{11}$  to  $4 \times 10^{11}$  dynes/cm. Equation (1) indicates that for a well tide amplitude of 1 cm porosity would range from 5 percent to 21 percent within this range of bulk modulus. Consequently, the accuracy of a porosity determination depends on the accuracy to which  $E_m$  is known. This dependence of  $n$  and  $E_m$  need not be considered in specific storage calculations which are obtained from the equation of DeWiest (1966):

$$S = pg \left( \frac{1-n}{E_m} + \frac{n}{E_w} \right) \quad (8)$$

and consequently  $S$  can probably be obtained to an accuracy of better than 5 percent if ocean tide effects can be neglected.

The porosity calculations represent the value of effective porosity for the entire sequence of confined aquifers penetrated by a well. Likewise the specific storage computed for a well-aquifer system represents the entire sequence of confined aquifers. The presence of an unconfined aquifer will probably not be detected in a study of tides in wells. For practical purposes, tidal analysis of well-aquifer systems is restricted to the response of the confined aquifers.

The presence or absence of tides in a well does not in itself indicate whether or not the well-aquifer system will be a good source of water. If present, tides may be used to investigate the effective porosity and storage capacity of a confined well-aquifer system.

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TABLE 1

Well	Location	Depth m	Tidal Harmonic Constituents			
			$M_2$ (cm)	$\phi_{M_2}$ (deg)	$\sigma_1$ (cm)	$\phi_{\sigma_1}$ (deg)
Blacksburg	37°14'N 80°25'W	146	0.7	-206	0.5	-170
Christiansburg	37°08'N 80°26'W	136	1.3	-49	0.8	-219
Cripple Creek No. 1	36°49'N 81°06'W	305	1.9	-218	0.9	-194
Cripple Creek No. 2	36°48'N 81°04'W	430	3.8	-220	3.1	-204
Camp Perry	37°19'N 76°39'W	120	11.3	107	1.9	172
Suffolk	36°47'N 76°33'W	307	2.5	97	0.4	154
Walkers Dam	37°25'N 76°56'W	191	3.8	30	0.5	34
Lee Hall Reservoir	37°11'N 76°34'W	135	.02	197	.06	22
Eastern State Hospital	37°18'N 76°44'W	169	.05	19	.06	129
Kilmarnock	37°42'N 76°23'W	215	.14	165	.26	345

TABLE 2

Well	% Porosity	$M_2$	$\sigma_1$
Blacksburg		33	33
Christiansburg			38
Cripple Creek No. 1		2	12
Cripple Creek No. 2		1	1

Well	% Porosity ( $\sigma_1/M_2$ )
Camp Perry	10
Suffolk	40
Walkers Dam	3

**MICROBIAL RELEASE OF SOLUBLE PHOSPHATE  
IN AN ACTIVATED SLUDGE ENVIRONMENT**  
Project A-024-VA

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## MICROBIAL RELEASE OF SOLUBLE PHOSPHATE IN AN ACTIVATED SLUDGE ENVIRONMENT

For the past two years research on the release of soluble phosphate in an activated sludge environment has been conducted at Virginia Tech. Phosphorus is an algal nutrient, and the present discussion is concerned with tertiary treatment of sewage plant effluents for phosphate removal to control the eutrophication of streams. Recently, however, there has been a good deal of controversy over just what should be done and what should not be done to control eutrophication.

A talk was presented this past spring at the Purdue Industrial Waste Conference by employees of the FWQA reporting that in some streams surveyed in the South, carbon was the limiting factor on algal growth rather than phosphorus. Also, researchers at the University of North Carolina have recently issued a statement saying that nitrogen limited eutrophication in work they did. To keep things in a better perspective in regard to phosphorus, carbon, and nitrogen, there is one thing that can be pinned down rather quickly. That is that algae need carbon, they need nitrogen, and they need phosphorus as nutrients. Further, in a closed aquatic system there is an external supply of nitrogen in the atmosphere and an external supply of carbon from carbon dioxide in the atmosphere. On the other hand, in the same closed aquatic system there is no outside source of phosphorus. The phosphorus source can be defined—it gets into streams from sewage effluents and, of course, agricultural run-off. Those are the sources. It cannot come from the atmosphere, it is not going to get into a closed system. A third thing that can definitely be said is that if there is a limited amount of phosphorus there will be limited algal growth. The phosphorus, in other words, is going to limit the total amount of algae that can grow. Nitrogen is less likely to limit total growth because it is available from a limitless source. Carbon dioxide is not going to limit growth because it is available from a limitless source. Obviously, for algal growth control phosphorus is the critical nutrient. The problem is that streams today are so polluted with nutrients that nitrogen and carbon dioxide can become growth rate limiting factors. They can limit how fast the algae grow, but not how much. This is the difference. The carbon dioxide will limit how fast algae grow if there is a large excess of phosphorus and nitrogen. The nitrogen can limit how fast algae grow if there is a large excess of carbon dioxide and of phosphorus.

To get back to this research, the problem is that one of the major contributors of phosphorus to our aquatic bodies of water is municipal

wastewater treatment effluent. High phosphate detergents cause much of the problem. At any rate, in sewage treatment plants there are no facilities for removing phosphorus or nitrogen other than what is normally taken up during the metabolism of the organic matter. Microorganisms have to have a certain ratio of carbon, nitrogen, and phosphorus for growth, so they incorporate a small amount into the new cells. However, there is no special facility for phosphorus removal. Such facilities were never designed to remove phosphorus, nobody cared about phosphorus when they were first designed. They were designed to remove organic matter, not phosphorus, so now treated sewage has become one of our major sources of nutrient pollution.

In sewage treatment plants there are ways that biological processes can remove a certain amount of phosphorus. The question is "How much can it remove?" This too, has been a matter of considerable controversy: "How much can I expect to remove in my waste treatment process?" is a question that has been asked many times. Before getting into what is right and what is wrong, there is another characteristic of sewage treatment plants that really led to the present work. A sewage treatment plant has a biological process that is followed by a final sedimentation basin. The effluent water flows out of the settling basin into the stream. With respect to soluble phosphorus level, there is a high concentration of phosphorus that enters the biological process coming in. The concentration decreases considerably in the aeration tank during organic stabilization, but then frequently in the latter part of the aeration unit and nearly always in the settling basin, the phosphorus is released back into solution and the concentration is right back to the initial level. There is a certain amount of biological removal of phosphorus achieved, but this is lost before the effluent leaves the plant. The sludge it is incorporated into is not taken out of the system in time to do any good. This research was conducted to obtain knowledge which could be used to increase the phosphorus removal efficiency in the activated sludge process. It is known that 100 percent removal of phosphorus cannot be attained in this system, or anything close to it. Removal of that magnitude requires chemical usage. However, if the removal is increased from zero to 40 or 50 percent for example, then quite a bit has been accomplished. If chemicals are then used for phosphate removal it will not be necessary to use as much, so the economic situation has been improved considerably.

The basic approach was to study the factors that determine how much phosphorus will be removed in the activated sludge process and then study the factors that cause phosphorus to be released back into solution before the sludge is removed from the system. The goal being that maybe sewage treatment plant operation could be revised in such a way that phosphorus

desorption would be minimized. There would still be a certain amount of phosphorus going out in the effluent, but considerably less than if desorption was not controlled.

There are many unresolved controversies in the phosphorus metabolism field. It seems that every time somebody does something different a new controversy is created rather than one being cleared up. One of the first controversies was "Can activated sludge organisms store phosphorus?" It has been argued that there can only be as much phosphorus removal as would logically correspond to the carbon uptake achieved. On the other hand, there are several activated sludge plants, like the one in San Antonio, where 90 percent phosphorus removal is being accomplished. This removal is with a typical activated sludge system, no chemicals are added, and there are no significant modifications. Obviously there is excess phosphorus removal, the question is why? There are controversies with respect to phosphorus release. What causes it? Is it a chemical process or is it a biological process? If it is a biological process what causes the biological release, leakage from viable cells or cell lysis? This research was designed to resolve some of the controversies.

Initially it was necessary to define how much phosphorus uptake could be expected with the experimental systems. By the carbon limitation theory mentioned previously, the removal of one pound of phosphorus for each 100 pounds of BOD removed was anticipated. In other words, the ratio between COD removal and phosphorus removal was expected to be at least 100:1. However, from several studies it was found that the ratios were considerably less than that. For example, a typical ratio was 36:1. There were several studies where there was excess phosphorus uptake. The question was "Why?" To point out a possible reason, one system that had a high food-to-microorganism ratio might be noted. That particular system actually incorporated a lot more phosphorus per cell than any of the other systems including the ones that had obvious luxury uptake. This agrees with the conclusion that a few other researchers have reached. If the activated sludge is to take up excess phosphorus the organisms have to be maintained in a rapidly growing state.

Uptake was not really the research objective, phosphorus release was. It is interesting to note what happened to the soluble phosphorus in the experimental units with time. It was found that phosphorus uptake occurred simultaneously with COD uptake but the phosphate uptake was more rapid during the early stage, indicating that the organisms were taking up more phosphorus than they needed. After the food source was depleted the phosphorus gradually leaked back to solution. This same result occurs in the

activated sludge system. When the microorganisms run out of food, phosphorus goes back into solution regardless of other environmental conditions. The amount released back into solution is a direct function of the amount of phosphorus the cell absorbed initially.

Following aeration, it is necessary to separate the activated sludge from the liquid before the effluent can be released to the receiving stream. This is accomplished by sedimentation. During sedimentation the organisms are in a situation where the oxygen runs out. What happens when the oxygen is gone? Instead of a slow release of phosphorus such as occurs during extended aeration, a much more rapid release of phosphorus occurs as soon as the oxygen level drops to zero, or shortly thereafter. The amount of anoxic phosphate release is directly proportional to the amount removed during the uptake of substrate. Just as with phosphorus uptake, some investigators have concluded that the release of phosphorus under anoxic conditions is not a biological process at all; they say it is a chemical process that is controlled by pH. The present work shows, however, that there is no relationship between pH and phosphorus release under anoxic conditions. On the other hand, the results did correlate very well with oxygen depletion, indicating that it was a biological process. The conclusion with respect to pH was convincingly demonstrated. In fact, in one experiment less phosphorus release was achieved with a drop in pH than with a parallel experiment where pH was not permitted to drop. It has also been reported by researchers that phosphorus release is controlled by oxidation reduction potential instead of by the absence of oxygen. Contrary to that conclusion, experimental results obtained in this work show that the change in oxidation reduction potential always occurs after release rather than before. Again, the release occurred after the oxygen was depleted, further indicating that phosphorus release is a biological phenomenon.

Having become convinced that phosphate release was a biological phenomenon the question became, "How can sewage treatment plant operation be changed to keep from losing too much once removed phosphorus back into solution?" The results showed that the amount of phosphorus released from the activated sludge per unit solids was relatively constant. That is to say, from 10 pounds of sludge the same amount of phosphorus is usually released. There is very good correlation in that respect. Again, this indicates the biological nature of release, that it is tied in very strongly with the amount of biological solids. From the same experiments an attempt was made to correlate release with solids destruction, however, the correlation was not consistent. The data were compared to those of another investigator and it was found that his phosphorus release per unit solids

destroyed was a lot higher, although there was one point in this work that fit his plot. Despite the variation, it is obvious that release increases as biological solids are destroyed. The question of how much food should be left over at the end of aeration when it is followed by sedimentation where the oxygen drops to zero was also investigated. The results showed that the higher the food concentration the less the amount of phosphorus released during anoxia.

Aeration rate is also a fundamental operational parameter and it was investigated to determine how rapidly activated sludge should be aerated to keep from getting release during the period of anoxic conditions that is likely to follow. We found that there was a relationship between aeration rate and subsequent phosphate release. At the higher aeration rates there is less subsequent release under anoxic conditions. With respect to aeration rate, it should be noted that if a low aeration rate is maintained in the biological unit, very little phosphorus will be incorporated into the cell during substrate stabilization and, while release may be low, the actual soluble phosphorus concentration will be high.

Further experiments were designed to study the effects of chemical addition on activated sludge phosphorus release. The purpose was multiple. It was hoped to learn something about the mechanism of biological release and to determine the feasibility of chemical control. A correlation of the experimental results shows that if chemical addition puts any stress on the microbial system, i.e., interferes with their metabolism in any way, soluble phosphorus will be released. The amount released will vary directly with the magnitude of the stress. In terms of chemical control, it was found that the addition of magnesium sulfate to a 2 percent concentration would cause a 50 percent reduction in phosphate release. The addition of other chemicals was tried to see what effect they would have on the activated sludge system, and it was found that activated alumina absorbs phosphorus very readily. The mechanism of removal is obviously absorption whereby the alumina just soaks up the phosphorus and the activated alumina causes no stress on the bacterial system. It does not cause any difficulty for them from a biological standpoint and so, therefore, they do not react to it by releasing phosphorus.

**THE EFFECT OF DETERGENTS ON THE  
OXYGENATION OF WATER**  
Project A-025-VA

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## THE EFFECT OF DETERGENTS ON THE OXYGENATION OF WATER

As a society we are more and more demanding the type of materials containing surface active agents. Not only is the population growing, but as a society we are using more and more types of compounds that have surface active agents in them. If we go back a few years we find that the use of synthetic detergents began in the late 1930's. This is when mass production really got underway, and since then detergents have replaced natural soaps. The number of these materials also has increased. It was in the 1940's and early 50's that quite a few people took a look at trickling filters and activated sludge units in domestic waste treatment plants and found that if you had no detergents, no surface active agents at all, in your activated sludge units and in your trickling filters, the rate of oxygen uptake would be just about doubled. In other words, half the amount of area would get in the same amount of oxygen if no surface active agents were present, or half the amount of oxygen coming in would transfer the same amount of oxygen. This fact has really been around for a long time, but nobody did anything about it. Nobody really got excited, particularly the public.

Surface active agents and detergents have excited the public a couple of times, the most notable one being the foam problem of the early 60's when the non-biodegradable type of surfactant was being used. It was common for a newspaper reporter to go down to the Chicago canal and take a picture of eight inches of foam. The point being that surfactants went right through treatment plants and foam built up. The public got stirred up thinking we were all going to be turning on our water spigots and have foam coming out — this kind of thing generated public interest. It was a glamorous problem to be working on because the public was so interested in it at the time.

In our study, we took a look at the several different classes of surface active agents that are commonly used in detergent formulations to see if there was a difference in the resistance that these different classes of compounds offered to gas absorption. If there is, this offers a real possibility of being able to increase the efficiency of secondary treatment simply by tailoring the structure of the molecule. This was essentially the study. We wanted to do a fundamental study, to take the pure surfactants, put these in a pure system, and measure a resistance at the interface. It was realized that the absolute number that we would come up with probably would not be correlated exactly, say to trickling filters and activated sludge units, but we wanted to find out if indeed there was a significant difference in the amount of the

resistance offered by these different molecules at the interface.

Our equipment was essentially a quiescent cell type of absorption apparatus in which we took a cell and put it in a certain quantity of water in which there was no convection, added a pure gas, and then measured the uptake by a manometer. There was a blank cell put on the system to compensate for temperature fluctuations. This is commonly known as a temperature compensated differential manometric absorption apparatus. What it really does is absorb gas under a condition that you can calculate mathematically. The partial differential equations can be derived to explain this equipment. We built the equipment, wrote the model, and compared the data to see if the pure gas does really absorb gas at the predicted rate. The next part was to put these pure surfactants in water. Because they are by nature surfactants, they collect at the gas-liquid interface. We could measure, using pure surfactants, the concentration that we had at the interface by measuring the surface tension. Gibbs' absorption isotherm then allows the surface tension to be related to the concentration of the various surfactants at this interface. The absorption experiments were repeated and the different resistances offered by the different surfactants were calculated.

One of the things that we wanted to study was the position of the so-called hydrophilic group on the surfactant. A surfactant can be modeled as having a head and a tail; the head likes water and the tail does not. The problem is that in the manufacture the tail might be placed on the end or in the middle; in fact, the surfactants that are being manufactured today have a distribution of this hydrophilic end along the hydrocarbon chain. It may be rather easy to change this. Nobody has ever had an incentive to change the manufacture to make sure that there is a high percentage of one or the other, but it was felt that this probably would make a difference in the resistance that the particular surfactant offers at the interface. None of the common ones, such as sodium lauryl sulfate where the sulfate was distributed along the hydrocarbon chain, could be obtained. Two very weak surfactants were selected: These were octanols, one in which the hydroxyl group was on the end, and one in which the hydroxyl group was in the middle. Hopefully then this would be representative of the more common surfactants. We did not really want to get into the synthesis of our surfactants, we wanted to be able to buy all the surfactants. In making our experiments we were able to determine the concentration of the surfactants at the gas-liquid interface and were able then to measure the resistance they offered. The normal octanol offered much less resistance at any given concentration than did the octanol in which the hydrophilic group was placed in the middle of the hydrocarbon chain. This has real implications as far as the efficiency of oxygenation goes

both in activated sludge and in trickling filters. The exact amount of oxygenation increase by going to a surfactant that has the hydrophilic group on the end of the chain cannot be specified, but certainly one can say that at a surface concentration of  $2 \times 10^{10}$  gm moles per square centimeter the resistance is about three times as great as for the surfactant in which the hydrophilic group is in the middle as opposed to the end.

The other classes of surfactants that we wanted to study are also commonly in use. The alkyl benzene sulfonates are certainly a very large volume surfactant. The alkyl sulfates among the anionic surfactants, and the alkyl amides (the non-ionics) are very high volume surfactants. So we used lauryl benzene sodium sulfonate, sodium lauryl sulfonate, lauryl diethanol amide, and lauryl diglycol amide; two non-ionics and two anionics. Cationic surfactants are not used very much in detergent and cleaner formulations. We were able to get these four different surfactants in a pure form in which the hydrophilic group was on the end of the hydrocarbon chain. We were not able to buy any of these surfactants with the hydrophilic group distributed along the hydrocarbon chain. We would have had to make these ourselves. Very interestingly, we found that there was a very wide difference between these surfactants. What came out rather unexpectedly was that as the molecular weight of the hydrophilic group increased, the resistance offered by the surfactant decreased. The hydrophobic portion was the same in all cases except one; a twelve chain carbon with 25 hydrogens, only the hydrophilic group was different. The only one that had a different hydrophobic chain was the one that had the benzene on it which is a hydrophobic group. It can be seen that as the molecular weight increases from the sulfonate to the sulfate to the diethanol amide to the diglycol amide, in every case the resistance goes down. This was totally unexpected. If the resistance had gone either way, we would have expected it to decrease with decreasing molecular weight. The really important point is that there is a big difference between the resistance offered at any given surface concentration between these four surfactants that are used in common detergent formulations.

This, then, is really the conclusion of the work. Where do we want to go from here and what do we do? The next logical step is to make a pilot unit and get some results as to what effects occur in gas uptake rates in activated sludge units. This cannot be done from our results. There is a great difference between these molecules and the oxygenation rate, and the next step is to test a pilot unit, possibly some type of an activated sludge unit. At that point, the next step would be to approach the detergent manufacturers.

**ADSORPTION OF ORGANIC COMPOUNDS ONTO  
SOLIDS FROM AQUEOUS SOLUTIONS**  
Project A-026-VA

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## ADSORPTION OF ORGANIC COMPOUNDS ONTO SOLIDS FROM AQUEOUS SOLUTIONS

The area of interest here is the use of solids to remove pollutants and, of course, this is not novel in the sense that solids are used for this purpose. The use of charcoal is well known and the use of alumina in phosphate removal has been reported in the literature. We have studied the removal of phenol from aqueous solutions on a variety of solids. The rationale for this study is as follows. An aqueous solution containing a pollutant (phenol) is a three component system consisting of a solute (phenol) and solvent (water) in contact with a solid. The question comes up, "What about the removal of the pollutant by the solid?" In many instances the kinds of solids that have been used are those which not only compete for the pollutant but also compete for water. Thus, we recognize that not only is the interaction between the pollutant and the solid important, but also the interaction between the water and the solid. In many systems, for example herbicides, insecticides, and phenol, you have a limited solute concentration; that is, you can only dissolve so much of the pollutant in water which means that there is a basic incompatibility in the system to start with. Then as this solution is put in contact with a solid surface, how much of the pollutant and how much water removed are relevant questions. If the solid has an attraction for water in addition to the pollutant, water may be removed and block parts of the solid which could be effective in removing the pollutant. This study has been concerned with aqueous solutions of phenol adsorbed on a range of solid surfaces.

A list of solids studied is shown in Table I arranged in order of decreasing interaction with water. Silica has a large affinity for water followed by carbon, Nylon, polyethylene, and Teflon showing the least affinity for water. One significant aspect of this study has been the use of polymers as solids on which possible interaction can occur. A lot of work in surface chemistry has been concerned with high surface area materials. Thus, activated charcoal has been used in water purification due in part to a high surface area.

The concept of surface area is important in adsorption from solution. Polymers, although having surface areas three orders of magnitude lower than charcoals (see Table I), may still be effective in pollutant removal since polymers do not have much interaction with water. The solids used in this study were characterized in several ways. First, surface areas were measured as shown in Table I. Contact angles ( $\theta$ ) of liquids against the solids were measured, as listed in Table II. The angle formed by a liquid droplet on a

solid is called the contact angle ( $\Theta$ ) and as you change the liquid, the contact angle also changes. If the liquid has a high surface tension it does not spread readily on the solid and thus gives a high contact angle. Dr. Zisman<sup>1</sup> at the Naval Research Lab has shown that if the cosine of the contact angle ( $\Theta$ ) is plotted against the surface tension ( $\gamma$ ) of the liquid, a linear plot results. Extrapolation to zero contact angle gives an intercept ( $\gamma_c$ ) which Dr. Zisman associates with the energy of a solid surface. Values of  $\gamma_c$  are shown in the last column of Table II.

Another series of measurements were the angles of contact not for different liquids, but for various concentrations of phenol solution against Alathon and Microthene. Figure 1 shows that with pure water or Alathon (zero phenol concentration) a high contact angle results, but as phenol concentration increases, the angle of contact decreases. It was interesting that one can differentiate between these two polyolefins using this method. Comparison of Figure 1 for Alathon with Figure 2 for Microthene shows that the initial contact angle of water was quite different. At increasing phenol concentrations the difference between the contact angles on the two solids is less.

A final method used to characterize the solids was infrared spectroscopy. The results are summarized in Table III for Alathon and Microthene. Again, these two polyolefins can be differentiated since a greater number of absorption bands are characteristic of Microthene.

The importance of characterizing the solid surface cannot be minimized. This has been a shortcoming in surface chemistry, and this is where some effort has gone in this study; different ways of trying to describe a solid surface so one can make some interpolation from the results of phenol on a limited series of solids to other solids.

The results for the adsorption of phenol from aqueous solution are now presented having discussed the characterization of the solids used. The first system shown in Figure 3 is a fairly classic one, that is, the adsorption of phenol from aqueous solutions on Graphon, a carbon black. The weight of phenol removed per unit weight of carbon is plotted as a function of phenol concentration; the curve represents uptake of phenol by this carbon surface. The uptake of phenol did not seem to be very temperature sensitive; these experiments were run over a 20-degree temperature range giving the same results. The results for the silica surface are shown in Figure 4 and we find again some characteristic uptake, although a maximum may be observed at No. 5. The polymers studied show more scatter in the adsorption data as

shown in Figure 5 for Microthene. The technique used to measure phenol uptake is a gas chromatographic one, and values along the abscissa correspond to very small quantities of phenol. This system exhibits a well characterized maximum and minimum followed by a rather sharp rise. At higher phenol concentrations, phenol is simply being pushed right onto the solid surface, and at low concentrations phenol is preferentially being taken out of solution. The results for Alathon shown in Figure 6 are similar to Microthene. The most scatter was observed for Teflon since one is working at the limit of detection of the gas chromatograph. Nylon gave unexpected results which is probably of some significance in adsorption studies. The first thing noted in Figure 7 is less scatter compared to other polymer surfaces. The linear relationship between the amount of phenol taken out and its concentration was not expected.

The results of the adsorption studies are summarized in Table IV. The amount of phenol adsorbed by all solids is compared at a relative concentration of 0.1. The trend is clear. Nylon takes out the most phenol down to Teflon which takes out the least on a weight basis. However, as commented above, the comparison should be made on a surface area basis not on a weight basis. Since the surface areas were known, the amount of phenol removed by the solids can be expressed on a unit area basis as done in the last column of Table IV. Some interesting reversals in the amounts of phenol which are taken out are apparent. The removal of phenol by nylon is anomalously high followed by interestingly enough the polyolefins, Alathon and Microthene, then carbon and Teflon (although Teflon may be an invalid case due to the extreme scatter in the data) and finally by silica which had the highest surface area. In other words, on a unit area basis, silica takes out the least amount of phenol. This is reasonable because water is competing for the sites on silica that phenol would otherwise be taking up.

In summary, this type of study suggests that polymers, although low surface area materials, represent potentially useful solids for removing pollutants.

#### References

1. Zisman, W. A., *Advances in Chemistry Series No. 43*, pp. 1ff, Am. Chem. Soc., Washington, D. C. (1964).
2. Krimm, S. et al., "Infrared Spectra of High Polymers. II Polyethylene," *J. Chem. Phys.*, 25:549 (1956).

TABLE I  
SAMPLE CHARACTERISTICS AND SURFACE AREAS

Type	Name	Lot No.	Supplier	Surface Area (m <sup>2</sup> /g)
Silica	Cab-O-Sil	-	Cabot	223.
Carbon	Graphon	-	Cabot	87.
Nylon	Aviamide-6	CRD-9455	FMC Corp.	1.5
Polyethylene	Microthene FN-510	-	Gulf	0.35
	Alathon Fluff	810253	DuPont	0.10
Teflon	Teflon-6	10295	DuPont	2.5

TABLE II  
CONTACT ANGLES OF TEST LIQUIDS ON POLYMERS

Liquid	Run No.				Avg.	$\gamma_c$ (ergs/ cm <sup>2</sup> )
	1	2	3	4		
MICROTHENE FN-510						35.
Water	83°	87°	82°	80°	83°	
Glycerol	67	89	74	82	78	
Formamide	69	82	67	76	74	
Ethylene Glycol	69	62	67	63	65	
Aniline	49	41	53	48	48	
Bromobenzene	28	(9)	20	28	25	
ALATHON						31.5
Water	89°	89°	88°	90°	89°	
Glycerol	88	89	(78)	88	88	
Formamide	80	80	86	90	84	
Ethylene Glycol	72	72	72	77	73	
Aniline	41	44	43	40	42	
Bromobenzene	27	24	38	28	29	

TABLE III  
PROVISIONAL ASSIGNMENTS OF ABSORPTION BANDS OF POLYETHYLENE

Wavenumber ( $\text{cm}^{-1}$ )	MIR(X1)		MIR(X10)		Assignment <sup>2</sup>
	Microthene FN-510 (No. 25-1)	Alathon	Microthene FN-510 (No. 33-1)	Alathon	
3100			X		(CH <sub>3</sub> ) stretch
2960			X <sup>a</sup>		
2920				X <sup>b</sup>	(CH <sub>2</sub> ) stretch
2900	X	X		X <sup>b</sup>	
2850	X	X	X <sup>a</sup>	X <sup>b</sup>	(CH <sub>2</sub> ) stretch
1500			X		(CH <sub>2</sub> ) bend
1450	X	X	X <sup>a</sup>	X <sup>b</sup>	
1190			X		(CH <sub>2</sub> ) wag
1100			X		
710-20	X	X	X	X <sup>b</sup>	(CH <sub>2</sub> ) rock

<sup>a</sup>present also in pressed sample  
<sup>b</sup>present also in melted sample

TABLE IV  
COMPARISON OF ADSORPTION CAPACITY FOR PHENOL  
AT A RELATIVE CONCENTRATION OF 0.1

Solid	g phenol/g solid	g phenol/m <sup>2</sup> solid
Aviamide	$6 \times 10^{-2}$	$4 \times 10^{-2}$
Graphon	$3 \times 10^{-2}$	$3 \times 10^{-4}$
Cab-O-Sil	$7 \times 10^{-3}$	$3 \times 10^{-5}$
Alathon	$8 \times 10^{-4}$	$8 \times 10^{-3}$
Microthene	$6 \times 10^{-4}$	$2 \times 10^{-3}$
Teflon	$5 \times 10^{-4}$	$2 \times 10^{-4}$

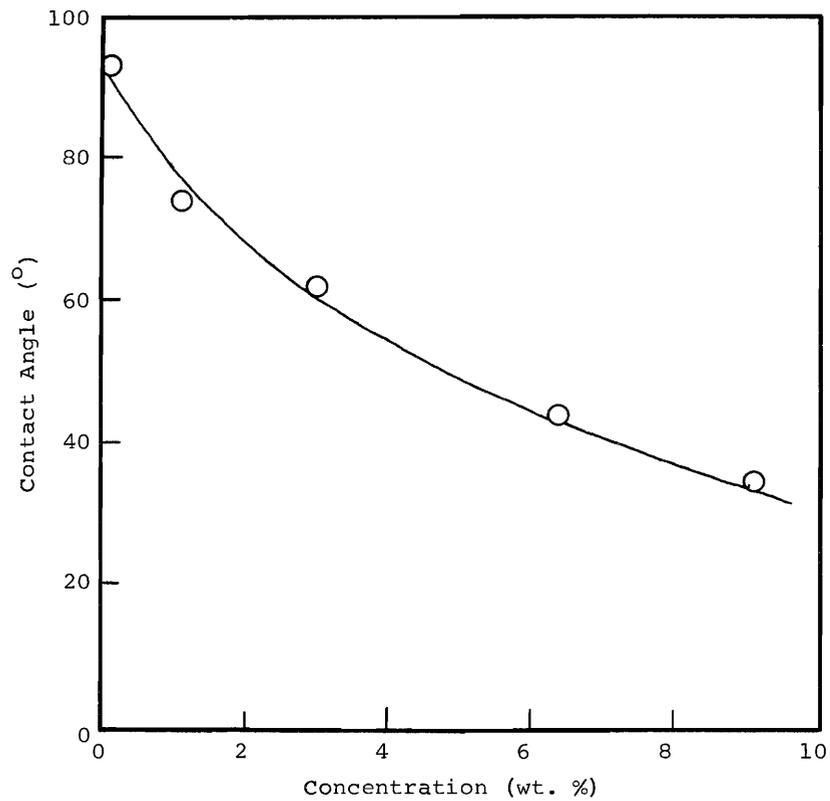


Figure 1. Contact angle vs. concentration of phenol solutions on Alathon.

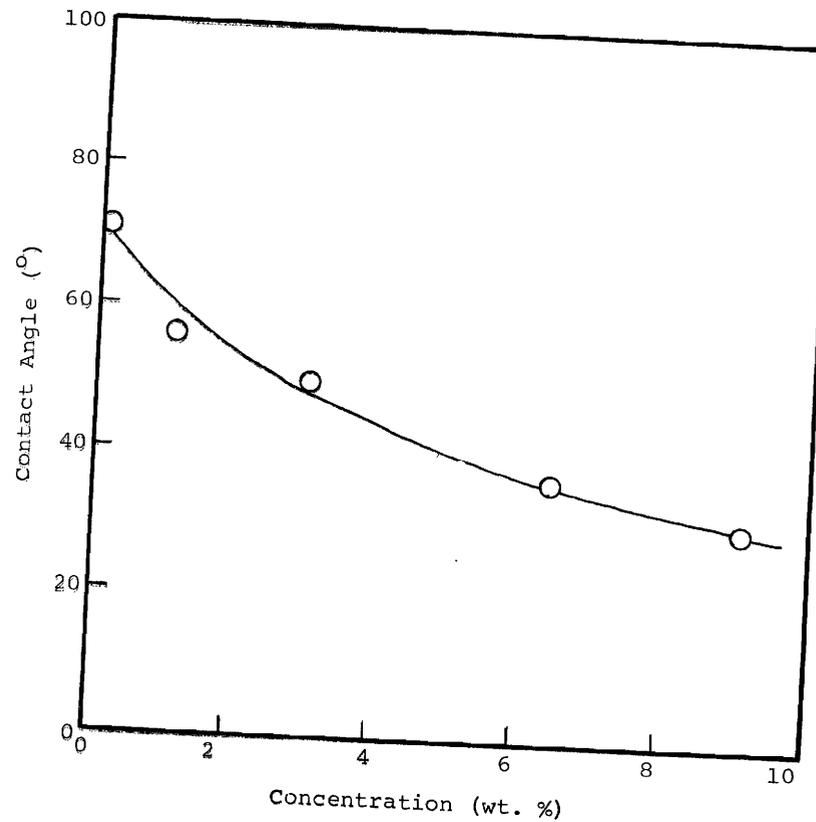


Figure 2. Contact angle vs. concentration of phenol solutions on Microthene FN-510.

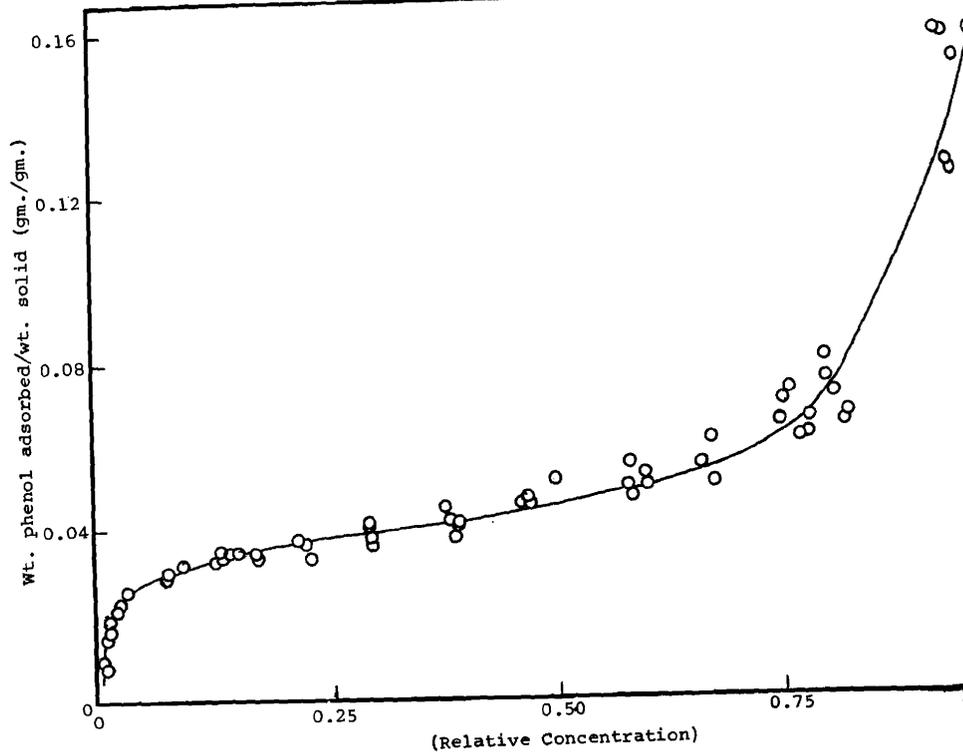


Figure 3. Adsorption of phenol from aqueous solution on Graphon at 25°C.

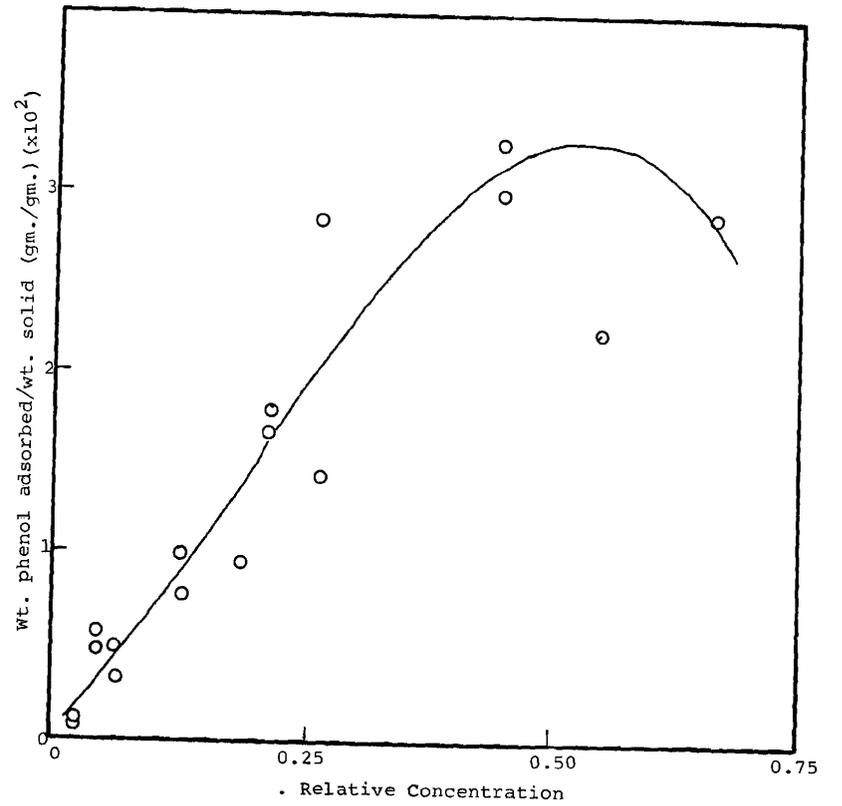


Figure 4. Adsorption of phenol from aqueous solution on Cab-0-Sil at 25°C.

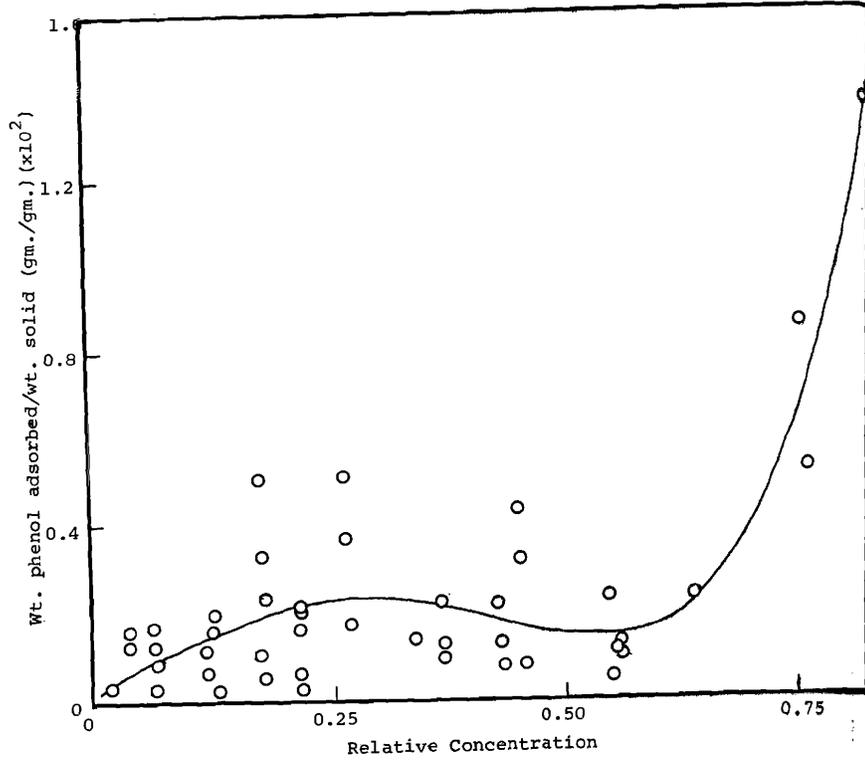


Figure 5. Adsorption of phenol from aqueous solution on Microthene-FN 510 at 25°C.

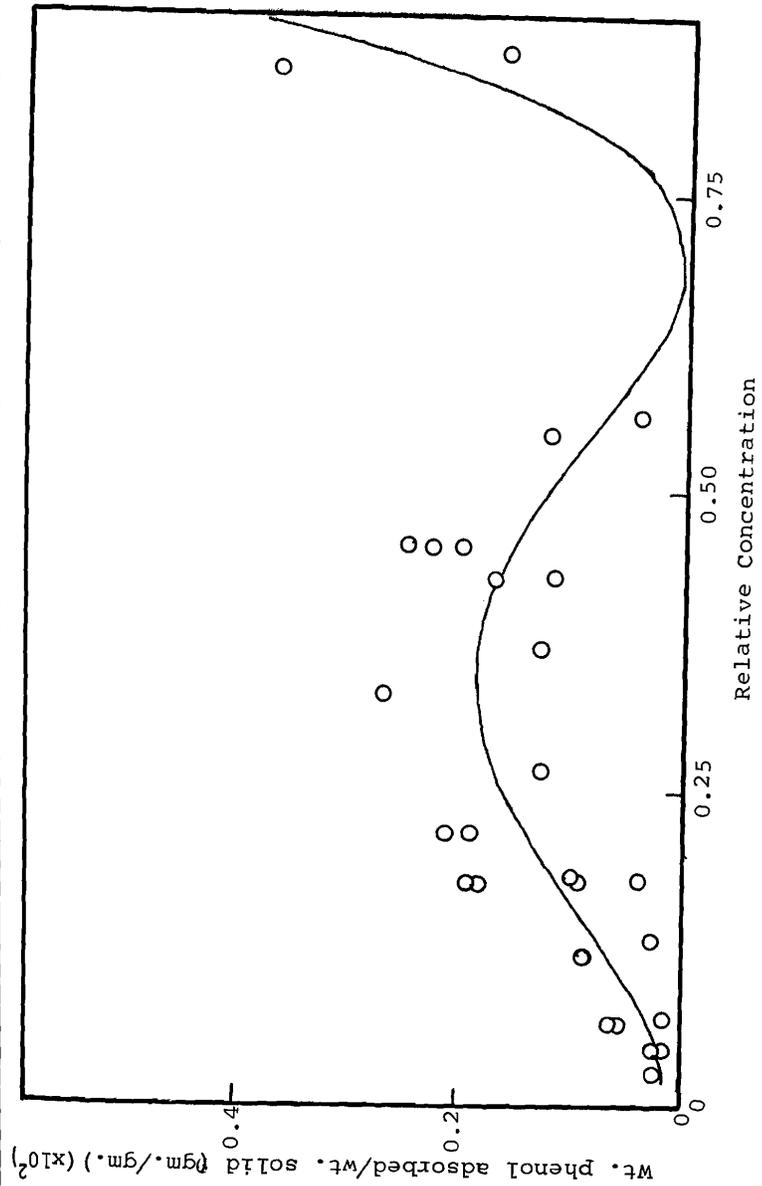


Figure 6. Adsorption of phenol from aqueous solution on Alathon at 25°C.

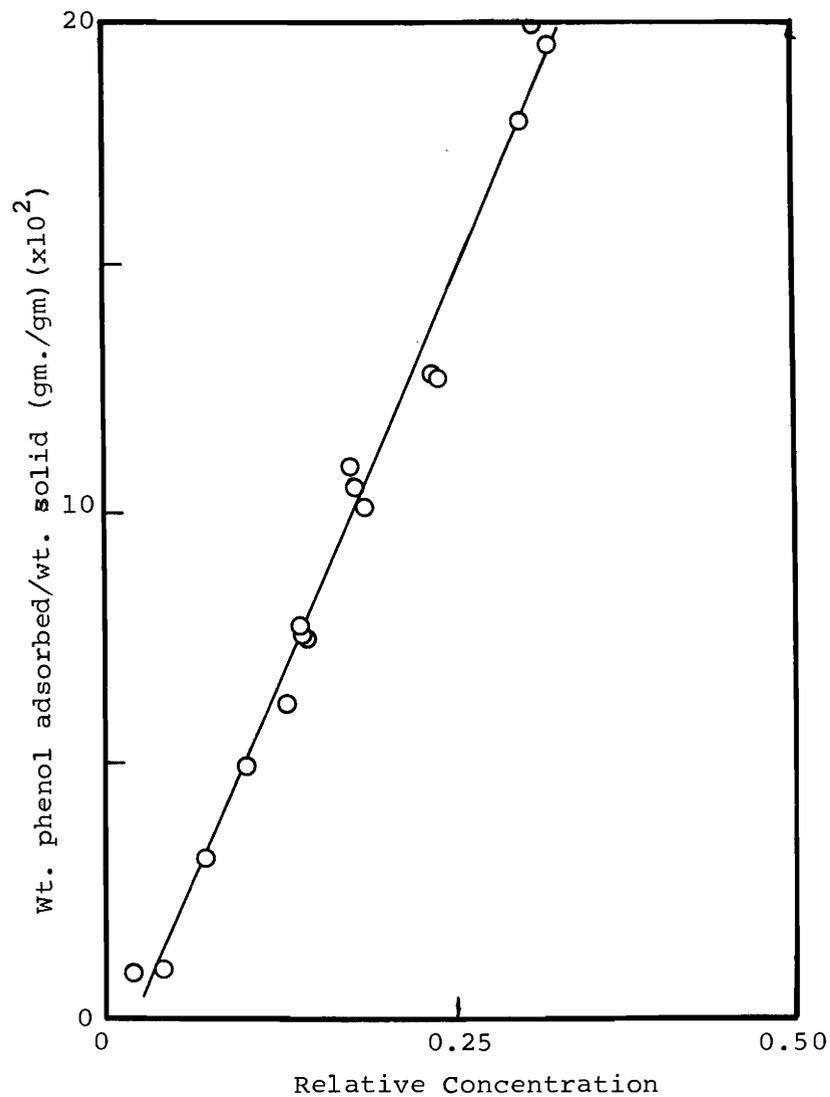


Figure 7. Adsorption of phenol from aqueous solution on Aviamide at 25°C.

INVASION OF THE AQUATIC HABITAT  
 BY AMPHIBIOUS SPECIES OF POLYGONUM  
 Project A-028-VA

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 December 1970

## INVASION OF THE AQUATIC HABITAT BY AMPHIBIOUS SPECIES OF POLYGONUM

This is the second and final yearly report on a study of aquatic smartweeds (Polygonum) which can be aggressive invaders of shallow waters of lakes, estuaries, and slow moving streams. A much more detailed account of the findings of this project will be published as Bulletin 41 in the near future.

Since Polygonum seeds are a valuable food for waterfowl, they are often purchased by hunting clubs and other owners of lakes for planting at the water margin. The smartweeds grow in the shallow water where there is usually little competition from shoreline grasses or weeds, and in summer and fall they shed their seeds which float at the surface and are easily available for feeding ducks and other water birds.

Polygonum species must not be planted indiscriminately, however, since some species can become weed pests and spread into fields and gardens, while others have amazing capabilities for spreading over the entire water surface in a matter of months and taking over the lake. This study was conducted to determine which species have these various capabilities and to rank them accordingly.

Polygonum amphibium var. stipulaceum is an extremely aggressive invader of lakes, and was of prime interest in this study. One of the most striking features of these plants is the tendency toward a prostrate growth habit accompanied by shortening of internodes. This is most extreme in the land-form of the plant found growing on dry soil and sandy banks after the water level recedes. In the author's publication (Mitchell, 1968) it was shown that prostrateness and internode length were correlated with drier habitats and light colored substrates in a sample of 20 populations in the field. At that time it was hypothesized that substrate-reflected light might play a role in inducing the "sand dune response."

To test this hypothesis ten clones each of P. amphibium (amphibious variety), P. amphibium (varietal intermediate), and P. amphibium (non-amphibious variety) were tested along with clones of P. opelousanum in the following manner: 20 ramets of each clone were divided equally between two treatments. All shoots were placed into trays in a horizontal position with their roots surrounded by moistened artificial soil (BR-8, American Can Company). Half the shoots were placed over filter paper blackened with india ink while the other half were above white filter paper. Trays were placed in

growth chamber facilities for 48 hours with constant illumination (2000 foot-candles) and constant temperature (70°F). At the end of the period measurements of shoot curvature were made. Each shoot was then rotated such that it was horizontal once more and lights were cut off. After 48 hours of darkness measurements were made again and compared with those from the illuminated treatment. Controls and duplicate experiments were run simultaneously.

Results of these experiments may be expressed as follows:

1. The difference of 400 foot-candles reflected from a white substrate and 7 foot-candles reflected from a black substrate produced no significant differences in the curvature of shoots, even though they were oriented horizontally.
2. The mean curvature of shoots under 2000 foot-candles continuous illumination was:

Angle of curvature

<u>P. amphibium</u> (amphibious) .....	43.5°
<u>P. amphibium</u> (intermediate) .....	51.4°
<u>P. amphibium</u> (non-amphibious) .....	90.0°
<u>P. opelousanum</u> .....	64.5°

3. In total darkness for 48 hours the responses of the same shoots were evidenced by greater upward curvature, indicating that the curvature is not primarily a photo-response, and that the upward curvature of shoots is inhibited by light. The differences between curvatures in dark versus light treatments match the data above in that amphibious plants are the most sensitive to the inhibitory effect of light upon upward bending:

Dark treatment versus light

<u>P. amphibium</u> (amphibious) .....	+21.3°
<u>P. amphibium</u> (intermediate) .....	+15.0°
<u>P. amphibium</u> (non-amphibious) .....	0.0°
<u>P. opelousanum</u> .....	+ 6.5°

Although much further study is needed before the physiological aspects of this problem can be adequately explained, this study appears to indicate that prostrateness is partly genetically controlled and partly a function of inhibition of negative geotropism by light. This inhibition operates most strongly on amphibious plants, with greater phenotypic plasticity, and does not operate on strongly erect plants of the non-amphibious variety of the same species. Substrate reflected light seems to have played little or no role under the light intensities used in this study.

The major phase of the work was a series of submergence experiments carried out in temperature-programmed environmental chambers (Sherer, CEL 25 HL). An aquarium was placed in each growth chamber and filled with water. In addition to the recording programmer, a dual probe thermograph recorded air and water temperatures simultaneously within each chamber.

In an attempt to simulate natural conditions as nearly as possible, yet maintain a controlled and repeatable scheme, a "summer day" program was designed. This consisted, first, of a light regime based on a 15-hour day, in which the first and last hour of the period were furnished only by incandescent lamps (simulation of dawn and twilight). In simulated full daylight the incandescent and fluorescent banks produced 6000 foot-candles at a distance of 12 inches from the bulbs. The temperature rose 10°F each hour to reach 92°F at noon, where it remained constant until 4 pm. At this time it began to decrease by 5-degree increments until midnight when it stabilized at 55°F. This program is shown graphically in Figure 1.

The purpose of the experiments was to test Polygonum populations for their amphibious responses to submergence under controlled conditions. An experiment proceeded as follows: twenty shoots per population were separated into sets of two ramets per clone. Soil was removed from the roots, and they were grown for six days under fluorescent lamps in the laboratory on artificial soil.

A control consisted of twenty shoots transferred to the growth chamber in pans where the substrate was kept water-saturated. An identical set of clones was placed in the aquarium and covered with water such that the tips of the plants were eight inches below the surface. After 30 days a complete set of measurements was made on all ramets and leaves and stems were pickled for a complete anatomical study.

Survival of inundated shoots was unexpectedly high in the growth chambers under the "summer day" program. Even those shoots which never reached the water surface remained green and living—in many cases after 30 days under water. Shoot mortality was over 50 percent in only three of the 23 populations studied, and 17 populations showed no mortality at the end of the experiment. Control populations often showed more than 100 percent survival due to vegetative reproduction.

Over 5000 measurements were made on both vegetative responses and internal anatomical responses to submergence in the 23 populations studied. Responses which indicated adaptation to the aquatic environment were scored, and the cumulative scores of populations put into the form of a histogram (Figure 2). In this "cumulative index of quantitative response" (Mitchell, 1968) high scoring populations showed the maximum adaptation to submergence, while low scoring ones exhibited few characteristics which aided their survival in the aquatic habitat.

The practical aspect of this work has been to establish some general guidelines for the planting of different species of Polygonum. Emergent Polygonum species have a tolerance for stable water depths of around three feet. Since they spread by rhizomes, they can eventually fill a body of water which is mostly shallower than three feet. They are ideally planted (if they do not already occur naturally) on lake margins where the shallows are not extensive, unless the desired effect is to produce large populations. Amphibious Polygonum (P. amphibium var. stipulaceum and varietal intermediates) grows primarily as a rooted plant, but can withstand depths of eight feet and still produce floating leaves. Also, it frequently breaks away from the substrate and forms large floating mats. In this way amphibious Polygonum can come to dominate a large aquatic ecosystem in a rather short time.

For those persons interested in the use of Polygonum species in lakes, the following recommendations may be made:

1. Polygonum punctatum Ell. Highly recommended as a shoreline plant; seed production is prolific, and plants rarely form floating mats, except for some southern populations.
2. P. hydropiperoides Michx. Highly recommended, but seed sources should come from coastal plain races, not from stream bed and ditch habitats where populations appear poorly preadapted to withstanding fluctuations of water level. Also a prolific seed producer.

3. P. robustius Fern. A good plant, closely related to P. punctatum. Seeds are not readily available, however, and the plants are more robust, producing fewer seeds per plant.
4. P. opelousanum Ridd. Highly recommended, close relative of P. hydropiperoides. These plants seem to do best on the coastal plain where they are prolific seeders.
5. P. hirsutum Walt. Recommended with reservation. This species has much vegetative growth with fewer seeds, and it is adapted to climates where there is not a hard freeze in winter.
6. P. setaceum Walt. Recommended with reservation. This coastal plain species shows little preadaptation to survival of water level fluctuations under which plants might be periodically inundated.
7. P. densiflorum Meisn. Not recommended. This is a very large relative of P. punctatum which produces few seeds per unit of dry weight. It is also a potential invader of deeper waters, being found most frequently in the water rather than on the bank. This species scored highest on the amphibious scale (Figure 2) except for P. amphibium itself.
8. P. amphibium var. emersum Michx. Not recommended. This non-amphibious plant does not invade deep water situations; however, it has become a pest in agricultural areas where soil is continually moist. In rice fields of California it is called "Devil's shoestring."
9. P. amphibium var. stipulaceum Colem. and intermediates between this variety and the one previously listed are not recommended for planting in lakes and reservoirs, due to their unusual capabilities for spreading over the entire water surface. Horizontal stems up to 15 feet long can be produced by a single plant, and these can fragment to produce many new plants. Growth chamber studies showed exceptional capabilities of some clones to withstand inundation and to thrive once the shoots attain the water surface.
10. P. pensylvanicum L. Not recommended due to the fact that it is a giant annual which can easily become a garden pest.

11. P. persicaria L. This species and P. lapathifolium L. are European plants which are now common weeds of our waterways and wet pastures. They are good seed producers, but are known for their aggressive invasion of any moist, disturbed site.

Reference

Mitchell, Richard S. (1968) "Variation in the Polygonum amphibium Complex and Its Taxonomic Significance"; University of California Publications in Botany; 45:1-65.

FIGURE I

"SUMMER DAY" TEMPERATURE AND LIGHT PROGRAM

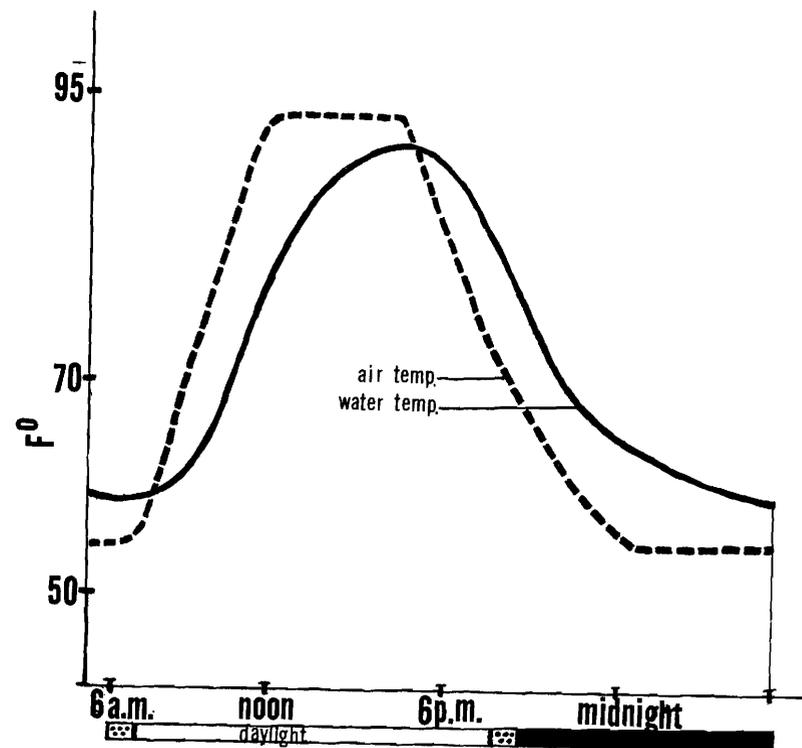
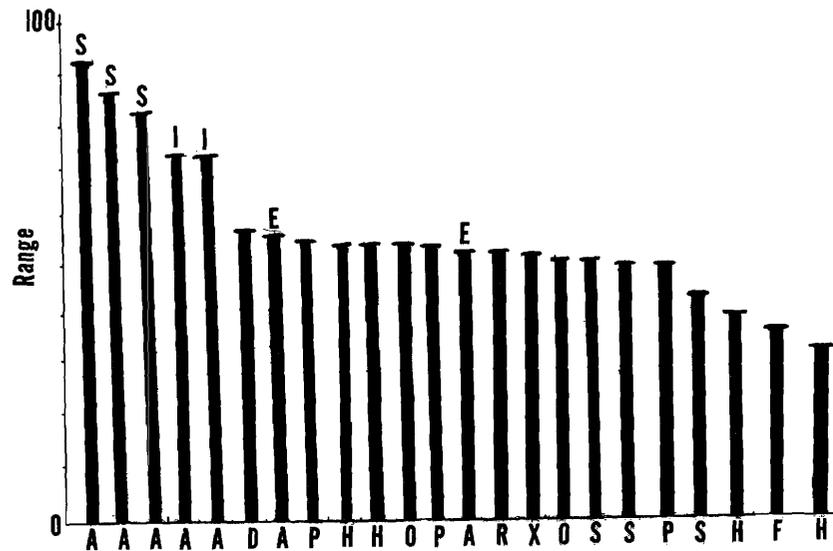


FIGURE 2  
INDEX OF RESPONSE CHART



Note: The chart shows the cumulative index of quantitative responses of Polygonum populations to submergence in growth chamber experiments. A high cumulative score indicates preadaptation to the aquatic environment.

Key: Species names are coded by a letter at the base of each histogram column, and varieties are presented by a letter at the top.

A - Polygonum amphibium  
 Varieties: S - stipulaceum; E - emersum; I - intermediate  
 D - P. densiflorum; F - P. fusiforme; H - P. hydropiperoides;  
 O - P. opelousanum; P - P. punctatum; R - P. robustius;  
 S - P. setaceum; X - P. hirsutum

ECONOMIC DISPOSAL OF WASTE SLUDGES  
 FROM WATER TREATMENT PLANTS  
 Project A-030-VA

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## ECONOMIC DISPOSAL OF WASTE SLUDGES FROM WATER TREATMENT PLANTS

Initial studies were aimed at characterization and conditioning procedures pertaining to alum sludges. Particular attention was given to conditioning sludges by use of synthetic organic polyelectrolytes. Such polyelectrolytes have been successfully used as aggregating agents in water and waste treatment and for sewage sludge conditioning. In this investigation polyelectrolyte conditioning of water plant sludges was shown to increase their dewaterability greatly.

The principal material investigated was alum sludge collected from the coagulation basin at the Blacksburg-Christiansburg-Virginia Polytechnic Institute and State University Water Authority Water Plant. One-liter sludge samples were conditioned with various anionic, cationic, and nonionic polyelectrolytes. The dewaterability of each sample was determined by the Buchner funnel specific resistance test. The variables affecting polyelectrolyte conditioning such as pH, agitation, solids content, and time of addition of coagulant aid were investigated. The final phase of the polyelectrolyte conditioning investigation included bench scale sand bed studies comparing the dewaterability of conditioned and unconditioned alum sludges.

The mechanisms involved in polyelectrolyte conditioning were postulated with the aid of zeta potential determinations. The bridging theory described by LaMer and co-workers satisfactorily described the mechanisms involved. In brief, the bridging theory postulates that solid particles are held together by polymer bridges which form a loose floc structure that permits rapid dewatering.

Acidification of alum sludge (2 to 3 percent solids by weight) reduced the volume of solids over 50 percent in less than one hour. Polyelectrolyte conditioning of the acidified samples was shown to increase the rate of solids volume reduction many-fold and reduce the volume of solids even more than acidification alone. The polyelectrolyte conditioned sludge dewatered readily. The supernatant contained over 1500 ppm aluminum which could be substituted for commercial alum.

Freeze and thaw studies on alum sludge (2 to 3 percent solids by weight) reduced the volume of solids over 80 percent to a total solids concentration of 18 percent. The supernatant was of excellent quality for recycle. Upon

thawing the solids dewatered readily and dried to a consistency like that of sand. The dried sludge could be handled easily.

All three of the methods investigated offer considerable promise for water plant sludge disposal. The results could definitely have an important influence on the design, cost, and operation of water treatment plants. In particular it is shown that polyelectrolyte conditioning and disposal of alum sludges may normally be accomplished for approximately \$5.00 per million gallons of water treated.

Tests were also performed on samples taken from a water treatment plant waste lagoon. The purpose of testing was to determine lagoon effectiveness in producing an effluent of acceptable quality and to appraise design parameters and operational and economical aspects for lagoon disposal of water treatment plant wastes. Testing consisted of standard residue and BOD tests on filter washwater and lagoon effluent, and drainability tests conducted on samples of settled sludge.

It was found that the lagoon produced a stable effluent of good quality, relatively low in solids, and having a five-day BOD of less than 5 mg/l. Dewatering of hydroxide sludge was deemed the most difficult phase of lagoon disposal. However, sludge which had been frozen was readily drained. It was also determined that lagoons should not be used for permanent storage and that shallow lagoons would best permit natural freezing of sludge. Lagoon effluents are normally suitable in quality for recirculation to raw water intakes.

Research is now being continued on the conditioning of iron sludges by use of various polyelectrolytes. The sludge used in the initial study was obtained from the Carvens Cove water treatment plant of the city of Roanoke. The effect of such variables as polymer dose, pH, mixing time, and solids concentration on the overall dewatering process is currently being evaluated.

Future work will be aimed at extending the work conducted on alum and ferric sludges to include studies on the conditioning of the sludges generated in lime-soda softening processes. In addition, further work aimed at elucidating the mechanism responsible for the evident improvement in sludge drainability associated with polyelectrolyte conditioning will be conducted. The feasibility of lime and ferric ion recovery will also be explored.

**A PRE-IMPOUNDMENT ECOLOGICAL STUDY  
OF THE BENTHIC FAUNA AND WATER QUALITY  
IN THE NORTH ANNA RIVER**  
Project A-031-VA

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**A PRE-IMPOUNDMENT ECOLOGICAL STUDY  
OF THE BENTHIC FAUNA AND WATER QUALITY  
IN THE NORTH ANNA RIVER**

The information gathered thus far on existing water quality conditions within the pre-impoundment basin shows a distinct contrast of characteristics above and below the entrance of Contrary Creek. Below the entrance, the river has not yet fully recovered from the polluting effects of the extensive mining operations. Moreover, there is a constant drainage of substances (acid, heavy metals, and silt) from the slag piles along the banks of the creek. The acid waste has depleted much of the vegetation in the creek bottom of Contrary Creek which allows extensive erosion during normal rainfall periods. On the upstream side of this entrance, the water quality of the river is very good, except for an occasional high coliform count. However, even in this area of the pre-impoundment basin, the river suffers a natural deterioration due to the lack of extensive riffle areas.

Most of the pre-impoundment basin frequently exhibits a high coliform count of bacteria which would prohibit primary contact recreation. The high bacterial population appears to be maintained by drainage from livestock areas along the river. Precipitation in the pre-impoundment basin is always reflected in increased coliform densities, especially in the downstream vicinity of known livestock areas.

The results of the study thus far support the observation that VEPCO is building their impoundment on the most suitable piedmont river because, ecologically speaking, the water quality is such that other potential uses have been eliminated. The presence of the impoundment will in all probability enhance the future water quality of the North Anna River Basin. There are potential biologically oriented water problems which may manifest themselves (i.e., bacteriological, siltation from Contrary Creek, etc.), but these are not insurmountable.

General Procedure

Sediment samples will be collected by a heavy walled metal cylinder with a known collecting volume. The samples will then be subjected to a standard sieve fractionation analysis (Cummins, 1962) on a Ro-Tap Shaker. In addition to standard analysis for coliforms, tests will also be performed on the samples for fecal streptococci by using BAGG broth.

During the second year of this project, emphasis will shift to Holiday Mill Pond, a small impoundment in the upper reaches of the North Anna River. Efforts will be made to characterize the limnetic parameters of this body of water with the idea of predicting the future limnetic properties of the main impoundment.

**ELECTROCHEMICAL ACTIVATION AND REGENERATION  
OF CARBON SURFACES FOR TERTIARY WATER TREATMENT**  
Project A-032-VA

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## ELECTROCHEMICAL ACTIVATION AND REGENERATION OF CARBON SURFACES FOR TERTIARY WATER TREATMENT

### Objectives

The objectives of this project are:

- (a) To develop an electrochemical procedure for activating carbon surfaces for use in waste water renovation.
- (b) To study in detail the processes responsible for the activation observed in (a).
- (c) To investigate the feasibility of electrochemically oxidizing pollutants absorbed on activated carbon surfaces.

### Summary

A thorough literature review has been completed. Objective (a), the development of an activation procedure, is substantially completed. Equipment and procedures have been perfected for activating carbon surfaces and quantitative methods have been worked out for measuring the resulting enhancement of the absorptive capacity of the carbon surfaces. Using these procedures, a number of different types of carbon have been successfully activated and increases of several orders of magnitude have been observed in their absorptive capacities following treatment.

Objective (b), a study of the mechanism of activation, has been partially completed. X-ray diffraction studies of treated and untreated carbon samples show that there is a sharpening of the distribution of lattice spacing following treatment. It has also been found that while a non-aqueous hydrocarbon film on the carbon surface is usually essential for successful activation, activation with no film was successful with one type of carbon.

### Experimental Results

Surface areas of carbon samples were increased by anodically electrolyzing in 20 percent by weight hydrochloric acid. Currents ranging from 0.05 amperes to 0.35 amperes and temperatures between 20 and 30°C were employed and changes in polarization curves were used as a measure of the relative change in

surface area of the carbon samples. Relative increases in surface area of 450 percent or greater were considered significant.

The technique of voltammetry at continuously changing potential was employed for the anodic polarization measurements. This procedure entailed the use of a potentiostat programmed with a time-potential ramp function of one volt per minute (0.167 volts per second) and an X-Y recorder to record the polarization curves.

The tests were conducted on the following four types of carbon:

- (1) Union Carbide Carbon, Catalog N. 52306
- (2) "Graphitar" Grade 18 Carbon
- (3) "Graphitar" Grade 39 Carbon
- (4) "Graphitar" Grade 2690 Carbon

The carbon from Union Carbide was fairly porous while the "Graphitar" type carbons were considerably less porous and were designed for mechanical uses.

Prior to any polarization measurement or anodic electrolysis, each sample was pre-treated in one of the following ways: (1) sample was saturated with n-dodecane, (2) sample was saturated with carbon tetrachloride, (3) sample was covered with paraffin, or (4) sample was not pre-treated.

The results of this investigation have led to the following conclusions. The surface area of "Graphitar" type carbons, Grade 18 and Grade 2690, saturated with n-dodecane, was significantly increased due to the electrolytic treatments. Likewise, the surface area of the porous carbon from Union Carbide, pre-treated with paraffin, was significantly increased as a result of the electrolytic treatment. Finally, the surface area of the "Graphitar" Grade 2690 carbon, with no pre-treatment, was significantly increased due to the electrolytic treatment.

Investigation of the feasibility of electrochemically oxidizing pollutants absorbed on activated carbon remains to be accomplished. The radioactive counting equipment for use in meeting this objective has recently been installed and tested but no further progress has been made.

Future work on this project will be centered on testing activated carbon samples for use in tertiary water treatment and on studies of electrochemical oxidation of absorbed pollutants.

**BIOLOGICAL AND CHEMICAL STUDY  
OF VIRGINIA'S ESTUARIES**  
Project B-003-VA

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Virginia Polytechnic Institute  
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Blacksburg, Virginia  
December 1970

## BIOLOGICAL AND CHEMICAL STUDY OF VIRGINIA'S ESTUARIES

Virginia's estuaries are dynamic systems characterized by high levels of instability. The reaches near Chesapeake Bay are the most stable since they are least affected by variations in freshwater inflow from the tidal river. The middle reach encompasses the gradient zone in which the water may be completely fresh during extremely high discharge periods and approach 17<sup>0</sup>/<sub>00</sub> or 50 percent seawater during drought conditions. The location of the transition zone between fresh and salt water also shifts with discharge levels and may vary as much as 20 miles upstream and downstream from the "average" point within a season.

The salinity structure in the James estuary is relatively compressed longitudinally, whereas the structure in the Rappahannock is extended. During low flow summer months the 15<sup>0</sup>/<sub>00</sub> isohaline may be as much as 20 miles upstream from the 20<sup>0</sup>/<sub>00</sub> isohaline in the latter system. Differences were also noted in the vertical structure of these systems both within and between seasons and years. This appeared to be influenced by Bay salinities, temperature, and freshwater discharge volume levels.

Dissolved oxygen levels in Virginia's three major estuarine systems did not approach sub-minimal values during the study period. An oxygen sag zone was noted in the vicinity of Mile 30 in the York River, a source of kraft process pulp and paper mill effluent. Low values were also recorded in the James River for one month where the location of the transition zone moved upstream into the oxygen sag zone produced by the industrial complex at Hopewell.

Virginia's estuarine waters are slightly alkaline with no significant differences in pH either within or between systems. The alkalinity values, however, differ both within and between estuaries with all three systems increasing in buffering capacity from the transition zone to the mouth, a relationship directly proportional to salinity. The James estuary had the highest buffering capacity, the York was intermediate, and the Rappahannock was the lowest.

Nitrogen and phosphorus nutrient levels and chemical states of the nutrients varied widely within systems within months and years and between systems. Total nitrogen levels generally reflected the upstream loadings with the James estuary usually showing the heaviest enrichment. A relationship between freshwater discharge levels and total nitrogen could be established for the

James estuary; however, this relationship did not hold for the relatively unenriched York or the moderately enriched Rappahannock. Also, in the James estuary the relatively high levels of the oxidized forms of nitrogen in the oligohaline reach were indicative of the source. During 1968 the particulate organic nitrogen levels did not indicate that the available nitrogen was being utilized by aquatic plants within the estuary, whereas in 1969 the organic levels increased as the inorganic levels decreased. Nitrogen levels and forms in the York and Rappahannock estuaries varied within stations between years and no definite correlations could be established. Nitrogen levels in the range capable of contributing to the development of algal populations sufficient to produce aquatic nuisance conditions and environmental degradation were not recorded in Virginia's estuaries during the study period.

Total phosphorus values in the James estuary were generally higher than those observed in the York and Rappahannock. Reactive phosphorus levels in the James and York showed a definite shift with seasons. Values were usually highest in the oligohaline areas during the winter and spring and in the lower reaches during the summer and fall. The ratio of particulate unreactive phosphorus to the other forms was usually higher in the York and Rappahannock than in the James.

All systems, but especially the James, consistently contained the lowest phosphorus levels in the middle reach. This may be the result of the action of temporary turbidity produced by wind action, settling after winds subside, and "coprecipitating" organic material containing high phosphorus levels.

Estuarine sediments contain on the order of  $10^3$  higher nutrient levels than the overlying water column. James estuarine sediments contained the highest nitrogen concentrations in the upper reach and the concentration decreased towards the mouth; no pattern could be established for the York; the Rappahannock was similar to the James except for an increase near a possible source at Mile 13. The sediment phosphorus levels were similar to those described for sediment nitrogen except that the Rappahannock values were more uniform from mouth to transition zone.

Calculations based upon the organic matter content as indicated by the loss on ignition and nutrient levels indicate a direct relationship between organic matter content and nitrogen content ratios at all stations in the three systems. This correlation did not exist for phosphorus.

Phytoplankton levels as indicated by chlorophyll "a" concentrations in the middle and lower reaches of the three estuaries were usually below  $10 \mu\text{g l}^{-1}$ . Levels in excess of  $50 \mu\text{g l}^{-1}$  are considered to indicate over-enrichment. Values exceeding  $100 \mu\text{g l}^{-1}$  have been measured in the degraded freshwater tidal section of the James River. Concentrations of chlorophyll "a" were usually higher in the York estuary than in the highly turbid James and the Rappahannock although the latter system indicated a higher level of stability than the other two.

No relationship could be established between concentrations of the oxidized forms of nitrogen and phosphorus and the standing crop of phytoplankton. Chlorophyll "a" values were higher in the York estuary during the "wet" year of 1969 than in the "dry" year of 1968 but this difference was not significant in the other two estuaries. With the exception of the summer of 1969 in the York, the levels varied greatly between stations within estuaries and within stations between estuaries.

The generic composition of the phytoplankton also showed high levels of variability. Filamentous Chlorophyta and Cyanophyta genera were usually dominant at the transition zone but were replaced by salt water forms in the estuary. Thalassiosira, Skeletonema, Nitzschia, and Cryptomonas were recorded most frequently from the estuarine stations.

**EFFECTS OF RESERVOIR OPERATING POLICY  
ON RECREATION BENEFITS**  
Project B-009-VA

Dr. Paul H. King  
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Water Resources Research Center  
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Blacksburg, Virginia  
December 1970

## EFFECTS OF RESERVOIR OPERATING POLICY ON RECREATION BENEFITS

In recent years the attention given recreation in multiple purpose water resource development has increased dramatically. However, because of their very nature, the benefits and losses accruing to such projects from recreation, or the lack of it, have been extremely difficult to quantify. One of the factors that affects recreation benefits is the fluctuation in the water level of the impoundment. It is taken as a general rule of thumb that drawdown decreases the recreational attractiveness of such impoundments, but none of the guidelines and discussions of benefit evaluation suggest an appropriate technique for determining the marginal changes in benefits associated with water level fluctuations in reservoirs. A number of very good models have been developed recently in an attempt to optimize, in terms of economics, the operation of multiple purpose reservoirs. However, the results obtained from each model are no better than the individual benefit-loss functions included for the various purposes. The functions are notably deficient in the case of recreation. This research was undertaken with the goal of making available to the water resources planner an improved tool for including a realistic recreation benefit-loss function in the development of a model to determine optimum reservoir operating policy.

The literature in the areas of benefit-cost analysis as it applies to reservoirs, the optimization of reservoir operation policies, the economics of recreation as a purpose in water resources projects, and the evaluation of the benefits accruing from recreation at such projects has been thoroughly searched. The general plan of action has been formulated and is presently being implemented. The effect of reservoir drawdown on recreation benefits is being studied with the aid of statistical analyses of pertinent data gathered from many sources and relating to as many different reservoirs as possible.

In the collection and analysis of data, primary attention is being given to reservoirs whose water levels change appreciably during the recreation season. Data from reservoirs that were not drawn down are also being collected in order to maintain a control, so that relevant conclusions can be drawn. Largely through the cooperation of the U.S. Army Corps of Engineers, Norfolk District, a great deal of data has been obtained and transferred to computer cards for ease of storage and retrieval. Computer techniques for the analysis of this data have been developed and at present, about forty reservoirs are being studied. Although results at this time are inconclusive, it appears that the best approach is to center attention on a relatively small

number of carefully selected reservoirs, and to study these intensively in order to test and refine the trends that are seen in the larger sample. This is currently being undertaken. Careful attention is being given to normal recreational usage, accessibility to large centers of population, weather, and competition from other nearby reservoirs, as well as other factors, in the selection of this smaller sample. It is believed that this approach will facilitate the development of valid empirical regression models which may be used to estimate the benefit or loss associated with reservoir drawdown.

In addition to the completion of the procedures outlined above, the investigators also feel it desirable to test the empirical loss function that will be derived by including it in modified forms of some of the functions that are available for optimizing reservoir operating policies. In this manner, the economic effects of drawdown on total reservoir benefits may be evaluated. This phase of the study will be a significant portion of the work contemplated for the second year of the two year project period.

**THE EFFECTS OF HEATED WASTE WATERS  
UPON MICROBIAL COMMUNITIES**  
Project B-017-VA

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Blacksburg, Virginia  
December 1970

## THE EFFECTS OF HEATED WASTE WATERS UPON MICROBIAL COMMUNITIES

### Diatom Studies

Research was initiated towards the study of the effects of thermal stress (i.e. increased temperature) on diatom populations. The major approach involved the development of effective staining techniques to clearly demonstrate physiological alterations induced by exposure to such stress. A laboratory assay was established and utilized to pre-screen and categorize various tissue component stains prior to their testing on natural populations collected in the field. Pure in vitro cultures of two relatively common diatom species (Navicula pelliculosa and N. seminulum) were examined repeatedly at different standardized age intervals—three to four, and seven to eight weeks post-innoculation. All stains tested were evaluated on diatoms after exposure to thermal stress in the form of high, short term temperature increases and lower, more prolonged temperature increases. Emphasis was directed towards known major cellular constituents in the carbohydrate and lipid groups as measured, after staining, under both the light and ultra-violet microscopes.

Three general contrast stains (Lugol's IKI, Sudan IV, Methylene Blue) and two fluorescent types (Acriflaving HCl, 3,4 Benzpyrene) were evaluated in the laboratory assay with varying degrees of success. One of the fluorescent stains tested, 3,4 Benzpyrene, has proven to be the most successful when used to measure the lipids of diatoms in the presence and absence of thermal stress. Collections of mixed natural diatom populations have been repeatedly made in the winter and spring of this year (on diatometers in the New River) and returned to the laboratory for testing and further development of the staining technique. As of this date, limited success may be reported in reference to the application of the 3,4 Benzpyrene stain to such mixed natural populations collected in the field.

Further research will be carried out involving the improvement of the 3,4 Benzpyrene staining technique as applied to mixed, natural diatom populations. Such research will encompass the determination of the optimum collection time of diatom populations required to minimize the laboratory holding time. (Such a holding period is presently required for effective staining.) Also, initial trials designed to study the feasibility of using 3,4 Benzpyrene stain on unstressed and stressed diatom suspensions, as measured on electronic photofluorometric instrumentation, are planned as soon as the equipment is available.

Attempts are being made to locate and develop a biological model consisting of an algal-chytridiaceous fungi relationship suited to controlled laboratory studies. The studies will measure the general effects of thermal stress on such a relationship as well as on the fungi alone, and will be conducted over standardized time periods.

#### Protozoan Studies

Protozoan studies have been divided into three categories:

a. Tests were conducted to determine the effects of a sudden heat shock on natural protozoan communities collected from bodies of water around Blacksburg, Virginia. These tests were run at 35, 40, 45, and 50 degrees C, and these temperatures were maintained for one of the following: 8, 16, 32, or 64 minutes. Each community was sampled to determine the number of species present before exposure and on the day the shock was applied as well as the first, second, fourth, eighth, and sixteenth days after the heat shock.

b. Time until death curves were constructed with various individual species of protozoans recording both maximum survival temperature and median survival temperature after the heat application. The important parameters of this experiment were a quick heating rate, a constant observation of the protozoans while being heated, and sufficient repetition of the experiment to evaluate individual variations. A schematic of the apparatus used for this particular series of tests is given in Figure 1. A literature search indicated that this is probably the first time that such an apparatus has been used anywhere for studies of this kind.

A brief description of the apparatus follows: The cell is a microscope slide constructed of two rectangles of 1/8-inch thick Plexiglas brand acrylic plastic, cemented face to face with a solvent. The upper section has a 3/4-inch diameter hole bored through it, which is the test chamber, and is bounded by the bottom sheet. A "heater" of 0.005-in. diameter insulated nichrome wire and three thermocouples (0.005-in. diameter insulated nichrome—0.0035-in. diameter insulated constantan) are located inside the test chamber and fastened with epoxy cement. Temperatures are read from a calibration chart for the thermocouples and EMF's are measured on a Honeywell potentiometer.

When a test is performed, the chamber is filled with a protozoan culture, covered with a coverglass, and observed through the 40x or 100x objective or a regular research microscope. An example of the data from this work is presented in Graph 1.

c. A simulation of the passage of water containing protozoans through the condensing coils of a steam electric generating power plant was conducted using the apparatus shown in Figure 2. These experiments are designed to explore two distinct effects—(1) the immediate stress of passage through the condenser and (2) the effects upon the downstream community in terms of reduced recruitment of new species (this might happen if the individuals passing through the condenser were harmed.) This apparatus took a considerable amount of time and energy to develop, but has proven to be a very profitable research unit. A brief description of the experimental protocol follows.

Three experimental communities were maintained in the following manner. Water was pumped from a simulated pond through a copper coil immersed in a hot water bath, to produce a 15 to 20°C increase in temperature. The water then flowed immediately into a similar cold water bath, cooling it back to its original temperature. It was then directed into three plexiglass troughs, 2 in. high x 1 1/2 in. wide x 30 in. long. Water fell over a 1 1/2-in. high end plate by gravity, back into the simulated pond.

Two control communities were maintained in the following manner. Water was pumped from the simulated pond into a length of copper tubing equivalent to that used for the experimental troughs, but with no heat shock. The water was then passed through two troughs, identical to the ones described above, and then back into the simulated pond. Flow rates in all five troughs were kept as nearly identical as possible—average deviation was about 5 percent.

In both the control and the experimental troughs, the water was returned to the pond out of necessity, for it would not have been feasible to dechlorinate the volume of water used by the five troughs and develop simulated natural conditions before using. The toxicity of copper was not ignored in the design of this experiment; but copper tubing was the only practical tubing both available and feasible for the job. The assumption was made that copper or its ions would be virtually insoluble in the test water. Continuous monitoring of the water for its copper content with atomic absorption spectrophotometry showed no detectable copper in any water in the test. A paper by Cairns and Dickson now in press shows that very low concentrations of copper have little short term effect upon the number of species in protozoan communities.

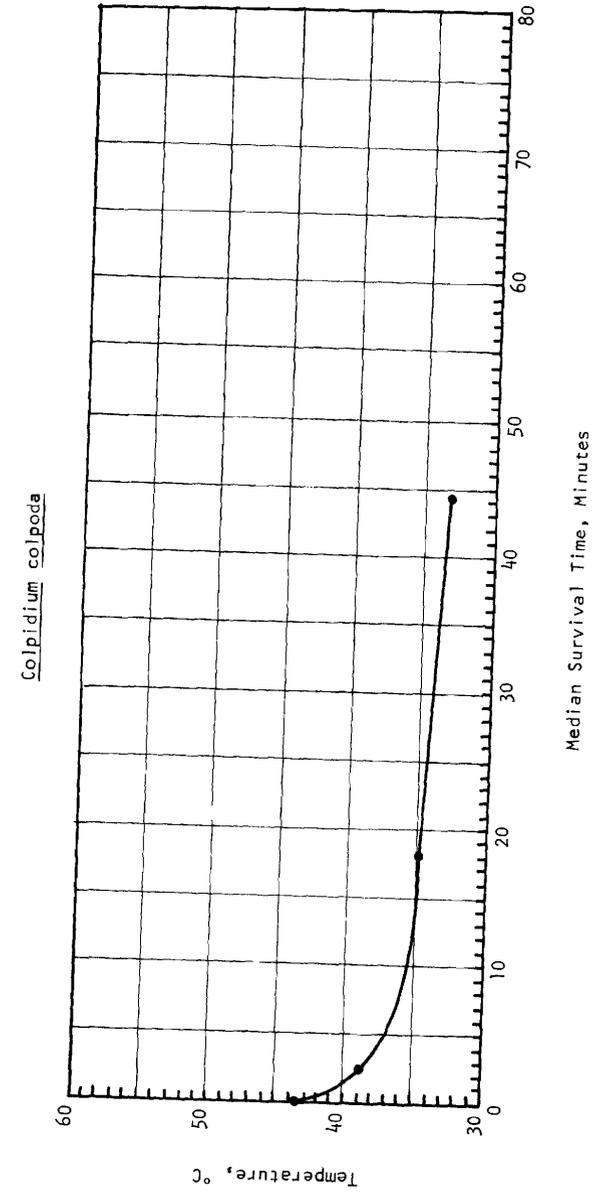
Sampling of the communities was conducted in the following manner. Each trough was given a number and all numbers were drawn at random, without replacement, each trough being sampled weekly. Diversity (i.e. number of

species) of the entire community and population density of each species was recorded.

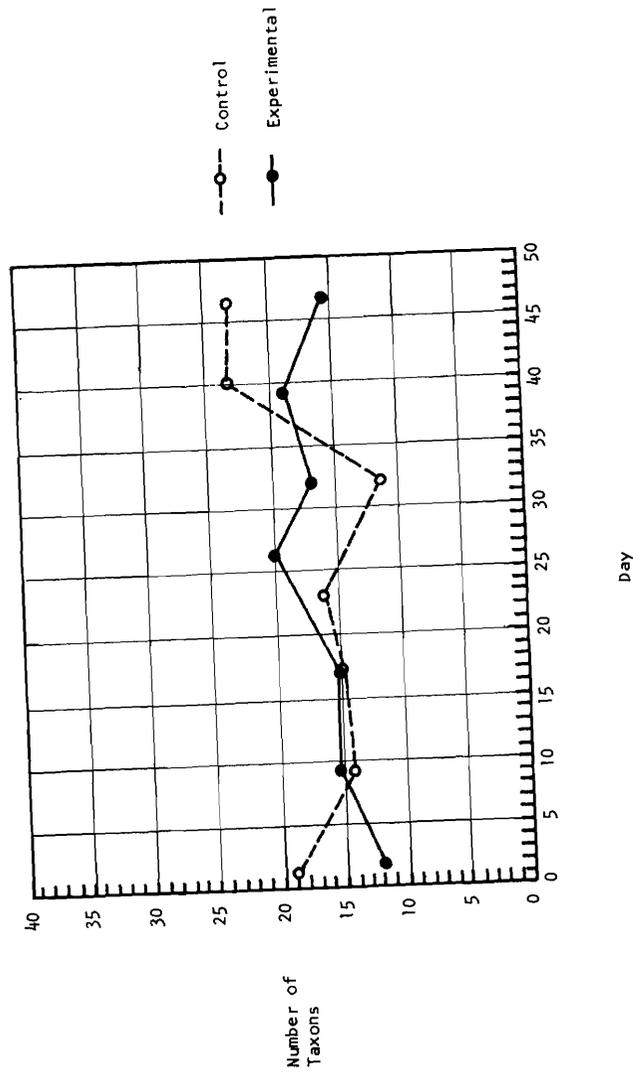
Some results of this work are shown in Graphs 2, 3, and 4. The results summarized in Graph 2 indicate that there was no significant reduction in diversity between control and experimental communities. However, another method of evaluating the data, presented in Graphs 3 and 4, shows that there may be subtle differences in the colonization rate and ultimate maximum population density between the control and experimental communities.

A considerable amount of data has been gathered on the protozoan studies. It is our intent to spend the remaining portion of this year evaluating the data already collected and preparing it for publication.

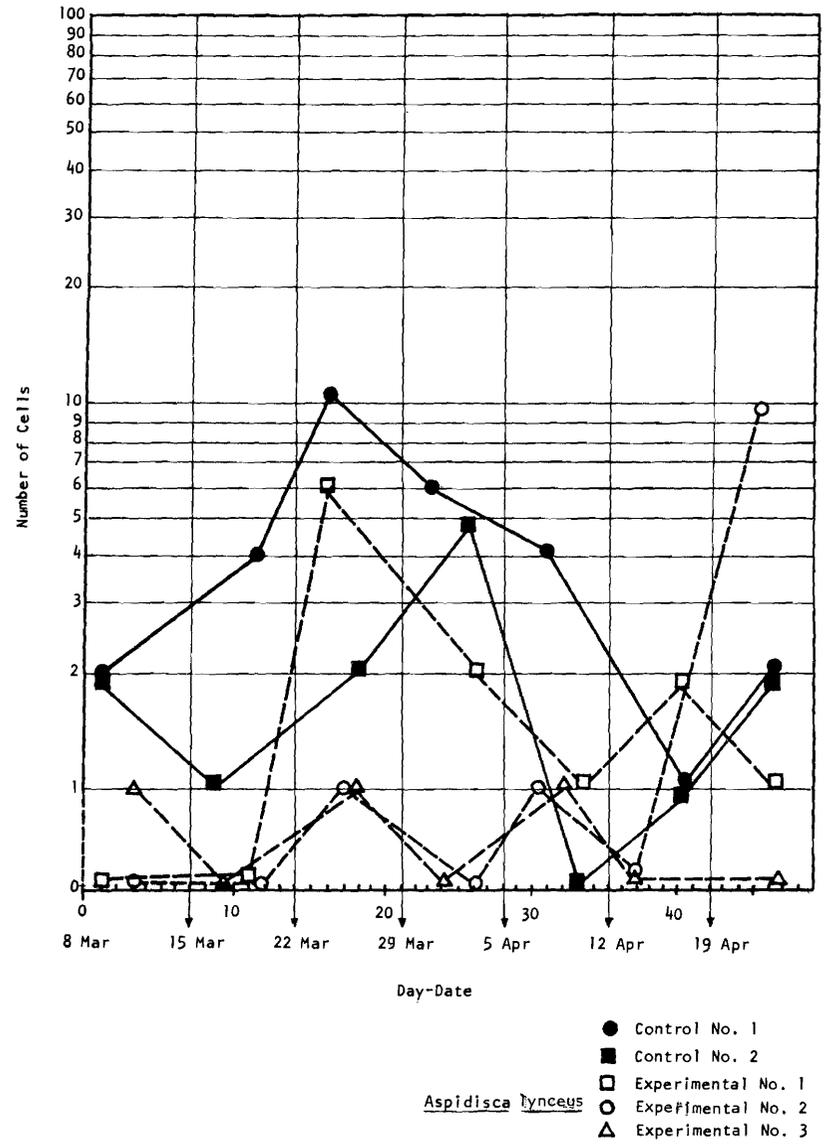
GRAPH 1  
TIME-TEMPERATURE MEDIAN SURVIVAL RELATIONSHIP FOR COLPIDIUM COLPODA.



GRAPH 2  
 AVERAGE DIVERSITIES OF CONTROL AND EXPERIMENTAL COMMUNITIES.



GRAPH 3  
 RELATIVE DENSITY-TIME RELATIONSHIP FOR ASPIDISCA LYNCEUS



GRAPH 4

RELATIVE DENSITY-TIME RELATIONSHIP FOR CYCLIDIUM SP.

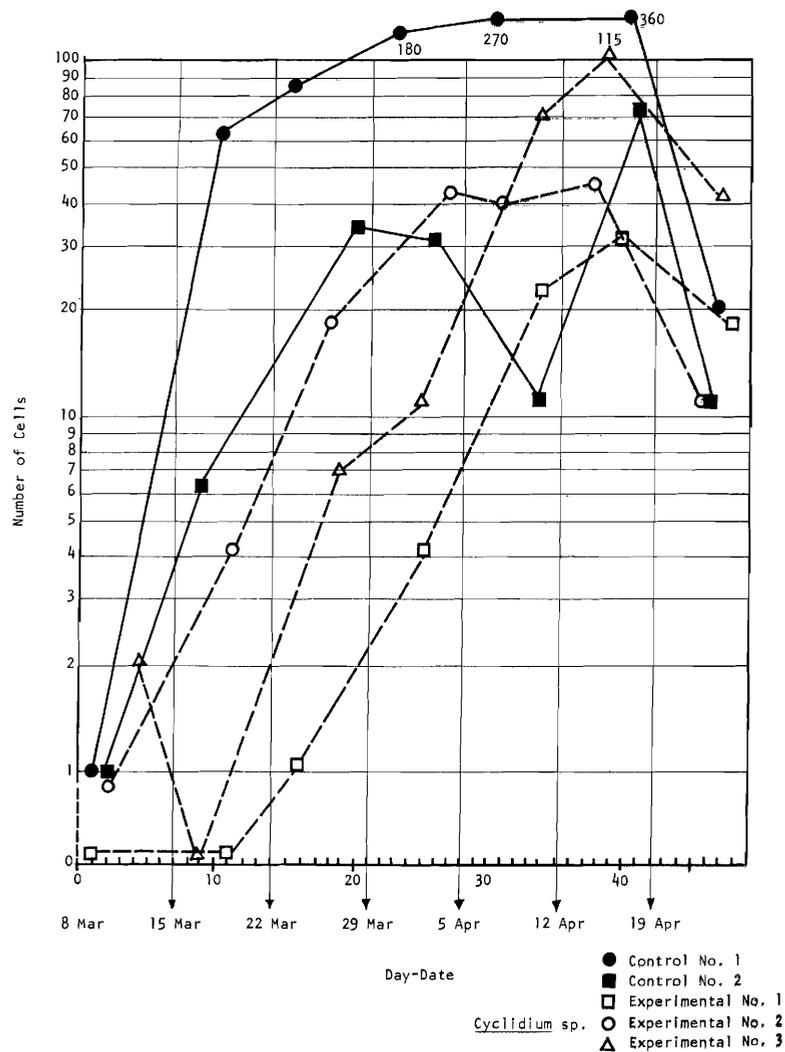


FIGURE 1  
 DIAGRAM OF APPARATUS USED TO OBSERVE MICROSCOPIC ORGANISMS UNDER THERMAL STRESS.

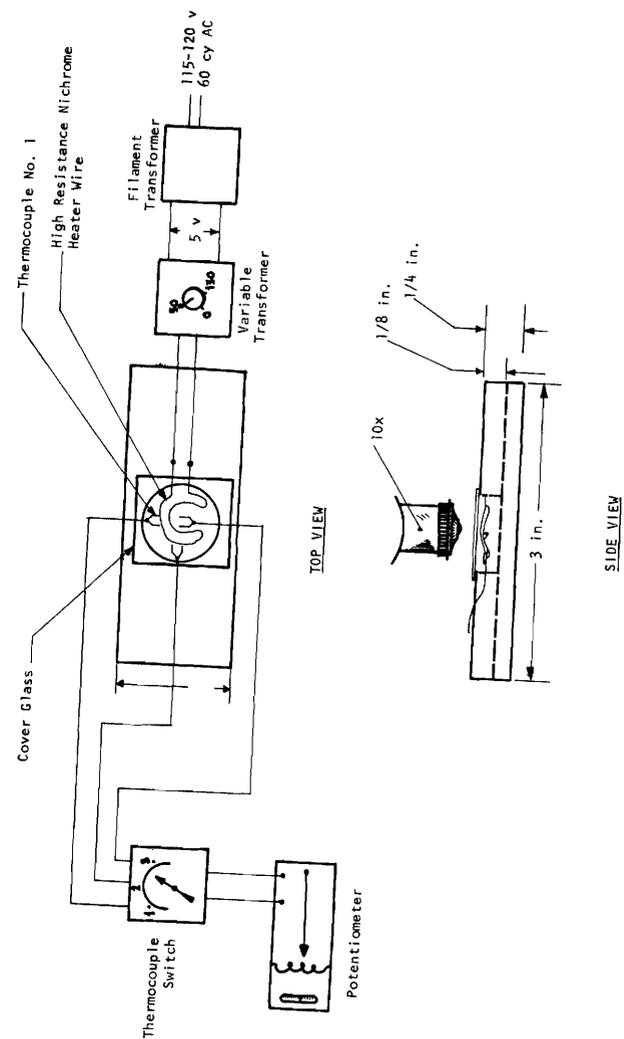
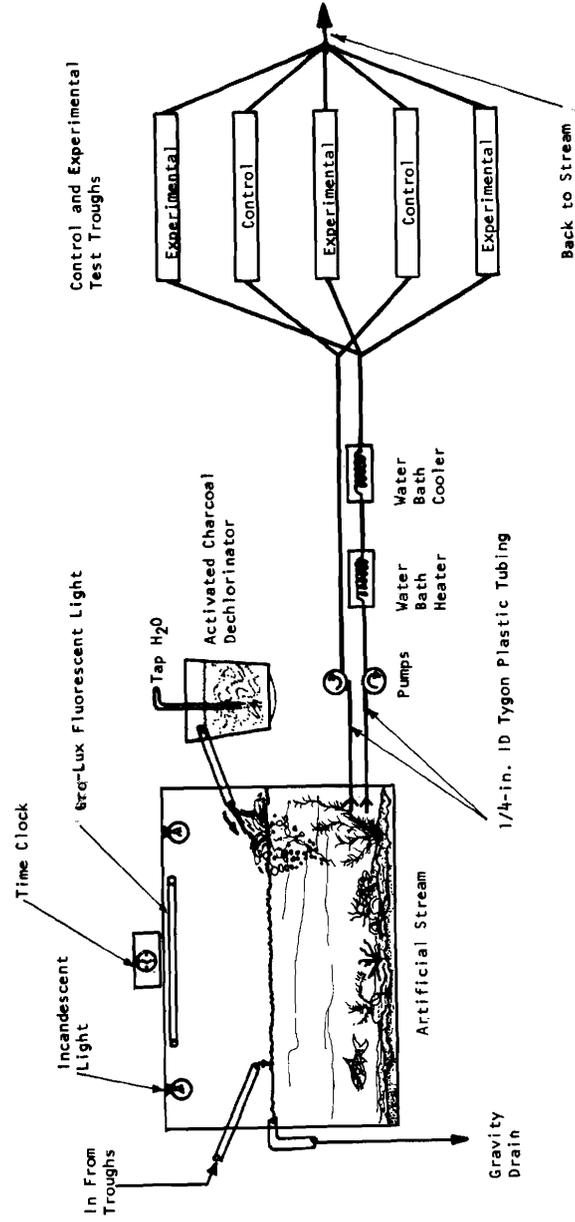


FIGURE 2

DIAGRAM OF APPARATUS USED TO SIMULATE PASSAGE OF WATER CONTAINING PROTOZOANS THROUGH THE CONDENSER OF A STEAM ELECTRIC STATION.



CONVECTION HEAT TRANSFER FROM WATER SURFACES  
Project B-021-VA

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December 1970

## CONVECTION HEAT TRANSFER FROM WATER SURFACES

This paper summarizes the theoretical and experimental work done in the area of heat, mass, and momentum transfer for flow of air over a moving stream of water. Such a study is required for many diverse applications and is of prime importance for predicting thermal pollution and evaporative losses from reservoirs.

### Theoretical Development

A two-dimensional steady laminar incompressible flow is assumed. Unity Lewis number approximation (which is reasonable for this case) was used to decouple energy and diffusion equations. Under these conditions momentum, energy, and diffusion equations were reduced to a similar form and are written as:

$$u_i \frac{\partial \phi_i}{\partial x_i} + v_i \frac{\partial \phi_i}{\partial y_i} = \frac{\partial}{\partial y_i} \left( \lambda \frac{\partial \phi_i}{\partial y_i} \right) \quad (1)$$

where  $\phi$  = property considered as velocity, temp. etc.

$i = 1, 2$  for air and water region

$\lambda = \nu, \alpha,$  for momentum, energy and diffusion equations respectively

A number of schemes were used to solve this equation for heat, mass, and momentum transfer for both the gaseous and liquid phase. They are given below.

(a) Fully developed flows: For fully developed flows, the equation reduced to the same form as used by Byers and King (1) in mass transfer studies. A more rigorous analysis is given by Apelblat and Katchalsky (2). Following their analysis temperature and concentration profiles hence shear stress, heat, and mass transfer relations can be obtained. The case of fully developed flow (which would normally occur for flow in long closed conduit) is not of much importance for open reservoirs.

(b) Approximate integral method for developing flows: Under this scheme equation (1) was integrated with respect to the vertical coordinate and a polynomial form,

$$\phi(n) = A + Bn + Cn^2 + Dn^3$$

was assumed for the velocity, temperature, and concentration profiles. The constants were determined from appropriate boundary conditions. After this momentum, thermal, and diffusion boundary layer thicknesses were obtained, from which shear stress as well as heat and mass transfer relations were obtained. One of the interface boundary conditions for energy equations required a prior knowledge of the concentration gradient which was obtained by first solving the diffusion equation and results used in the solution of energy equation.

Numerical values for a particular case (small water/air velocity ratio and large value of viscosity and density ratio) were obtained. The resulting dimensionless relations are of the same nature as that of flow over a solid flat plate but with a different value of the constants. The solution shows a substantial increase in heat and mass transfer due to the interfacial motion. This observation is in line with those of Byers and King's investigation.

(c) Exact solution for developing flows: The partial differential equations were reduced to ordinary differential equations using variation of parameters. The ordinary differential equations obtained are non-linear. An exact solution is proposed for simultaneous solution of momentum, energy, and diffusion equations for the gaseous and liquid phase. The analog computer has been used successfully for solving these equations.

#### Experimental Investigation

A wind-water facility to simulate the conditions used in the theoretical development has been designed and fabrication is nearing completion. The test section is being made of optically flat glass so that the interferometer can be used. The Mach-Zehnder interferometer will be used extensively for measurement. A six-inch version of this instrument has been developed and has been properly adjusted and aligned. Completion of the experimental work will provide a check of the analytical results which have been referred to.

#### Results and Conclusions

The experimental set up has been partially fabricated. Velocity and humidity

measuring probes are being procured and a traversing system for the measuring instruments is under preparation.

#### References

- (1) Byers, G. H. and C. J. King, "Gas-Liquid Mass Transfer with a Tangentially Moving Interface," Part I, AIChE Vol. 13, n. 4, 1967.
- (2) Apelblat, A. and A. Katchalskym, "Mass Transfer with a Moving Interface," Int. J. Heat and Mass Transfer, Vol. 11, 1968.

The remaining work to be done includes the conclusion of the experimental apparatus construction, the taking of data, the comparison of experimental and analytical results, and the publication of information.

**ANALYSIS OF WATER RESOURCES ADMINISTRATIVE AGENCIES**  
Project B-025-VA

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December 1970

## ANALYSIS OF WATER RESOURCES ADMINISTRATIVE AGENCIES

The majority of the research that has been performed consists of the compilation and analysis of various statutory enactments and reports of the Virginia Advisory Legislative Council (VALC) which concern the administrative agencies in Virginia involved with water resource management. Statutory authority for the different agencies and organizations is spread throughout the code of Virginia; therefore, an essential first step was to compile this legislation in order that it might conveniently be reviewed and compared. A primary objective at this stage has been to determine the powers and duties conferred on each agency in an attempt to identify areas of overlapping or conflicting authority. Statutory provisions for cooperation and coordination between agencies have also been of primary interest during this analysis of legislation.

Research concerning the VALC report on water resources has been undertaken because these reports have often considered the question of the efficiency of water resource management in Virginia. In some instances these advisory reports have dealt with the total administrative framework and in others with the activities of specific agencies.

Another aspect of the project where research has been initiated concerns coordination between the state and federal governments in the area of water resources. In addition to study of legislation and other literature, contact has been made with officials of some of the federal water resource agencies operating within the state.

The present status of the project is not such that final conclusions can be reached. As an initial conclusion, it appears that the management of water resources in Virginia has been hampered in the past by deficiencies of coordination between the various water resource agencies. However, concern about this situation has existed and some steps have been taken to facilitate coordination between agencies and to promote the efficient development and use of water resources. Further study will be necessary in order to determine whether additional changes, legislative or otherwise, appear desirable. Project work remaining to be accomplished includes additional research and the preparation of the final report.

One important aspect of the research remaining to be undertaken involves interviews with officials of the various state agencies with which the study is concerned. This personal contact is essential for several reasons. In some cases

the authorizing legislation allows considerable discretion in agency operation, and actual operating procedures can only be obtained directly from the agency involved. These interviews will also provide the opportunity to determine any informal cooperation or coordination that might exist between agencies. In addition, an opportunity for officials to present ideas for administrative changes which they might view as desirable will be provided.

Another objective remaining to be accomplished is a study of water resource management in other states where different forms of administrative organization are exhibited. Comparison of these various administrative structures can then be undertaken and conclusions drawn concerning the advantages and disadvantages of each.

**TRAINING AND EDUCATIONAL ASPECTS  
OF THE  
WATER RESOURCES RESEARCH PROGRAM**

TRAINING AND EDUCATIONAL ASPECTS OF THE WATER  
RESOURCES RESEARCH PROGRAM UNDER P. L. 88-379

A. New Courses Developed

Advanced Separation Processes

Fishery Ecology

Phycology Systematics

Algal Physiology

Algal Ecology

Advanced Seminar in Sociological Theory I, II, III

Advanced Seminar in Social Organization I, II, III

Advanced Seminar in Group Process I, II, III

Comparative Demography and Human Ecology I, II, III

Community Development I, II, III

New Towns Planning Seminar

Housing Economics and Policy

Analysis and Planning of Mass Transit Systems

Student Internship in Planning

The Modern City

The Study of Urbanization

Policy for Urban Studies

Urban Systems Analysis

Urban Ekistics I, II

Urban Conceptual Subsystems I, II

Urban Functional Subsystems I, II

Public Policy Implementation I, II

B. New Staff Members Added

Virginia Commonwealth University

K. K. Asplund - Ph.D. - Ecology

C. R. Blem - Ph.D. - Zoology

G. C. Llewellyn - Ph.D. - Bionucleonics

J. F. Pagels - Ph.D. - Mammalogy

R. D. Parker - M.S. - Botany

Virginia Polytechnic Institute and State University

(Mrs.) M. L. Ayars - M.S. - Sociology  
 Jerry D. Cardwell - M.S. - Sociology  
 J. C. Chu - Ph.D. - Chemical Engineering  
 Russell E. Crescimanno - M.S. - Sociology  
 Michael C. Cunningham - M.S. - Urban Design  
 C. R. Dollar - Ph.D. - Chemical Engineering  
 James H. Dorsett - Ph.D. - Sociology  
 John N. Edwards - Ph.D. - Sociology  
 M. Hamdan - Ph.D. - Statistics  
 David L. Klemmack - Ph.D. - Sociology  
 Robert McDonald - M.S. - Urban Design  
 Alfred M. Mirande - Ph.D. - Sociology  
 J. F. O'Connor - Ph.D. - Statistics  
 Bruce C. Parker - Ph.D. - Psychology  
 W. R. Pirie - Ph.D. - Statistics  
 Frederick D. Regetz - M.S. - City Planning  
 Joel J. See - Ph.D. - Sociology  
 Vernon O. Shanholtz - Ph.D. - Agricultural Engineering  
 A. W. Sherdon - Ph.D. - Statistics  
 Robert C. Stuart - M.R.P. - Regional Planning  
 C. P. Tsokos - Ph.D. - Statistics

Roy J. Burroughs - Ph.D. - City Planning  
 Visiting Professor

A. Michael Marsden - Ph.D. - Electrical Engineering  
 Visiting Professor

Walter Messcher - M.S. - Mechanical Engineering  
 Visiting Lecturer

Jack R. Warner - M.E.A. - Engineering Administration  
 Visiting Lecturer

C. Student Enrollment

	<u>Number Enrolled</u>	<u>Number Graduating</u>
Juniors	79	0
Seniors (Bachelor's degree candidates)	92	81
Master's degree students	92	24
Doctoral degree students	34	17
Postdoctoral degree students	0	0

D. Number of Students Using Equipment and Supplies Purchased Wholly  
or in Part with P.L. 88-379 Funds

<u>Category of Students</u>	<u>No. Using Equipment, Supplies, etc.</u>
Undergraduates	23
Master's students	23
Doctoral students	14
Postdoctorate students	0

E. Number of Students Receiving Employment or Other Financial Support Through the P.L. 88-379 Program

<u>Category of Students</u>	<u>Scientific Discipline</u>	<u>Number</u>
Undergraduates	Biology	2
	Architecture	1
	Chemistry	1
Master	Biology	2
	Chemical Engineering	1
	Statistics	1
Doctoral	Mechanical Engineering	1
	Biology	1
	Sanitary Engineering	3
	Chemistry	1
	Agricultural Engineering	1
Postdoctoral		0

F. Employment Status of 1969-70 Graduates in Water-Related Fields

Category of grad. by degree obtained	No. of Graduates Engaged in Water-related Work in:					
	University or College		Agency or pvt. water resources research	Oper-ating and mgmt.	Plan-ning	Other wtr. re-sources work
	teach. prim.	resrch. prim.				
Bachelor	0	0	0	42	0	0
Master	0	1	3	8	2	0
Doctoral	0	1	5	1	1	1
TOTAL	0	2	8	51	3	1

G. Type of Employment of 1969-70 Graduates in Water-Related Fields

Category of graduate by degree obtained	No. Employed in Water-Related Positions in:				No. ret. for adv. degree	No. entering military service	No. unemployed or unknown
	Federal agencies	State agencies	Col. and univ.	Other such as private			
Bachelor	1	0	0	41	16	12	1
Master	3	1	0	11	5	3	0
Doctoral	0	0	4	5	6	0	1
TOTAL	4	1	4	57	27	15	2

PUBLICATIONS  
AND  
THESES

## PUBLICATIONS AND THESES

### Publications

- Beard, J. Taylor and John L. Gainer  
1970. "The Influence of Solar Radiation Reflectance on Water Evaporation," Journal of Geophysical Research, Vol. 75, No. 27, Pages 5155-5163. (A-019-VA)
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1970. "Iterative Technique Using a Laser for Alignment of the Mach-Zehnder Interferometer," Proceedings of the I.S.A., Instrumentation in the Aerospace Industry, Vol. 16, Page 51. (B-021-VA)
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1970. "Polyelectrolyte Conditioning of Alum Sludges," Journal of the American Water Works Association, In press. (A-030-VA)
- Chen, Charles S. and J. Taylor Beard  
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