ANNUAL REPORT
WATER RESOURCES RESEARCH ACTIVITIES
UNDER PUBLIC LAW 88-379
FISCAL YEAR 1967

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

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 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 third 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

TABLE OF CONTENTS

DIRECTOR'S REPORT

Significant Technical Accomplishments

Of the twelve projects which were active during the fiscal year, seven were terminated as of June 30. Of these seven, four were commenced with the original appropriation to the Center. The significance of the research will be discussed in terms of each project.

Concentration of Phosphate Sludges. The increased usage of water associated with an industrialized civilization has resulted in the accumulation of waste products in the natural watercourses. One of the manifest deteriorations in water quality has been the overgrowth of algae and other aquatic plants which have been attributed to the presence of increased concentrations of fertilizer constituents, particularly nitrogen and phosphorous.

One source of fertilizer elements is in treated sewage effluents inasmuch as nitrogen and phosphorous are incompletely removed in conventional processes. Substantial research along various avenues is currently underway with the object of upgrading sewage treatment in respect to removal of fertilizer ingredients. Since phosphorous is a nonvolatile constituent, it is necessary to fix it into the solids fraction leaving the sewage treatment process which is not discharged to a watercourse. The precipitation of phosphate with lime has been demonstrated as effective in the fixing of the constituent in the solids fraction, but the process has been accompanied by voluminous, slow settling sludges.

The research reported herein was undertaken to increase the general understanding of the lime precipitation process as it applies to digester supernatant liquor and to investigate particle nucleation as a technique for improving sludge settling and dewatering characteristics. It was the intention to provide designers with an increased measure of guidance in respect to the design of processes involving precipitation of phosphate with lime.

Multicomponent Mass Transport in Aqueous and Membrane Systems. Processes involving multicomponent mass transport are to be found throughout the water resource field. For example, the kinetics and efficiency of membrane desalination processes are governed by rates of mass transport. Similar membrane processes have been proposed for use in contaminate removal from a wide variety of industrial waste disposal streams. Another example are those processes in which rates of oxygen transfer into natural bodies of water is an important parameter in pollution control.

This project was concerned with mass transport in aqueous and membrane systems. The objective has been to develop the underlying theory and to propose and test practical, quantitative models for the rates of mass trans-

port in such systems. The information developed should prove invaluable in the engineering of pollution control processes, since it is necessary to quantitatively predict rates of mass transport in order to rationally design such processing equipment.

Water Quality in Relation to Aquatic Plants and Their Control. Chary vulgaris is probably the most prevalent problem plant in the hard water regions of Virginia. A better understanding of its nutrition and growth phenomena will give insight into its control which will assist in the better utilization of pond, stream, river, and lake waters. The techniques developed in this research will facilitate the study of intercellular movement of nutrients and metabolities.

Since it has been shown that aquatic plants can accumulate and utilize nutrients directly from the water, it is suggested that algae plants be screened for efficiency in nutrient uptake and accumulation. These plants could be introduced into sewage settling bases, ponds, and other waters where tie-up or elimination of nutrients is desired. The plants might then be harvested for food or fertilizer.

The effects of simazine and 2,4-D (two common herbicides) on chary have been studied. Field and greenhouse studies have shown that chara is not affected by 2, 4-D at rates up to 100 ppm, but is effectively controlled by simazine at rates of 2-4 ppm. Research has shown that this plant can accumulate and decarboxylate 2, 4-D that is, it can degrade the herbicide molecule and render it nonphytotoxic.

Analysis of Hydrologic Systems. This research will probably not have immediate application. It was designed to be exploratory in nature to determine the feasibility of applying systems analysis to watersheds. Application of the research results should be helpful in the design of paved areas, however, since it provides a time history of the runoff from rainfall information, using analog computation devices and techniques.

Application of the results in the case of natural watersheds is not immediately likely. This research will need considerable expansion to develop completely the theory in the case of natural basins. The infinite variation of natural watersheds will cause the theory to he modified to take into account significant basin parameters, such as slope, vegetal cover, relief, drainage density and so on. The relative significance of these factors relative to the systems analysis parameters must be studied before broad application to natural watersheds is possible.

Instantaneous Unit Hydrograph Response by Harmonic Analysis. This research has application as a design method for computing probable runoff from assumed values of precipitation and in flood routing.

Particularly, water resource operation systems should find the method useful since the numerical values which are used to compute the runoff as a function of time can easily be stored and manipulated in a computer. The computer could then rapidly assemble the information necessary to compute runoff, perform the computation and determine operation criteria for the water resource system. Such computer application the operation sense is presently performed, using more traditional methods of computing runoff values.

Effect of Pump-Storage Reservoir Operation on Biological Productivity. This investigation will provide a basis for recommendations concerning pumped storage reservoir operation. These recommendations will encompass suggestion on the schedule of operation that will produce optimum biological productivity. Other suggestions will be concerned with alleviating the effects of undesirable industrial and domestic effluents. Lack of knowledge of reservoir characteristics, particularly pumped-storage reservoirs, under various operation schedules and climatic conditions can be corrected with data collected during this study. Already the Virginia State Fish and Game Commission has made use of temperature and oxygen data in planning their stocking program of Smith Mountain Lake. The U. S. Fish and Wildlife Service is very interested in having at hand basic limnological data on pumpedstorage reservoirs, since several other reservoirs of this type are under construction or are contemplated.

Relation of Selected Engineering Land Treatments to Soil Water Storage and Rainfall Use Efficiency of Crops. Agriculturists in Virginia are annually faced with the problem of developing procedures or techniques to increase soil water storage and plant use efficiency so that optimum crop yields may be obtained. Short drought periods of two to three weeks, which are quite prevalent throughout much of Virginia, cause considerable loss of revenue due to insufficient water.

As a direct result of experimental work conducted by the VPI Agricultural Engineering Department in cooperation with ARS and *VWRR* on row crop tillage systems, no tillage is being advocated by extension personnel as a determent to short drought periods, i.e. better soil water storage is obtained followed by better rainfall use efficiency. Many farmers are incorporating the no-tillage system into their farming operations. Unless extreme drought conditions prevail, better crop growth and yields are being experienced. Other obvious benefits include less erosion and surface runoff. Also the system allows for the altering of land use patterns to obtain a higher production management efficiency.

Research is being conducted in an effort to determine quantitative estimates of the benefits being received, i.e., how many additional inches of water may be stored? -- or how many more bushels per acre can be expected?

Hopefully a final result will be that given the probability of a given set of climatic conditions, then the expected benefits from the no-tillage system may be given.

Prediction Models for Investment in Urban Drainage Systems. In practice the basis for design of urban drainage systems involves factors of experience and judgment on the part of the designer, and not an evaluation and subsequent balancing of the relevant costs and benefits. Examination of over 100 small urban areas reveals that investment costs in urban drainage systems depend upon design factors and characteristics of the drainage area. Physical properties, including geographic features of the basin and hydrologic characteristics, are most significant in determining required investment; however, design factors are also important. Regression techniques and analysis of residuals from the regression models, aid in explaining differences in design methods and assumptions. Prediction equations based on area, drainage density, length-slope factors, runoff intensity, and storm frequency are used to estimate the cost component of benefit-cost studies for various levels of protection.

The analyses completed in the first year of the project are sufficiently good to indicate the average cost of conventional storm drainage installations up to one square mile in area when preliminary designs have been worked out. At that stage of design, applying the existing prediction equations would offer little advantage over continuing the design to work up a cost estimate. At the conclusions of the project, however, it is felt there will be definite advantages. With better predictors, agencies like the Federal Housing Administration and municipal and regional planning commissions, as well as engineering offices, will be able to judge alternatives after a rapid and reasonably accurate prediction of costs.

A Regression Model for Water Quality Estimation in a Small Watershed. Buckingham and Churchill applied the technique used in this research to a large stream in the Tennessee Valley Authority and obtained an equation of the same form as obtained in this project. Only one model was formulated and no attempt was made to measure impact of algae by use of day and night models. They did not try to delete variables, and thus evaluate the relative effect of the various factors. McDonnell and Koontz in their study did attempt to delete variables, but not to relate the variables to the same stretch of stream by allowing for time of transit. They obtained values by random sampling techniques. Their conclusion was that algae effects outweighed the effects of organic pollution in a small watershed. This conclusion was reached by an analysis similar to the one utilized in this research. It is likely that the short time of transit, turbulence, and algae concentrations in a small watershed are

factors which vary from stream to stream, and are especially important in the receiving waters of small streams.

The need for a means of estimating the effects of the wastes on a small stream is evident. Most of the towns and cities of Virginia discharge their waste into small water courses.

If the model had been successful, it would enable planning and regulatory agencies to estimate the water quality effect of point discharges in advance of their construction. There would be less need to rely on "20-20" hindsight.

Center's Involvement in Public Affairs

The past year has been one of substantial growth not only in the activities of the Center but with respect to its image within the academic community and throughout the state. The Center is becoming more and more the focal point for research in the area of water resources. Every effort is being made to coordinate the activities in this area and to establish effective liaison between other institutions doing research and those organizations and individuals involved in formulating policy in this general area. Although much of the liaison is through personal contact and speaking engagements, one of the structured groups is the State-wide Advisory Committee for the Center. Although in no formal capacity, the Center has reviewed and submitted comments to the State Water Control Board on the standards set on interstate streams pursuant to the Water Quality Act of 1965. At the last meeting of the General Assembly, funds were made available to Division of Water Resources to do the first extensive planning in the area of water resources in the state's history. The director and staff members of VPI had numerous conferences with this agency regarding alternative methods of approaching this assignment. The Center is currently working with the Division of Water Resources on a proposed research project to implement a phase of their planning activity.

The Spring meeting of the Interstate Commission on the Potomac River Basin was devoted to "Run Off--A Factor in Potomac Basin Pollution." The director presented a paper at this meeting, "What Needs to Be Known." By indirection it brought to the attention of the group the research potential available at the Water Resources Research Centers in each of the basin states.

Through the years the state has developed a number of agencies to work on various facets of water-related problems. Since the political boundaries of the state cut across multiple river basins, the federal agencies working within the state are more numerous than in others. In an effort to focus attention on the number of groups involved and to afford an opportunity for each group to present their program and future plans, the Center

sponsored in October, 1966, a symposium on "Water Resource Programs in Virginia." The specific purpose was to bring together representatives from various agencies, commissions, and citizen groups who are actively involved in the planning and executing of water-related activities in the state. The program included the following speakers: Dr. William B. Harrison, Dean of Research Division, VPI; C. J. Robin, Chief of Engineering Division, Norfolk District, Corps of Engineers; E. G. Long, Jr., Chief of Engineering Division, Wilmington District, Corps of Engineers; C. F. Pfrommer, Chief of Engineering Division, Baltimore District, Corps of Engineers; Donald T. Williams, Engineering Divison, Huntington District, Corps of Engineers; A. H. Paessler, Executive-Secretary, State Water Control Board; E. C. Meredith, Director, Dvision of Engineering, State Department of Health; E. W. Mundie, Cooperative Extension Service, VPI; R. Leland Crouch, Director, Virginia Soil and Water Conservation Commission; Eugene D. Eaton, Associate Director, Office of Water Resources Research, Department of the Interior; J. M. Alexander, Commissioner, Division of Water Resources; FitzGerald Bemiss, Chairman, Virginia Commission on Outdoor Recreation; Eric W. Rodgers, Secretary-Treasurer, Roanoke River Basin Association; W. Martin Johnson, President, James River Basin Association; Carl J. Johnson, Executive-Director, Interstate Commission on the Potomac River Basin; William R. Walker, Director, Water Resources Research Center; William J. Hargis, Jr., Director, Virginia Institute of Marine Sciences; Reed A. Elliot, Director, Water Control Planning Tennessee Valley Authority; Gary Gardner, Deputy Director, Chesapeake BaySusquehanna River Basin Study, Federal Water Pollution Control Administration; Gerald W. Ferguson, Regional Water Supply and Interstate Carrier Sanitation Consultant, Department of Health, Education and Welfare; J. W. Gambrell, District Chief, U. S. Geological Survey; Tom F. McGourin, State Conservationist, Soil Conservation Service.

It was hoped that with more detailed information regarding the thinking and planning being done in the various private and governmental organizations, better coordinated objectives could be attained, duplication of effort minimized, and freer interchange of ideas fostered, resulting in a better utilization of one of the state's most valuable resources -- water. A complete change in operating procedure will not come suddenly, but there are signs indicating improvement.

Papers presented at this symposium were printed as Bulletin No. 4.

In an effort to overcome the general feeling in some quarters that research in pollution control was solely in the province of the engineers, Dr. Leon W. Weinberger, Assistant Commissioner for Research and Development, Federal Water Pollution Control Administration, was invited to make a presentation

to the faculty in February, 1967, on "Multidisciplinary Research in Water Pollution Control." His talk was very effective, and we are beginning to see evidence of added interest by faculty in physical and social sciences.

While Dr. Weinberger was on the campus, we invited to the afternoon meeting representatives from water-oriented industries to hear him speak on the impact of the Clean Water Restoration Act of 1966. One of the significant provisions of this legislation was the authorization of funds for pilot plant studies and the construction of operating size units for industrial firms confronted with the need for advance waste treatment and/or in-plant modification. It was hoped that through this initial step the Center might develop closer contacts with a larger segment of the industrial community of the state and let them be made aware of the research potential and assistance available through the Center. The working relationship to be developed with the industry of the state will come only with time, and as we are able to successfully perform satisfactory service in the form of research.

Center's Involvement in Academic Activities

The current allotment program includes work being done by the Civil Engineering Department of the Virginia Military Institute. During the next fiscal year, this project will continue and a new one will commence at the University of Virginia with coinvestigators from the Mechanical Engineering and Chemical Engineering Departments. The next fiscal year will include a matching fund proposal with Virginia Institute of Marine Science. A concerted effort is being made to expand the program of the Center to utilize the capabilities at the schools of higher learning.

The Statistics Department in a cooperative program with Sanitary Engineering produced the research results printed in Bulletin 3, Stochastic Model for Pollution and Dissolved Oxygen in Streams. The Statistics Department with the encouragement of the Center has produced a study for the U. S. Weather Bureau, "Probability Forecasts of 30-Day Precipitation," and has pending with the Federal Water Pollution Control Administration a model study on estuarine pollution.

The most significant speaking engagements for the director include the following:

American Water Works Association
(Virginia Section)
Washington, D. C., October, 1966

Symposium on Water Resource Programs in Virginia
Richmond, Virginia
October, 1966

Roanoke River Association
Buggs Island, Virginia
November, 1966

National Meeting of Water Resources Directors
Washington, D. C.
January, 1967

James River Association
Lynchburg, Virginia
March, 1967

Water Pollution Control Federation
(Virginia Section), Roanoke, Virginia
April, 1967

Southern Water Resources and Pollution Control Conference
Chapel Hill, North Carolina
April, 1967

Water Law Conference
Penn. State College, College Station, Pennsylvania
April, 1967

Interstate Commission on the Potomac River Basin
Washington, D. C.
May, 1967

In cooperation with Department of Urban and Regional Planning, the Center spearheaded a multidisciplinary resources studio during the Spring Quarter on "A Methodology for Evaluation of the Dismal Swamp." This was to complement the research project on the Dismal Swamp which is included in the annual allotment program for fiscal year 1968 in cooperation with North Carolina Water Resources Center. The students were graduates in four disciplines. Resource leaders were taken from at least nine disciplines. The problem was extremely large and very open-ended. It was a very effective teaching experience and the students learned a great deal - probably more about the problems of working with other disciplines and open-ended problems than about the Dismal Swamp itself. The students had an opportunity to carry a project from its inception to completion - a rare experience in most academic curriculums. I think the directors of the studio became aware that the students are not well equipped to handle open-ended problems, but were encouraged with their adaptability and determination, although the students felt frustrated during most of the experience. We will probably attempt a similar type problem in the future.

Other Accomplishments

The proper planning and development of the state's water resources is dependent on the availability of the

information and data for the formulation of policy decisions. In an effort to meet the immediate informational gap and to anticipate the data requirements in the future, the Water Resources Research Center devised in excess of 60 problems or planning areas which should have the attention of the Commonwealth during the next several years. These research needs were presented to the Statewide Advisory Committee for the purpose of determining those which should have immediate priority and those in which the time factor is a little less critical. On the basis of the response by the Statewide Committee, nine areas were deemed most critical. The Center requested approval from the University for the establishment of seven research faculty positions to mount a formidable attack on these problem areas. The positions requested were resource planner, political scientist in public administration, resource economists, chemical engineer, aquatic biologist, and sanitary engineer. Funding for these positions will be sought when the General Assembly meets in January, 1968.

C O N C E N T R A T I O N

OF

PHOSPHATE SLUDGES

Dr. William A. Parsons
Professor of Civil Engineering
Department of Civil Engineering

Water Resources Research Center

Virginia Polytechnic Institute

Blacksburg, Virginia

August 1967

CONCENTRATION OF PHOSPHATE SLUDGES

Objectives

Sludges are derived from most treatment processes for domestic sewage by the mechanisms of sedimentation of suspended materials and by conversion of nutrient constituents to biological growth. In many treatment plants, sludges are transferred to a digester where anaerobic fermentation takes place. The end products of the fermentation are gas, a stabilized digested sludge, and a liquid fraction termed "supernatant liquor." The volume of supernatant liquor may amount typically to 0.3 to 1.4 per cent of the sewage flow. However, supernatant liquor generally contains substantially higher concentrations of pollutional matter than the sewage from which it is derived; e.g., it may contain a major fraction of the phosphate removed by the attendant sewage treatment process. Supernatant liquor is a low-volume high-concentration flow customarily recycled to the influent of the sewage treatment plant.

The removal of phosphorus from treated sewage effluents is of interest inasmuch as it may contribute to overgrowths of aquatic plant life in receiving watercourses. Phosphates may contribute also to the dispersion of turbidity and increase the coagulant demand at downstream water treatment plants. Studies by Vacker et al have suggested that more efficient removal of phosphate at sewage treatment plants may occur if supernatant liquor is disposed of to lagoons rather than recycled through the treatment plant. Such a procedure would be generally applicable.

The removal of phosphate from supernatant liquor by treatment with lime has been investigated previously. Rudolfs[2] reported that lime treatment was effective for the removal of phosphate and other pollutional constituents, but that a slow settling sludge was formed. Studies of lime treatment of sewage effluents [3,4,5] have also indicated efficient removal of phosphate with attendant production of slow settling sludges.

The present study was undertaken to investigate the feasibility of a return sludge process for the improvement of the settling and dewatering characteristics of sludges formed during lime treatment of digester supernatant liquor. Return sludge processes have been demonstrated as effective for the improvement of settling characteristics of sludges from waste acid neutralization[6,7] and from water softening operations. Insofar as improved sludge characteristics may increase the practicality of phosphate removal, the ultimate objective was the upgrading of the

quality of treated sewage effluents.

---

[1] Vacker, D., Connell, C. H., and Wells, W. N., JWPCF 39, 5, 750 (1967).

[2] Rudolfs, W., Sewage Works Journal 19, 2, 178 (1947).

[3] Nesbitt, J. B., Engineering Research Bulletin B-93, Pennsylvania State University (February, 1966).

[4] Owen, R., Sewage and Industrial Wastes 25, 5, 548 (1953).

[5] Sawyer, C. N., Sewage and Industrial Wastes 24, 6, 768 (1952).

[6] Foust, S. D., and H. E. Oxford, Industrial and Engineering Chemistry 50, 10, 1537 (1958).

[7] Parsons, W. A., Chemical Treatment of Sewage and Industrial Wastes, National Lime Association, Washington, D. C. (1965).

Methods and Materials

Samples of digester supernatant liquor were obtained from the municipal sewage treatment plants serving the towns of Blacksburg and Christiansburg, Virginia. Both towns can be classed as "domestic" in respect to sewage characteristics. Both treatment plants feature primary settling, standard rate trickling filtration, final settling and separate heated sludge digestion in their flow sheets. The samples of supernatant liquor were drawn from the mid-region between the scum and sludge layers.

Experiments were conducted on a batch basis using sample sizes of 0.5 to 1.0 liters. Mixing was provided by a "jar test" multiple stirrer. All experiments were conducted in a controlled temperature room set at 20^0 C. The lime employed in all experiments was a chemical grade of high calcium hydrated lime.

The experimental procedure consisted of the addition of measured volumes of 15 per cent lime slurry to samples of supernatant liquor of 100 rpm for 30 minutes. At the end of the agitation period, the pH of the mixture was determined, and the mixtures were transferred to 1-liter Imhoff cones for quiescent sedimentation and observation of sludge volumes. After one hour of settling, the sludge volume was recorded and samples of the settled mixture were withdrawn for determination of the suspended solids and phosphate concentrations. Settling of the mixture was continued over a 24hour period with periodic readings taken of the sludge volumes, and periodic withdrawal of 20 ml samples of settled mixture for analysis of phosphate. At the end of the settling period, the sludge was resuspended by agitation and a determination of suspended solids was made on the mixture.

The suspended solids determination consisted of passing a 20 ml sample through a tared Gooch crucible lined with a glass fiber filter mat. The capture of suspended solids was estimated by reweighing the crucible following a 24-hour period of drying at 103°C.

The concentration of phosphate was estimated by a manual method designed to estimate total phosphate (organic, ortho and polymerized), and by an automated method for estimation of orthophosphate. The manual procedure involved a hot digestion with concentrated nitric and sulfuric acids added to decolorize the solution and convert organic and polymerized phosphates to orthophosphate. Following digestion, the mixture was diluted and neutralized prior to analysis for orthophosphate by the amino naphthol sulfonic acid method described in Standard Methods.[8]

A Technicon Autoanalyzer was employed in the automated analysis of orthophosphate. The method, developed by Lundgren,[9] involved the clarification of the sample by dialysis prior to colorimetric analysis by the amino naphthol sulfonic acid technique. A series of comparative analyses indicated that the automated method detected consistently about 75 per cent of phosphates indicated by the manual method on raw samples, and on samples treated for up to 85 per cent removal of phosphate. Consequently, the automated method was employed to determine the phosphate concentrations reported in this investigation. To avoid continued precipitation of phosphate in samples collected and stored for subsequent analysis, 3.0 ml of 1.ON acetic acid was added to each 20 ml of sample. This procedure effected a pH of about 4.3 in the stored sample.

The determination of pH was accomplished electrometrically using a glass-calomel electrode system. Biochemical oxygen demand (BOD) was determined manometrically. An appropriate dilution of sample plus 3.0 ml of buffer (50 g/L KH_2PO_4 adjusted to pH 6.7) was added to the manometrically monitored bottles. The bottles were incubated at 20°C and the periodically observed manometer readings were converted to BOD. Samples of lime-treated supernatant were neutralized with dilute sulfuric acid and seeded with 1.0 per cent settled sewage prior to transfer to the manometer monitored bottles.

General Discussion

The process developed in this investigation involves phosphate removal and sludge concentration. The mechanisms contributing to phosphate removal may include precipitation and coprecipitation of soluble phosphate, plus coagulation of dispersed phosphate.

Orthophosphate was indicated to be the dominant form of phosphorous in the samples of supernatant liquor analyzed. In a review of precipitation of phosphates at ordinary temperatures, Stumm[10] concluded that under alkaline conditions, hydroxyapatite, $Ca_{10}(P0_4)_6\ (OH)_2$, is the stable calcium phosphate phase. The solubility of hydroxyapatite is very slight, but the equilibrium is slow and many anomalies have been reported in the solubility behavior. From the standpoint of ionic equilibrium, the residual concentration of phosphate would be expected to depend upon the level of calcium ion activity and the pH. Experimental evidence was presented indicating that for one hour reaction periods, in an alkaline pH range, the phosphate residual was essentially pH dependent when the ratio of calcium ions to phosphate ions was greater than 4.0. It was noted that phosphatocalcium complexes may exist and

that colloidal calcium phosphates are not readily settled.

Digester supernatant liquor is a complex mixture of chemical substances, consequently the addition of calcium hydroxide effects precipitation of other substances as well as hydroxyapatite. An analysis of the relative concentrations of alkalinity and phosphate would suggest that the lime treatment would effect precipitation of far greater quantities of calcium carbonate than of hydroxyapatite. In addition, other precipitates such as magnesium hydroxide or organic substances could be present in quantity. In the presence of a large extraneous precipitation, coprecipitation of phosphate ions within or on the extraneous precipitate would be expected. Since the precipitation of calcium carbonate would be essentially complete at pH levels above 11.0, the mechanism of coprecipitation would presumably be most important at the lower lime dosages.

The samples of digester supernatant liquor employed in the study generally contained from 600 to 2,000 ppm of suspended solids. It would be expected that some *phosphate* would be contained as a component of the suspended solids and that additional phosphate would be held by interfacial forces. Consequently, the coagulation of the dispersed phase would constitute a mechanism for the removal of some *phosphate*.

The proposed treatment process for supernatant liquor involves the adjustment of conditions in the system by.addition of calcium hydroxide such that the solubility of hydroxyapatite, calcium carbonate, and possibly other substances is exceeded. When the solubility is exceeded above some limiting level, spontaneous precipitation occurs with the formation of micro-sized particles of precipitate which because of their small mass and large surface are characteristically difficult to settle or to dewater. In many systems precipitation will occur at a lower level of supersaturation in the presence of previously precipitated material, and in some cases precipitation will form a deposit on surfaces. The object of the addition of previously precipitated sludge to the supernatant liquor prior to lime treatment was to induce reaction product to deposit on previously formed nuclei--thereby preventing the formation of microcrystals and increasing the size of the existing sludge particles. Sludge particles of large size would be expected to possess improved settling and dewatering characteristics.

---

[8] Standard Methods for the Examination of Water and Wastewater, American Public Health Association, 11th Edition, New York, New York (1960).

[9] Lundgren, D. P., Analytical Chemistry, 32, 7, 824 (1960).

[10] Stumm, W., Advances in Water Pollution Research, Vol. 2, p. 216, The Macmillan Company, New York, (1964).

Two reaction rates, the rate of build-up of supersaturation and the rate of deposition of reaction product on seed nuclei, require consideration in an induced precipitation process if a limiting level of supersaturation is not to be exceeded. In the present system, the rate of build-up of supersaturation would depend upon the rate of dissolution of lime. The rate of dissolution would depend upon the feed rate, the pH, and the intensity of agitation. The rate of decomposition of reaction product on seed nuclei would depend upon the level of supersaturation, the dosage and properties of the return sludge, and agitation. Adequate agitation is necessary to maintain uniform levels of concentration throughout the reactor, and to provide the mass transfer involved in the dissolution of the lime and the delivery of reaction product to the surfaces of the seed nuclei. Temperature is a most influential variable that was not considered in the present study because all experiments were made under controlled conditions of 20°C.

The experimental results established that the addition of return sludge did improve sludge settling characteristics. However, it was not determined whether induced precipitation actually occurred, or whether it occurred with hydroxyapatite or with calcium carbonate. It is noted that induced precipitation of calcium carbonate is employed successfully in some water softening operations; whereas the results of Corsaro[11] discouraged the visualization of appreciably induced precipitation of hydroxyapatite. If induced precipitation of calcium carbonate is responsible for the observed decrease in sludge volume effected by the return sludge, it would be expected that the best results would be obtained below pH 11.0 where a greater fraction of the precipitation would consist of calcium carbonate.

The design of a practical system for treatment of digester supernatant liquor by lime precipitation would involve the conception of lime dosages, lime feed rates, agitation, return sludge dosages, settling periods, and possibly stripping-bioaeration. The selection of a lime dosage would depend upon the desired residual of phosphate and the characteristics of the supernatant liquor. In general, it would seem logical to treat supernatant liquor to about the same residual phosphate concentration as would prevail in settled sewage (e.g., 15 to 30 ppm). Such a practice would avoid the imposition of a shock load of phosphate during periods of recycle of supernatant liquor to the influent of the sewage treatment plant.

---

11 Corsaro, G., P. Landerbach, and H. Schwantje, JAWWA 56, 3, 347 (1964).

Although the results of the present study showed phosphate residuals in treated supernatant to differ between samples and with the addition of return sludge, it would appear that lime treatment to a pH level of 11.0 to 12.0 would usually produce residuals of from 20 to 30 ppm.

Lime feed rates and agitation intensity were not evaluated as variables in the investigation. From consideration of theory, it can be deduced that low rates of lime addition would assist in the avoidance of excessive supersaturation that could lead to spontaneous precipitation of microcrystals. Also, it was observed that some of the best settling sludges were obtained in experiments where a low rate of lime feed was employed to facilitate adjustment of pH to a specified value. In the absence of quantitative information, it is recommended for design that lime feed can be extended over a period of for 10 to 20 minutes to allow time for decomposition of reaction product on return sludge nuclei at low levels of supersaturation. An additional reaction period of 10 minutes is recommended to provide for reasonably complete dissolution of the lime.

The results given on the following page indicated increased effluent suspended solids and increased phosphate residuals with increased dosage of aerated return sludge. The-implication was that the structural integrity of the return sludge was impaired during the 24-hour storage period presumably by biological action. A possible remedy to this situation would be to shorten the storage period, which was selected arbitrarily, and to reduce the intensity of shear present in the mixed reactor. In general, a low shear environment is desirable for biological >ludges. Therefore, agitators incorporating low tip speeds and back slopes are recommended for lime-supernatant reactors. Judkins[12] demonstrated the existence of an optimum intensity of agitation relative to sludge settling and dewatering characteristics for lime-acid waste sludge systems. Excessive agitation was shown to impair sludge settling and dewatering characteristics, presumably through erosion of the sludge structure. Inferior results were obtained at low levels of agitation, possibly because of attrition between settled particles and moving bed load. There is reason to suspect that lime-supernatant liquor sludge systems may behave in similar fashion.

The results of this investigation indicated generally a progressive reduction in sludge index with increased return sludge dosage. However, the most dramatic reduction in sludge index was obtained with return sludge dosages of

---

[12] Judkins, J. F., Jr., Dissertation for Degree of Doctor of Philosophy, Virginia Polytechnic Institute, Blacksburg, Virginia (June, 1967).

EFFECT OF LIME TREATMENT ON QUALITY OF LIQUOR
UNAERATED SUPERNATANT

Determination	Raw Supernatant	Settled Treated Supernatant	Percentage Decrease
pH	7.8	12.1	--
Alkalinity, ppm as $CaCO_3$	3050	2260	26
Hardness, ppm as $CaCO_3$	1160*	785*	32
Total Solids, ppm	3960	2130	46
Volatile Solids, ppm	2180	849	61
BOD, ppm	560	300	46
Phosphate, ppm as PO_4	172	11.5	93

*representative value

from 1.2 to 2.0 times the weight of precipitate formed on a dry weight basis. A settling period of 12 hours would seem to be a reasonable design value to provide essentially complete sedimentation of phosphate and good sludge compaction.

Generally, it would seem desirable to include a stripping-bioaeration operation in the flow sheet of a treatment process for digester supernatant liquor. The benefits derived therefrom would appear to be a 25 to 45 per cent reduction in lime dosage, a 35 to 45 per cent reduction in sludge volume, and an effluent much improved in quality. The principal mechanism involved in the reduction of lime dosage appeared to be stripping inasmuch as the reduction in BOD was substantially less than the reduction in lime dosage, and a pronounced upward drift in pH was observed. Since the fractions of carbon dioxide and ammonia are small in the neutral to slightly alkaline pH range of supernatant liquor, a stripping process would be expected to be relatively inefficient.

Experience with aeration of supernatant liquor indicated that aeration periods of two hours did not reduce the lime dosage materially. It appeared that if long stripping periods were to be required, the oxygen in the air could be used to advantage in a simultaneous bioaeration process. The results indicated a substantial reduction in lime dosage was effected during 24 hours of aeration, and that additional aeration was less effective in this regard.

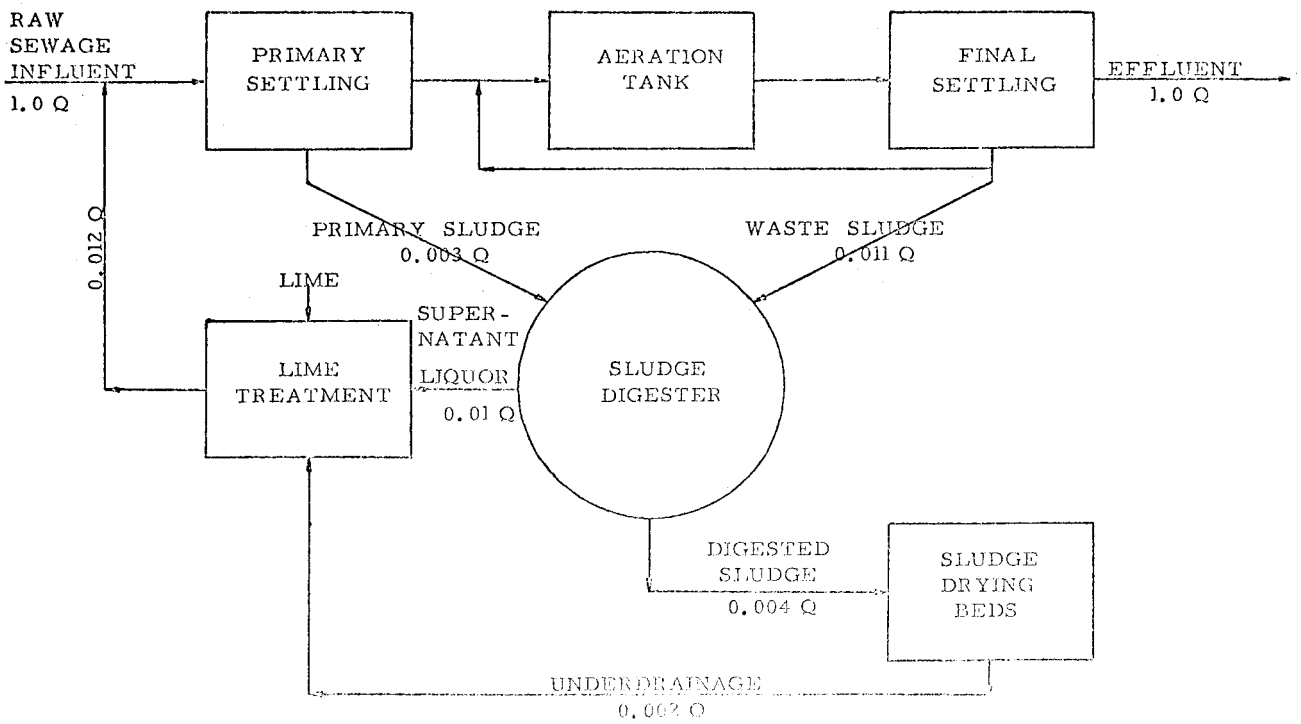
However, effluent quality was improved by 48 hours of aeration so this period is advocated for design.

The conception of a flow sheet for lime treatment of supernatant liquor would involve consideration of a number of factors including the volume to be processed and the frequency of withdrawal of supernatant from the sludge digester. The volume of supernatant depends upon the size of the connected population, the type of treatment provided and the operating practices employed. The volume of supernatant liquor (plus sand bed drainage) per thousand connected population per day may amount to about 500 gallons for trickling filter plants and about 1,400 gallons for plants incorporating the activated sludge process. The release of supernatant from sludge digesters may be continuous, or periodic over intervals ranging from several times per hour to a week or more, depending upon the design of the sludge digestion system and operational practices.

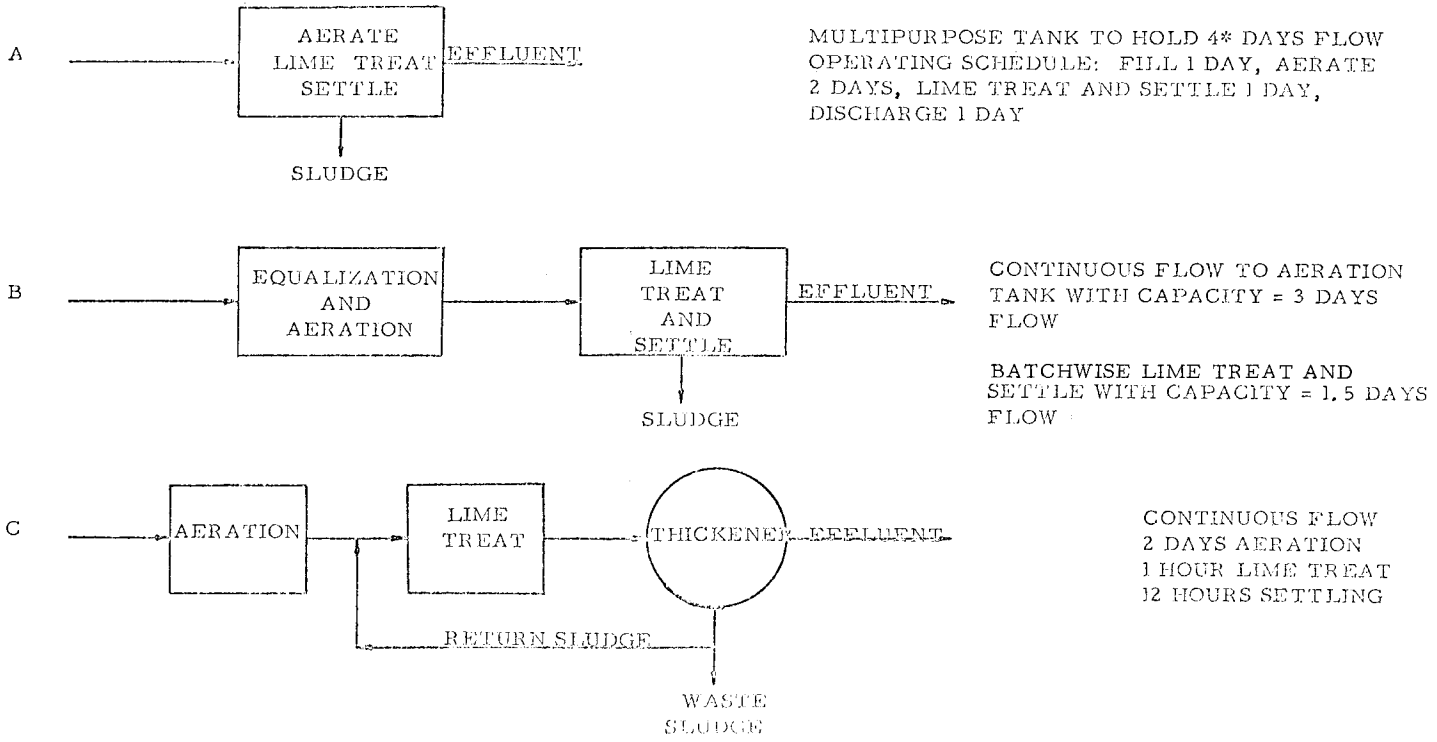
The diversity between treatment plants suggests that a treatment process for supernatant liquor would have to be subject to a wide range of modification in order to adapt to specific situations. n treatment plants employing separate sludge digestion and sand drying beds, the overall flow sheet might be similar to the configurations illustrated on Page 28. Many options are possible for the phosphate removal process - three possible flow sheets are illustrated on Page 29. The first flow sheet on Page 29 employs a single multipurpose tank, providing about four days of detention, in which aeration, lime treatment and sedimentation are effected on a batch basis. Such a scheme might be applicable at a treatment plant with a small volume of supernatant and a withdrawal period of every three days or twice a week. The system features simplicity of operation and low capital outlay for low flows.

The second flow sheet could be utilized for short-period intermittent withdrawals of supernatant or for continuous withdrawal of supernatant. The flow sheet incorporates an aeration-equalization tank to store the flow to allow for subsequent batchwise lime treatment and sedimentation in a second tank on a daily basis. The aeration-equalization tank is visualized as providing from 2.5 to 3.0 days of detention and the treatment-sedimentation reactor would provide about 1.5 days of detention. The process would feature one lime treatment per day and could incorporate lime treatment in the presence of return sludge to improve sludge settling characteristics. This process scheme would be feasible for larger flows than would be normally feasible for a single multipurpose tank.

The third flow sheet could be employed with intermittent or continuous withdrawal of supernatant liquor. The process features aeration-equalization followed by continuous flow lime treatment and settling. It is visualized that the detention times provided by the aeration tank, the lime reactor, and the sludge thickener would be



HYPOTHETICAL FLOW SHEET FOR ACTIVATED SLUDGE PLANT



HYPOTHETICAL FLOW DIAGRAMS FOR TREATMENT OF
SUPERNATANT LIQUOR BY BIOAERATION AND LIME

two days, 1.0 hour and 12 hours respectively. The process is adaptable to instrumented control, and would be expected to yield sludges with relatively good settling characteristics. Continuous flow processes are most applicable to large flows. The provision of stages in the aeration tank and in the lime treatment reactor would warrant consideration.

The increase in capital cost effected by the provision of lime treatment of digester supernatant liquor in a sewage treatment plant is estimated as 2.5 per cent for a trickling filter plant and six per cent for an activated sludge plant. The cost estimates include an allowance for expansion of sludge drying facilities. The operating cost for lime is estimated as $1.50 per mgd for a trickling filter plant and $4.50 per mgd for an activated sludge plant.

The overall efficiency of phosphate removal in a sewage treatment plant is dependent upon the efficiency of capture of phosphate by mechanisms of sedimentation and biological treatment. The role of lime treatment of supernatant liquor would be the provision of a positive purge of phosphates from the system prior to recycle of the treated supernatant through the treatment plant. It has been estimated that about three-fourths of the phosphate captured as sludge may be recovered in the supernatant liquor if sludge digestion is employed. Therefore, it is essential that this source of phosphate be removed from the system if efficient phosphate removal is to be achieved at sewage treatment plants. For trickling filter plants, phosphate removals of from 10 to 40 per cent are probably representative of performance. With activated sludge plants, phosphate removals of from 30 to 80 per cent appear representative for systems in which supernatant liquor is disposed of by separate lagooning. At one plant an average removal of 89 per cent was reported for an 11-day period.[13] Presumably, a lime treatment process would serve in lieu of the separate lagooning of a digester supernatant liquor. The lime treatment would be expected to yield about the same residual phosphate concentration at a given pH regardless of the influent concentration, and the dosage would be fairly independent of the phosphate concentration so long as the concentrations of bicarbonate alkalinity and ammonium ion were present in gross excess of the phosphate. However, differences in phosphate concentrations in raw supernatant could influence sludge settling characteristics materially. Increased concentrations of phosphate would be expected to adversely affect sludge settleability.

---

[13] Vacker, et al, JWPCF 39,5,750 (1967)

It is a matter for conjecture whether the removal of 50 to 80 per cent of the phosphate from sewage by adjustment of process conditions and treatment of supernatant liquor will resolve the problem of overgrowths of aquatic plants in receiving watercourses. However, it is evident that the removal of any significant fraction of phosphate will upgrade water quality. The proposed process is practical from the standpoint of cost and effects on across-the-board improvement in the quality of the supernatant liquor to be recycled to the sewage treatment process. No problem of high effluent pH is expected because of the high dilution and buffer provided by the sewage.

Conclusions

The following conclusions have been derived from and pertain to the experimental studies on lime treatment of sludge digester supernatant liquor.

1. The results of previous studies showing lime treatment to be effective for the removal of phosphate from supernatant liquor have been confirmed. The pH level reached in the process is the principal variable affecting phosphate residual. A pH level of 11.0 to 12.0 usually was adequate to obtain phosphate residuals of from 20 to 30 ppm.

2. Bioaeration of supernatant liquor prior to lime treatment can reduce the lime requirement for phosphate removal and the volume of sludge yielded from the process. Two days of bioaeration reduced lime dosages by 20 to 45 per cent and the indicated reduction in sludge volume was 45 per cent.

3. The addition of previously precipitated sludge to the supernatant liquor (aerated and unaerated) prior to lime treatment increased rates of sludge subsidence and reduced the volume of waste sludge derived from the process. With aerated supernatant liquor the practical return sludge dosage of 3.2 times the weight of precipitate formed in the reaction reduced the sludge volume by 42 per cent. High unaerated supernatant liquor practical return sludge dosages of from 1.2 to 2.0 times the weight of precipitate formed in the reaction reduced sludge volumes by about 20 per cent. The overall reduction in sludge volume affected by aeration plus return sludge was 63 per cent.

4. The removal of phosphate from aerated or unaerated supernatant liquor by lime treatment is accompanied by significant removal of total solids and BOD. Some decrease in alkalinity and hardness is usually achieved. The combination of bioaeration and lime treatment produced an effluent of good quality.

5. The increase in capital cost affected by the provision of lime treatment of aerated supernatant liquor is

estimated as 2.5 per cent for a trickling filter plant and six per cent for an activated sludge plant. The operating cost for lime is estimated as $1.50 per mgd for trickling filter plants and $4.50 per mgd for activated sludge plants.

Summary

An investigation of lime treatment of sludge digester supernatant liquor for the removal of phosphate has been made. Batchwise laboratory experiments were conducted in which raw supernatant liquor and supernatant liquor subjected to bioaeration were treated with high calcium hydrated lime in a process in which return sludge was employed to determine the prospect of improving sludge settleability by particle nucleation techniques. Variables investigated were phosphate residual, pH level of treatment, lime dosage, settling time, aeration period, return sludge dosage, and sludge production.

The results agreed with previous studies indicating pH level to be the principal variable affecting phosphate residual, although some affects were attributed to coprecipitation and sludge dispersion. Generally, treatment to pH levels of from 11 to'l2 was required to obtain phosphate residuals in the 20 to 30 ppm range. A settling period of 12 hours following lime treatment produced stable phosphate residuals and effected a practical degree of sludge compaction. Two days of bioaeration reduced lime dosage by 20 to 45 per cent and reduced sludge production by about 45 per cent.

The addition of return sludge to supernatant liquor prior to lime treatment increased sludge subsidence rates, and reduced the waste sludge volume. Practical return sludge dosages ranging from 1.2 to 3.2 times the weight of precipitate formed in the reaction reduced the volume of waste sludge by 20 to 42 per cent.

A reduction in sludge volume of 63 per cent was effected by two days of bioaeration at an optimum dosage of return sludge.

MULTICOMPONENT MASS TRANSPORT

IN

AQUEOUS AND MEMBRANE SYSTEMS

Dr. George B. Wills
Assistant Professor of Chemical Engineering
Department of Chemical Engineering

Water Resources Research Center

Virginia Polytechnic Institute

Blackshurg, Virginia

August 1967

MULTICOMPONENT MASS TRANSPORT IN AQUEOUS AND MEMBRANE SYSTEMS

Objectives

The basic objective of this project has been to develop and critically test models for multicomponent mass transport in aqueous and membrane systems. More specifically, this basic aim has been pursued through the following set of subobjectives:

(a) Selection of a set of aqueous systems for detailed study followed by a comprehensive literature review to collect all pertinent data for the selected systems.

(b) Measurement of multicomponent mass transport data in a selected system over a wide range of compositions.

(c) Development of a general mathematical model for multicomponent mass transport.

(d) Obtaining optimum parameters for the mass transport models developed in (c).

(e) Determining whether or not the effective water of hydration of solutes in aqueous solutions can be reasonably determined as that value giving the best fit of the experimental transport data.

Achievement of Project Objectives

The objectives of this project have been completed with the possible exception of (b): "Measurement of multicomponent mass transport data in a selected system over a wide range of compositions." Measurements of electrical conductivity in the system NaC1-HNO_3-H_20 were completed, but multicomponent diffusion measurements were planned in this same system. To date, the equipment has been constructed, but this work will not be completed until about January 1, 1968. While the final results of this work will not be reported here, it is anticipated that they will appear in a brochure to be issued at a later day by the Water Resource Research Center at Virginia Polytechnic Institute. It also appears desirable to complete the data available for the NaN03 H_2O system by obtaining diffusion data at 25°C, and this work is also planned.

System Selection and Theoretical Considerations

The transport phenomena selected for study were diffusion, electrical conductivity, and transport number. The systems selected for detailed study were those formed from the ions H+, Na^+, Cl-, $N0_3^-$, and water, H_20. The possible binary and ternary systems are as follows:

Binary Systems	Ternary Systems
$NaCl-H_20$	$HC1-HN0_3\ H_2O$
$HNO_3\ H_2O$	$HCl-NaCl-H_20$
$NaN0_3\ H_2O$	$NaCl-NaN0_3-H_2O$
$HCl-NO_3$	$HNO_3-NaNO_3-H_20$
	$NaCl-HNO_3\ H_2O$
	$NaNO_3-HC1-H_20$

For analysis the data were divided into binary and ternary systems. A numerical procedure was then developed to extract optimum parameters from the transport data for each system.

Summary and Conclusions

A general model for multicomponent mass transport was developed. A numerical procedure was developed for determining the optimum parameters for mass transport models, and this was used to establish the optimum parameters for several systems for the particular model derived here. The mass transport model developed was shown to reproduce experimental transport data of several types over an extended range of concentrations with an average accuracy of about two to three per cent.

Water of hydration was shown to be an important parameter in the determination of the average deviation between experimental and predicted data. In two cases studied (NaCl, HCl) an optimum water of hydration was found, corresponding to a physically reasonable value for this parameter. In a third case (HNO_3) the optimum parameter was found to be zero, but there appeared to be other anomalies in this same data.

Experimental electrical conductivities were measured in the system $NaCl-HN0_3-H_20$, and optimum model parameters were extracted from this data. The comparison between experimental and theoretical results was less satisfactory for this ternary system than for the binary system in certain ranges of concentration and this was thought due to experimental errors.

It is planned to recheck the ternary conductivity data and make diffusion measurements in this same system before terminating this work.

WATER QUALITY IN RELATION TO AQUATIC PLANTS AND THEIR CONTROL

Thomas 0. Evrard
Graduate Student
Department of Plant Pathology and Physiology

Water Resources Research Center

Virginia Polytechnic Institute

Blacksburg, Virginia

August 1967

WATER QUALITY IN RELATION TO AQUATIC PLANTS AND THEIR CONTROL

Objectives

1. To determine the effects of aquatic plants on the potability of water.

2. To investigate the effects of nutrition on establishment and growth habits of prevalent aquatic plants of Virginia waters.

3. To study the effects of water components on the action and fate of herbicides in water including dispersing, degredation, and absorption by aquatic flora, fauna, and soil.

Revised Objectives

Two of Virginia's problem aquatic plants were chosen for study. Results using Chara vulgaris are given in detail, but the work related to Myris phyllum brasiliense will not be completed until next year. The latter research was stimulated by this project and is being sponsored with other than *OWRR* funds. Herbicide and nutrient uptake and translocation by chara and milfoil were studied in detail using radioactive tracers. Degradation of the herbicides, simazine and 2, 4-D by chary were also investigated. The objectives pertaining to the effects of aquatic fauna and soil on the fate of herbicides in water was deleted.

Achievement of Objectives

The ability to absorb and translocate nutrients such as phosphorous, calcium, carbon, and sulfur, both acropetally and basipetally, was established in both of the aquatic plants, chary and milfoil. The roots, or those parts of the plant which are attached to the soil, can absorb and translocate the previously mentioned nutrients with the exception of carbon. These species have also shown the ability to absorb nutrients directly from the water surrounding them. Chary was able to accumulate the herbicides, simazine and 2, 4-D, when these chemicals were supplied to the water surrounding the plant. Results show that carboxyl ^{14}C, labelled 2,4-D, was decarboxylated by the chara plant and the ^{14}C was available for fixation into sugars. Fixation of carbon was found to be light dependent and the carbon catalyzed in the plants' synthesis of sucrose.

Research Procedures

^{45}Ca, ^{35}S, ^{32}P, and ^{14}C as $NaH^{14}C0_3$, sucrose ^{14}C, 2,4-D-1-^{14}C and ring labelled simazine ^{14}C were supplied to the water medium surrounding chara. Autoradiographs were made of chara plants partitioned with eicosance (wax) barriers enabling certain portions of the plant to be treated. Plants were grown in light or

preconditioned by placing them in darkness for 24 hours prior to treatment. Chromatographic analysis were made of plants treated with $NaH^{14}CO_{3'}$ ring labelled simazine -^{14}C, and 2,4-D-1- ^{14}C.

Results

1. Chromatographic analysis of simple water extracts showed that sucrose and glucose were the predominent sugars found in chara with sucrose being the most dominent

2. Images produced on X-ray film by autoradiography showed that ^{14}C, when applied to the water medium as $NaH^{14}CO_{3'}$ moved both acropetally and basipetally in chara when the plants were subjected to periods of light. Movement of ^{14}C from treated rhizoids (soil attachment parts) to untreated areas was not detected on the film even after four days of exposure to the solution containing NaH14CO3. ^{14C} movement occurred from morphological plant apexes and bases in light. However, when the plants were preconditioned by placing them in darkness for 24 hours prior to the ^{14}C treatment and remained in the dark for an additional 24 hours, no ^{14}C movement was detected in the untreated portions of the plant from the morphological apexes or bases.

3. When the ^{14}C was supplied in the water medium as sucrose,-^{14}C movement occurred both acropetally and basipetally in the light and dark. Slight movement out of the treated rhizoids was detected also.

4. Chromatographic analysis showed that when $NaH^{14}CO_3$ was supplied to the water medium surrounding chara, the ^{14}C was synthesized into sucrose and other metabolites in the light, but ^{14}C fixation did not occur in the dark.

5. Since chara is a type of nonvascular filamentous algae, movement of the radio tracers from cell to cell must be considered intercellular movement. These results indicate that ^{14}C fixation or synthesis into an organic molecule is light dependent. Detected intercellular movement of 14C occurs when the ^{14}C is synthesized into an organic molecule such as sucrose.

6. The images produced on X-ray film from partitioned chara plants exposed to ^{35}S, ^{45} Ca, and ^{32}P disclosed radio tracers movement throughout the plant when applied in the water medium surrounding the partitioned plant parts. Acropetal and basioetal movement was detected in all cases. Rhizoids appeared to be functional in absorption of the tracers and images produced on the X-ray film indicated that movement out of the treated rhizoid occurred even though the area treated was relatively small. The thallus was also functional in absorption and translocation of these elements from treated to untreated areas.

7. Movement of ^{32}P, ^{45}Ca, and ^{35}S in trough partitioned plants occurred from morphological plant apexes and bases in both light and dark periods of the experiment. However, in ^{32}P treated plants, lighter images were produced from the untreated portions of the autoradiograph made from plants preconditioned in dark than images from those grown in light.

8. Chara was found to absorb nutrients directly from the surrounding water and from the pond bottom by way of the soil attached parts. These nutrients were transported throughout the plant. The results indicated phosphorous uptake by chara might be more pronounced in continuous light. There was evidence that nutrients from water might be more effective by water fauna than by chemical means.

9. Movement of ^{14}C, supplied as carboxyl labelled 2,4-D-^{14}C to the water surrounding chara, was not great. Chromatographic analysis of plant extracts indicated that chara could decarboxylate the 2,4-D and that the ^{14}C released was available for fixation into glucose and fructose, found as the disaccharide sucrose in the plant.

10. Chara was not found susceptible to the effects of 2,4-D at rates up to 100 ppm when applied to the water medium surrounding it. The ability of this plant to decompose the 2,4-D molecule may account for its resistance.

11. Application of simazine to the water medium surrounding the plant at concentrations of 2 to 4 ppm, was found to be an effective herbicide for the control of chara in all of the field trials. However, very little movement was found in the chara when simazine was applied to isolated portions of the plant. For simazine to be an effective control, it appears that each cell must absorb the herbicide.

12. The chromatograms prepared by chromatographing known solutions of ring labelled simazine -^{14}C with chara plant extracts prepared from plants treated with ring labelled simazine -^{14}C produced radioactive areas in the chloroform, hydrochloric acid, and methanol portions of the extracts. The radioactive areas in the chloroform and methanol extracts appeared to be very similar to those produced by the chromatographed known ring labelled simazine -^{14}C. The greatest activity was found in the hydrochloric acid portion of the extract. The results show that chara can accumulate simazine from the water surrounding it and convert the herbicide into a form which is not chromatographed as simazine.

EVALUATION OF GEOHYDROLOGIC FACTORS IN ESTIMATION OF RUNOFF COEFFICIENTS ON WATERSHEDS EMBRACING MULTIPLE GEOLOGIC TERRANES

Dr. Byron N. Cooper
Professor of Geology
Department of Geological Sciences

Water Resources Research Center

Virginia Polytechnic Institute

Blacksburg, Virginia

August 1967

EVALUATION OF GEOHYDROLOGIC FACTORS IN ESTIMATION OF RUNOFF COEFFICIENTS ON WATERSHEDS EMBRACING MULTIPLE GEOLOGIC TERRANES

Objectives

This project involves a study of the upper 15 square miles of the watershed of Peak Creek in Wythe and Pulaski Counties, Virginia, which feeds Gatewood Reservoir for the town of Pulaski. This reservoir is underlain by sandstone and shales, limestones and dolomites, and limestones and calcareous shales ranging in age from Cambrian to Mississippian. This area has been geologically mapped in detail by Cooper[1] and Webb[2]. The mapping provides an accurate basis for determining the areas underlain by different types of bedrock.

Procedures

Gaging equipment was installed at seven localities in the area to measure rainfall and stream heights for various stages of discharge, and current measurements were made to provide the additional data needed for calculating discharge rates for different water-gage heights for carefully surveyed stream cross sections by the gaging wells. The stations were selected on the basis of a careful study of the area and the equipment was installed in the late Spring of 1966.

With the installed equipment, stream discharge data were accumulated for sample areas of different kinds of bedrock in the reservoir area. One master gaging station just below Gatewood Dam monitored the water released from the impoundment area. Allowances were made for evaporation loss in order to determine the total discharge that would have taken place if the dam and reservoir of impoundment had not been present.

---

1 Cooper, Byron N., Geology of the Draper Mountain Area, Virginia, Virginia Geological Survey Bulletin 55, 98 PP.,(1939).

2 Webb, Fred, Geology of the Big Walker Mountain-Crockett Cove Area, Bland, Wythe, and Pulaski Counties, Virginia, Ph. D. Dissertation, Carol M. Newman Library, Virginia Polytechnic Institute, 171 pp. (1965).

Results

Two very significant variations in rainfall-runoff relations were noted: The Mississippian-Devonian sandstone-shale terranes have an amazingly high runoff factor amounting to 52.5 per cent of the total precipitation; and valley-forming limestone-dolomite terranes have a runoff factor of only 27.3 per cent.

Normally, in estimating the direct runoff, a rule-of-thumb figure of 30 percent or one-third of the total precipitation is assumed to be valid. However, from the data obtained in the upper reaches of Peak Creek, such an assumed figure is inapplicable in any accurate estimation of the discharge of a drainage basin if Mississippian-Devonian sandstones and shales predominate as they do in the Peak Creek watershed. Because of the fact that the sandstones and shales make up more than 80 per cent of the watershed area feeding Gatewood Reservoir, the large runoff factor of 52.5 per cent of total precipitation is especially important.

In evaluating small impoundment areas in the Central Appalachians, the great variation in discharge from sandstone-shale terranes compared to that from limestone-dolomite terranes needs to be taken into consideration. In general terms, in order to impound a given quantity of surface water, almost twice as large an area underlain by limestone and dolomite will be needed compared to the watershed area underlain by sandstone and shale.

Some of the best, small reservoirs of impoundment are located on Mississippian-Devonian sandstones and shales, and in evaluating their potential for impoundment of surface water, it would appear reasonable to assume a runoff factor of 50 per cent of total precipitation instead of the commonly used 30 per cent or one-third factor.

The effect of miscalculating the probable impoundable runoff in a watershed increases with decreasing size of the watershed. Preliminary results of the study suggest strongly that evaluation of small reservoir sites in the folded Appalachians of Western Virginia cannot be made with any accuracy without knowing the rainfall-runoff characteristics of different kinds of bedrock occurring in the impoundment area.

Because bedrock geology controls relief, topographic fabric, slope characteristics, nature of the forest cover, solid characteristics and amount of infiltration, the nature of the geologic terranes is the primary factor in determining the proportion of rainfall that leaves as direct runoff.

FLOOD DAMAGE ABATEMENT

STUDY FOR VIRGINIA

William R. Walker
Director
Water Resources Research Center

Water Resources Research Center

Virginia Polytechnic Institute

Blacksburg, Virginia

August 1967

FLOOD DAMAGE ABATEMENT STUDY
FOR VIRGINIA

Objectives

Almost all of the river basins of the state have experienced extensive water damage at some time in the past due either to high intensity rains over extended periods of time or from hurricanes which periodically harass the coastal regions. The economic loss has not been limited to actual physical damage in the flooded areas, but extends to the general economy of the state by interfering with business, disrupting transportation, and causing a drain on other resources which provide relief to distressed localities.

Results

Today, most of the efforts directed toward reducing this economic drain has been directed to flood prevention measures (dams, levees, etc.) with little activity in the general area of flood damage mitigation. Our investigation reveals that the general populace has been lulled into a false sense of security as to the extent of relief being provided by flood prevention measures, and that there prevails in many communities complete indifference or active resistance by local leaders to zoning, subdivision regulations, etc., which could reduce damages in a community which has had a rather extensive history of water damage. This situation prevails in the mountainous areas of the state where the only convenient building sites are on the narrow flood plains in the valleys. It also exists very extensively in areas which have undergone explosive-type urban expansion. The study seems to indicate that the present situation will not he changed until such time as the state government takes more active leadership in the area of flood damage prevention. It will probably take a proper mix of the "carrot and big stick" to accomplish the needed reforms. It is hoped that the legislators will read our report and he moved to action. It will require dedication, perserverance, and an astute politician to obtain the legislation necessary. Armed with this report, legislators will have, for once, an appraisal of the magnitude of the problems, documented history of the results of past inaction, and some guidelines for improving the situation in the future.

QUEUEING MODEL

FOR POLLUTION TRANSPORT

IN STREAMS

Dr. William A. Parsons
Professor of Civil Engineering
Department of Civil Engineering

Water Resources Research Center

Virginia Polytechnic Institute

Blackshurg, Virginia

August 1967

QUEUEING MODEL FOR POLLUTION TRANSPORT IN STREAMS

Objectives

The project was authorized originally for the purpose of applying the queueing theory, probability theory and finite Markov chains to the stochastic variation in stream pollution. Objectives were to predict quality and quantity of stream flow based upon temperature, pattern of flow, shape of channel and location of dams, and pattern and type of loading of pollutants.

Revised Objectives

In June, 1966, the principal investigator, Professor F. E. McJunkin resigned and Dr. W. A. Parsons assumed direction of the project. The queueing theory approach was altered in favor of a modified linear regression model. A more correct title for the project now would be "A Regression Model for Water Quality Estimation in a Small Watershed." The regression model was designed to improve upon the procedures suggested by Churchill and Buckingham,[1] who related independent variables such as stream flow, temperature, and biochemical oxygen demand to the dependent variable of dissolved oxygen drop between upstream and downstream points.

The regression model would have dissolved oxygen concentration as the dependent variable with independent variables of dissolved oxygen upstream (above the sewage treatment plant), biological oxygen demand (pounds of oxygen per day) in the stream at site of sewage treatment plant, stream flow, stream temperature, benthal demand, algae growth, and slime growth.

After the model was established, it was to be analyzed by systematically deleting the variables and determining the significance of each deletion on the altered model. Theoretically, the test would result in a model containing only significant parameters.

Basically, the research project was to establish time of transit for stream water flowing from the sewage treatment plant to the sag point. Dissolved oxygen, biochemical oxygen demand, and stream temperature were to be measured at the point of time (t), while dissolved oxygen, biochemical oxygen demand, algae, etc., were to be measured at the sag point at time $(t + t_t)$ where t_t is time of transit.

---

[1] Churchill, 14. A., and R. A. Buckingham, Sewage and Industrial Wastes, p. 517, (April, 1956).

When sampling began in July, 1966, it was discovered that the methods for ascertaining benthal, slime and algae effects were not sensitive enough for determinations. For benthal, no other determination technique was available in a study of this type. The benthal effects probably would not be important as the stream had a large gradient which resulted in turbulent flow and an absence of deposits. Slime effects, which would probably be more important, could not be measured because the time of transit was too small to permit measurable differential growth to take place on the Aufwuchs meter. Since another applicable method was not available, the slime determination was abandoned.

Algae effects were thought to be important and their deletion would appreciably influence the model. To compensate for the algae deletion, two models were formulated: a day model (with algae respiration present), and a night model (without algae respiration). The two models would then be tested to ascertain if they were significantly different. In addition, each model was to be tested further by deleting the remaining variables.

Site Description

Stroubles Creek, located in the New River Basin, Montgomery County, Virginia, was selected as research site. At the initial point of measurement, the stream has a mean flow of approximately four cubic feet per second.[2] The watershed is predominantly rugged terrain typical of the Appalachian Plateau Region.

The sewage treatment plant for Blacksburg serves a population of approximately ten thousand persons. The plant's process consists of primary sedimentation followed by a trickling filter and final sedimentation.

Data Collection

1. Sag Point. The dissolved oxygen content of the stream was to be measured at the sag point as determined by the dissolved oxygen profile of the stream. Dissolved oxygen determinations were made at selected points along the stream for a distance of four miles. The sag point was found to be approximately two miles downstream from the sewage treatment plant.

2. Time of Transit to Sag Point. Dye studies, using uraine dye, were conducted to determine the time of transit. A Hach Chemical Company Chlorine Analyzer (Model 1119) was adapted and used as a colorimeter to measure the dye concentration at the sag point. The dye was added at the sewage treatment plant and dye curves plotted by

---

[2] Stream flow has not been gaged except during the research period.

continuously monitoring the stream at the sag. A strip chart recorder plotted the dye concentration versus time. A typical longitudinal dispersion of the dye in the stream caused the dye concentration to persist in the stream for approximately 20 minutes, thus the peak dye concentration was taken as the time of transit. The time of transit varied inversely with the stream flow with a maximum time of transit being 12.5 hours at low flow (approximately 3.5 cfs).

3. Dissolved Oxygen Concentration. The dissolved oxygen concentration was measured with a Yellow Spring DO meter at the sag point and 50 yards upstream from the sewage treatment plant outfall.

4. Biochemical Oxygen Demand. Samples were taken in the stream above the plant from the sewage treatment effluent, and at the sag point downstream. The Biochemical Oxygen Demand of these samples was determined by the single dilution technique of Gellman.[3] The laboratory procedure of the above technique was to saturate the sample with air immediately upon return to the laboratory, add 5 ml of O.1N Sodium Thiosulfate to remove the chlorine residual, provide seed from downstream receiving waters, measure the dissolved oxygen concentration, and then stopper the bottles. The bottle was incubated at 20°C and the oxygen concentration checked daily. If the depletion of oxygen was greater than 4.0 mg/l, the sample was aerated before restoppering. Plots of oxygen depletion versus time were prepared and the five-day BOD determined.

The Biochemical Oxygen Demand desired was the quantity present in the stream (pounds per day) below the sewage treatment plant outfall. This was obtained by weighing the BOD upstream by the stream flow and the BOD from the plant by the effluent flow rate, i.e., $BOD_s = 5.4\ (BOD_p)\ (Q_p) + 5.4\ (BOD_u)\ (Q_u)$, where:

BOD_S = BOD immediately below sewage treatment plant outfall; (Pounds per Day)

BOD_p = BOD of sewage treatment plant effluent; (mg/1)

BOD_u = BOD of stream water above the plant; (mg/1)

Q_p = Flow rate of sewage treatment plant effluent; (cfs)

Q_u = Flow rate of stream above plant; (cfs)

5. Flow Rate. The plant effluent was measured by means of a rectangular weir at the end of the settling tank. BOD samples were collected as head measurements over the weir were taken. A rock dam was used to

---

[3] Oxford, H. E., M. C. Rand, and I. Gellman, "A Single Dilution Technique for BOD," Sewage and Industrial Waste, Vol. 25, p. 284, (`larch, 1954).

divert the flow across a broad crested rectangular weir which was built in the stream to measure stream flow at thesag point.

6. Temperature Measurements. The temperature of the water was measured by means of athermocouple attached to the DO meter. The temperature used in the model was that determined in the stream above the sewage treatment plant at the time the upstream BOD samples were taken.

7. Benthal Determinations. The benthal demand was determined by placing an inverted plastic bucket on the stream bottom at the sag point and measuring the difference in the initial and final oxygen concentration within the bucket during the flow time from the sewage treatment plant to the sag point.

8. Algae Determinations. The algae effects were to be ascertained by either a determination of chlorophyll concentration in the stream, or a measurement of differential growth of slime and algae on an Aufwuchs meter.

Chlorophyll was concentrated by means of a centrifuge and a spectrophotometric method was used to estimate the chlorophyll content. The spectrophotometric method measures the optical density of light passing through an acetone dilution of the concentrated water sample at two different wave lengths. The creek samples did not exhibit any difference in optical density indicating the chorophyll present was too small for determination by this technique.

The Aufwuchs meter is simply a concrete block used to hold a rectangular piece of plastic. The measurement of slime and algae is obtained by measuring the thickness of the plate at the specified times. The time of transit was not a sufficiently long time to obtain the required differential growth.

Discussion

The purpose of the data collection and analysis was to formulate an equation to estimate the dissolved oxygen concentration downstream from a point pollution source. Originally, the model was visualized as containing a parameter for algae effects. The parameter would have been negative during night flows to reflect secondary loading from algae and it would have been positive during day flows to reflect the production of oxygen by photosynthetic mechanisms.

As discussed above, the estimation procedures for algae were ineffective, requiring the classification of flows as either night or day. This was reflected in the sampling schedule. Therefore, two models were formulated, one for night and one for day.

The first question requiring an answer was: Did the day and night models significantly differ from one another, or were they similar? The null hypothesis that they were similar was tested against the alternate hypothesis that they were different. An F test was formulated and the procedure failed to reject the null hypothesis. The two models were apparently from the same population. The results apparently indicated that algae effects were negligible in the stream, which is a conclusion quite in disagreement with the results of McDonnell and Kountz's study in Pennsylvania on a similar stream.[4]

The second question requiring an answer was: Could variables be deleted from either model without significantly changing the model? The general linear significance test was used to investigate the alternate deletion of each variable from both equations. The results were that any variable apparently could be deleted from either model without changing the model. This conclusion is contradictory and cannot he true.

The explanation for the above results might he that the small amount of data taken was not sufficient to define the model. The error term might not be distributed normally, thus violating the assumption required in these procedures. According to the central limit theorem, the error term will approach normality when a large number of samples are taken. The quantity of data taken was not sufficient to guarantee a normally distributed error term.

The data collection for the project was not initiated until early August because of attempts to utilize Reed Creek downstream from the Wytheville, Virginia Sewage Treatment Plant as the test site. After location on Stroubles Creek, summer thunder showers and unusually high flows for the late summer season reduced the number of days that the stream could be utilized for data collection, resulting in a lack of data.

---

[4] McDonnell, A. .J., and R. R. Koontz, "Algae Respiration in a Eutrophic Environment," Journal [later Pollution Control Federation, p. 381, (May, 1966)

Conclusions

The results of the study are inconclusive. When the two models for day and night flows were formulated, tested, and compared, no significant differences were found. To complete the analysis, each variable was deleted from the models and F tests determined for the deletions. Conclusions drawn from F tests results were that any variable could be deleted from either model with little significant change. F test statistics from the data was 0.88775, a figure well above any rejection value, regardless of significant level.

The above test results are difficult to justify. Large growths of algae found in the stream should have been noted in the day and night models, but instead, the models were comparatively alike. Also, the fact that deletion of any variable would produce insignificant changes in either model is unlikely. The inconsistencies might be corrected by increasing the number of data points and by developing a better method for estimating algae effects.

RELATION OF SELECTED ENGINEERING LAND TREATMENTS TO SOIL AND WATER STORAGE AND RAINFALL USE EFFICIENCY

James H. Lillard
Professor of Agricultural Engineering
Department of Agricultural Engineering

Water Resources Research Center

Virginia Polytechnic Institute

Blacksburg, Virginia

August 1967

RELATION OF SELECTED ENGINEERING LAND TREATMENTS TO SOIL AND WATER STORAGE AND RAINFALL USE EFFICIENCY

Objective

The research summarized in this annual report is a continuation of the work initiated late in fiscal year 1966. The experimental design and procedures followed in fiscal year 1967 were identical to those set forth in the annual report for 1966. Experimental plots have been instrumented for data collection for the summer of 1967.

Two radically different row crop tillage systems, conventional (clean) tillage and no-tillage, are being studied. In the conventional tillage system, several tillage operations are required for seedbed preparation, whereas in no-tillage, as the name implies, no tillage operations are required. In the no-tillage system grass sod is chemically killed and the row crop is planted in the resulting mulch. Limited experimental results indicate superior growth and yields from this system. These results indicate better water conservation and improved environmental conditions in the topsoil profile. From a practical viewpoint the soil and water conservation and economic advantages or value of such a farming program to the agriculturist become quite numerous. For example, erosion and surface runoff will normally be less on the no-tillage areas. Better crop growth and yields are normally experienced. Land-use patterns can be altered to obtain higher production management efficiency.

One of the major objectives of this program is to gain a better understanding of the water conservation potential of no-tillage and conventional tillage systems. It is hoped that this objective may be achieved by collecting sufficient hydrologic and climatic data over a statistically designed experiment so that a complete water budget may be maintained during the growing season. From these data, water use efficiency by plants and water storage efficiency of the two systems may be compared. The ultimate goal is to develop a prediction model whereby the moisture conditions under the two systems may he estimated. With these estimates the time of drought may also be evaluated for given conditions.

Results

One year's data has been collected, although it was not in the detail desired for the reasons given in the 1966 annual report. The data has been reduced, summarized and stored on magnetic tape for final analysis in the fall of fiscal year 1968.

Soil moisture data collected during fiscal year 1967 show that a higher moisture content was maintained in the 0-12 inch profile of the notillage system, while a lower moisture content was observed at the lower depths. Corn on no-tillage plots gave superior growth, which would be accompanied by a more massive root system, caused the extraction of more water at the deeper depths. Detail sampling procedures are being designed to test this theory during fiscal year 1968.

Short term drought conditions constitute a yearly problem for Virginia agriculturists. It is felt that the no-tillage system, with its superior water conservation potential, can alleviate some of these problems. During prolonged droughts moisture will become deficient in both systems. However, the no-tillage system serves as a buffer against short drought periods of one, two or three weeks. Data collected this past year indicated that the drought-free period could he extended two to three weeks by using the no-tillage system.

Two computer programs have been developed to analyze soil moisture data collected by nuclear soil moisture equipment. The total number of thermal (slow) neutrons counted over one minute time periods, plus a calibration table serves as input to the first program. The soil moisture in percentage by volume is determined for given depths and stored on magnetic tape. The second program utilizes as input the output from program one. The data are sorted and coded for a factorial design analysis of variance. The total moisture content for the soil profile is determined by three and six inch increments to a maximum depth of 72 inches. The moisture may be accumulated by three and six inch increments or determined for the increment of depth in question.

Another very useful option is that plottings may be made of all possible treatment combinations at any depth desired. Single or multiple treatment combinations may be averaged over the entire experimental design for all depths and plotted.

Analysis of variance may be run using program BMD02V from the VPI computing center program library and the coded punch card output from program two. These two programs are quite useful to persons involved in soil moisture research with statistically designed experiments or simply individual isolated point measurements. Program two is being documented for publication in fiscal year 1968. Exploratory efforts have been in effect to develop a soil moisture prediction model using a modified accounting system. The model is of the form:

$$SM_t = SM_t - 1 + R - Q - ET - P$$

where:

Sli_t = Soil moisture at time t

R = Precipitation

Q = Runoff

ET = Evapotranspiration

P = Deep percolation

t = Date in question

Runoff is predicted from the model $Q = as^n + f_c$
where:

S = Unused storage capacity in the soil profile to some impeding layer

f_c = Final infiltration rate

a&n = Constants which depend on the soil type, slope, vegetal cover and season of year.

Average values are: a = 0.60 and n = 1.4

In initial studies daily ET has been determined using an empirical procedure proposed by Penman.[1] Future efforts will include a more refined procedure for ET estimates, e.g., Van Bavel.[2] Precipitation estimates came from a nearby recording rain gage. Deep percolation estimates were incorporated in the estimates of f_c.

Numerical experiments with this model using moisture data collected during 1960-1964 have been very encouraging. For the most part, very close agreement between actual and estimated values were noted. It is planned to publish details of this model in fiscal year 1968.

A more detailed sampling procedure has been made possible by the late arrival last summer of net radiation and wind movement equipment. The experimental plot design is identical to last year's layout. It has been moved to an adjacent location where good coverage for the no-tillage experiment was available.

Pictorial coverage of the research work has been maintained. The following pictures with captions illustrate the instrumentation for the spring of fiscal year 1967 and summer *of* fiscal *year* 1968. Pictures showing soil temperature and soil moisture instrumentation were given in the 1966 annual report. Figure one depicts the

[1] Levine, G., "Methods of Estimating Evapotranspiration," Transactions of the ASAE, Vol. 2, No. 1, pp. 32-34, 1959.

[2] Van Bavel, C. H. M., "Potential Evaporation - The Combination Concept and Its Experimental Verification," Water Resources Research, Vol. 2, No. 3, pp. 445-467, 1966.

two tillage systems being studied. Note the mulch cover afforded by the no-tillage. The cover provides for a maximum conservation of water as it falls and later during periods of no rain fall. The more vigorous growth of the no-tillage system is quite evident.

Figure two shows a standard weather station located beside the plot area. Precipitation, relative humidity, air temperature, pan evaporation, and wind movement data are collected at this station. Surface runoff measurements are obtained by placing sheet metal borders around three sides of the plot as partially shown in the left foreground of Figure three. The surface runoff is caught in a standard 20 foot section of flat-bottomed guttering which is embedded as shown in the photograph. Down spouting is connected to the guttering through which the water flows to the approach box of a prefabricated H-type flume. A Coshocton type soil sampler or water wheel is attached at the flume outlet as shown in Figure four. With this type of installation, one per cent of the total runoff is sampled. The aliquot is collected through a slot in the wheel and is passed downslope to a collection container where it is hand measured. The H-type flume has been so fabricated that a FW-l water level recorder can be easily installed to obtain a continuous recording of runoff. Correction factors have been determined to account for rainfall intercepted by guttering and approach channels.

Figure five shows the moisture sampling design that is being used to measure spatial variation of moisture within the individual plots. Figure six shows a net radiometer mounted at the end of a 10 foot aluminum frame which may be rotated to any desired point along the circumference of this 10 foot radius. The aluminum frame is mounted on a steel rod (Figure three) and may be moved up to maintain a constant distance between the net radiometer and the corn. A recording potentiometer for recording emf output from the net radiometer may be seen in the background. A close up with the instrument in operation is given in Figure seven.

Figure 1 - Comparison of no-tillage and conventional tillage systems.

Figure 2 - Standard weather station for collecting precipitation, temperature, relative humidity, and evaporation data.

Figure 3 - Surface runoff measurement plot with net radiometer installation in the background.

Figure 4 - H-type flume with soil sampler attached.

Figure 5 - Excess tube design for determining spatial variation of soil moisture.

Figure 6 - Net radiometer and recording potentiometer.

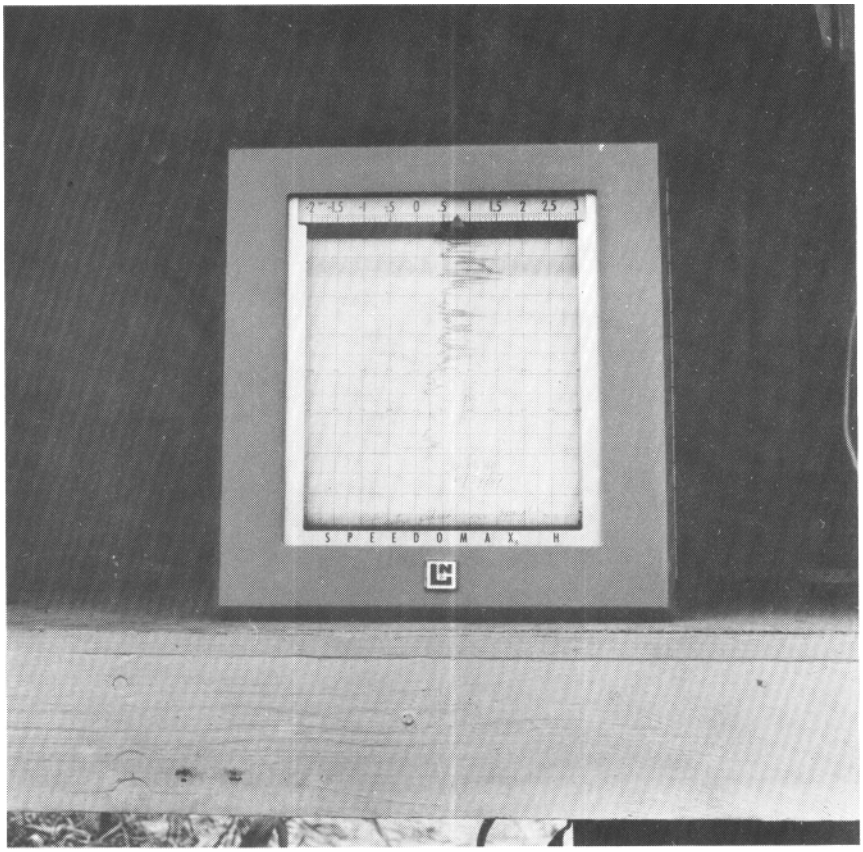


Figure 7 - Recording potentiometer.

PREDICTION MODELS

FOR INVESTMENT IN

URBAN DRAINAGE SYSTEMS

Dr. John Knapp
Professor of Civil Engineering
Virginia Military Institute

Water Resources Research Center

Virginia Polytechnic Institute

Blacksburg, Virginia

August 1967

PREDICTION MODELS FOR INVESTMENT IN URBAN DRAINAGE SYSTEMS

Summary

Research during fiscal year 1967 consisted principally of collecting and analyzing data on existing urban drainage systems. Available data were incomplete and not suited to analysis, hence, these were supplemented by correspondence with over 100 municipal, county and separate agencies that design and build drainage projects, and by visits to local, state, and federal agencies whose work involved drainage systems. Analysis of the data has resulted in various forms of prediction equations for the cost of installed storm drainage projects. Preliminary results have indicated significant factors governing the design and cost of these systems and they will guide the research during the coming year. The prediction equations developed thus far are useful in predicting investment costs for systems already fully designed, but they can be greatly improved to serve the planning task of selecting optimum designs.

Collection of Data

Several sets of information on typical urban drainage systems were collected from municipal agencies around the country. An initial set of data was taken from "An Economic Study of Urban and Highway Drainage Systems," Technical Report No. 2, Storm Drainage Research Project, John Hopkins University (June 1965). These data were supplied by 28 municipal municipal agencies and included a total of 96 drainage systems. To broaden the scope of the current study, the original 28 agencies were asked to furnish additional information and plans of the original projects. Eleven provided information that was useful from a total of 30 drainage systems.

From a list provided by the Federal Water Pollution Control Administration, 53 additional agencies that recently completed drainage projects were asked for information and plans in order to increase the number of drainage systems in the sample set. Twenty-two agencies answered, sending drainage calculations and plans. Of these, 14 agencies provided usable information on 40 drainage systems. Thus, the total set with detailed project information, including the 11 original agencies, comprised 25 agencies and 70 drainage systems. For only 47 of the 70 systems was it possible to determine the length of all drainage lines required for an analysis of drainage density. In summary, the sample sizes were 96 in the original set, 70 in the detailed set, and 47 in the complete set with all lengths.

Analysis of Data

Various regression analyses were made on the three sets of sample data. For the original set of 96 drainage systems, the variables studied were frequency, per cent industrial area, lot size, length and slope of the main drain, per cent of upstream contributing area, ending diameter, capacity (cfs), total drainage area, and cost of construction. For the detailed set of 70 drainage systems, the variables studied were frequency, average slope of all lines, the design runoff factor, total number of inlets and manholes, beginning diameters, ending diameter, capacity (cfs), total length of lines, area, per cent of upstream contributing area, and cost.

For the 47 drainage systems from which total lengths and sizes of pipe were available ratios were computed. For example, total length of 12-inch diameter pipe to lengths of all other sizes, and the length of each size to the length of the next larger size. The average ratio in each category then was regressed on area and cost per unit area. With each of the sets of data, a separate regression analysis was made on a regional basis whenever there were more than 10 usable drainage systems within a region.

All regressions involving cost were run on the 1963 regional costs and the 1963 national average costs. Cost indexes were needed to account for time and regional differences in project costs. Most available indexes have been developed either for general fields of activity or for specific types of construction. The most popular general index is Engineering News Record's Construction Cost Index. However, in recent years when sewer construction has expanded rapidly, the ENR index has not been truly representative of sewer construction costs. The U. S. Public Health Service compiles an index for sanitary sewer construction which does not include storm drains specifically, but does provide the most representative index available for all similar construction. For this reason, it has been used throughout this study to compare costs.

The PHS index has a fixed base equal to 100 for the 36 month period 1957-59, and it has been computed for the years 1930 to the present. Computations are made with labor and materials prices in 20 regional trade centers as reported by Engineering News Record and the Bureau of Labor Statistics, U. S. Department of Commerce. Both the regional indexes and the national average index for each year are based on a hypothetical sewer project with standard cost components. Approximately 57 per cent of the costs in the standard project involve pipe, manholes, inlets, and earth excavation which can be summarized in graphical form showing cost per linear foot for each pipe size at various depths. The remaining project costs involve items such as special structures, rock

excavation, paving, profit, and overhead which vary considerably for each project and must be evaluated separately in estimating construction costs.

The PHS indexes were used to reduce reported project costs to three standards of comparison. First, the 20 regional indexes were used to adjust all project costs to their 1963 regional costs. Next, the national average index was used to find the 1963 national average cost for each project. Finally, the base regional cost for each project was determined for the period when the PHS index was 100. Little difference was found in the correlations studied with each of these costs, hence, subsequent analyses were confined to the 1963 national average costs for analyzing all data (country-wide) and the 1963 regional costs for analyzing only projects within one region.

Preliminary Results

Multiple linear regressions of all data have shown, as expected, that physical features of the drainage system account for the largest fraction of total cost. Total area and total length of lines are the main variables. Area is an obvious basin characteristic governing size and extent of systems,•and it also is the determining factor for intensity of rainfall to be handled and capacity required in the drains. Length in conjunction with area is a shape factor, but it is also a gage of drainage density which in a developed area represents articulation of streets as well as drainage courses.

Area and length account for 53 per cent of the variance of costs in the original set where length represented only the main drainage lines. In the detailed set with length representing all lines, the variance explained was 64 per cent. In logarithmic form, these percentages were raised to 70 and 77 per cent, respectively.

The variables next in importance are design features, subject to control by standards and techniques of design. Examples are the coefficient of runoff, frequency of design storm, and design discharge, all of which are interrelated hydrologic factors involved in the design of drainage systems. In particular, it was noted that the number of manholes and inlets specified had a significant effect on cost. This factor and the total length of lines, both available only in the detailed set of 70, were responsible for raising the percentage of variance explained from 53 to 73 per cent, respectively, in the linear regression analysis of the original set and the detailed set.

The factors unexplained in the regression analyses can come from a variety of sources, usually from a poor choice of the regression model or failure to include a significant variable. That they arise from special conditions in

each area, or what is more important, from a bias in the design procedure is evident in the grouping of the residuals about the regression plane. There are apparent differences in the designs and costs for drainage projects between various municipal jurisdictions. It is not clear yet whether the reason is a physical or a design factor.

EFFECT OF PUMPED-STORAGE RESERVOIR OPERATION ON BIOLOGICAL PRODUCTIVITY AND WATER QUALITY

Dr. Stuart E. Neff
Associate Professor of Zoology
Department of Biology

Water Resources Research Center

Virginia Polytechnic Institute

Blacksburg, Virginia

August 1967

EFFECT OF PUMPED-STORAGE RESERVOIR OPERATION ON BIOLOGICAL PRODUCTIVITY AND WATER QUALITY

Objectives

Routine operation of pumped-storage hydroelectric generation plants should produce a number of beneficial limnological effects. In these projects, large quantities of water are pumped back into an upper holding pool during periods of low power demand (at night and on weekends) and held for electric power generation during periods of peak demand. In summer, the recycling procedure causes a mixing of warm, oxygenated water which is pumped back with the stratified layers of water into the upper impoundment. The recycling disturbs, and to some extent, offsets the dettrimental effects of lake stratification. As water is recycled (at a rate of about 4,000 cfs), it entrains volumes of the colder, metalimnetic water of the reservoir. This entrainment facilitates the mixing of dissolved gases and nutrients in the water column and makes them available for utilization by phytoplankton. This increased utilization by plankton should be evident in an increase, or at least in a relatively high biological productivity.

Procedures

To determine the primary productivity in the pumped-storage reservoir and to establish regional primary productivity levels for comparison, assays of primary production have been carried out on Smith Mountain Lake, Virginia, and Claytor Lake, Virginia. These estimates of primary productivity have been made using the conventional ^{14}C- isotope production techniques (Steemann Neilson, 1952; Goldman, 1961). Our results indicate that although the Smith Mountain impoundment is only two years old, the lake is rapidly attaining primary production levels of a temperate, entrophic lake. Carbon assimilation figures for four stations on Smith Mountain Lake range from 68.0 mg $C/M^2/day^{-1}$ in late fall to 575.2 mg $C/M^2/day^{-1}$ in spring during the vernal phytoplankton pulse.

Results

While these assimilation rates have increased rather quickly, the rates of carbon fixation do not appear to be detrimental to water quality at this time. One of the reasons for the rapid increase in levels in Smith Mountain Lake appears to be the quantities of domestic and industrial effluents contributed to the impoundment by municipalities at the headwaters. Prior to impoundment, the Roanoke and Blackwater Rivers had handled to a large extent this effluent load. With impoundment, a catchment basin was established, and effluents pass through

the system too slowly to permit degradation. We are now attempting to establish more precisely the intensity of domestic and industrial pollution in the reservoir. We also want to know the effect of recycling large quantities of water in the pumped-storage operation in alleviating the pollution in the impoundment. Recycling does have a salutary effect in reducing the effects of pollution.

Total coliform counts at the upper end of the reservoir (Hardy Ford) exceeded 1,100 MPN/100 ml. At the confluence of the Roanoke and Blackwater arms of the impoundment, an area influenced by the recycling process, total coliform counts drop to 0-20 MPN/100 mi.

This study should provide a basis for recommendations on pumped storage reservoir operation to produce optimum biological productivity and to alleviate the effects of undesirable effluents. Our lack of knowledge on reservoirs and their limnological characteristics will be corrected through this and similar investigations.

ANALYSIS
0F
HYDROLOGIC SYSTEMS

Dr. James M. Wiggert
Associate Professor of Civil Engineering
Department of Civil Engineering

Water Resources Research Center
Virginia Polytechnic Institute
Blacksburg, Virginia
August 1967

ANALYSIS OF HYDROLOGIC SYSTEMS

Objectives

The purpose of this study is to examine the hydrologic runoff process in terms of fundamental systems analysis. The primary phase of the research is the study of model watersheds in the laboratory. Rainfall was imposed upon simply shaped (plane, rectangular) watersheds, and the runoff response was monitored. Methods of systems analysis (or information theory) were applied to the data so acquired. These data yielded results which verify that the runoff process can be described in such a mathematical manner, that is, significant parameters can be evaluated. Computer programs have been used which simulate the process by the mathematical model and demonstrate the feasibility of this approach as a design method.

The same mathematical techniques are being applied to natural watersheds with encouraging results in that the form of the response function is similar to those found in the model studies. The parameter values vary inexplicably for natural watersheds, however, and it remains to relate these variations to physical basin parameters.

Results

The results show that the rainfall excess-runoff process can be modeled by a nonlinear second order equation. The parameters (time constants and gain) can be determined from the data with considerable consistency. Scaling techniques have been attempted which promise to permit designing full scale watersheds, such as parking lots and runways, from laboratory information.

As in all rainfall excess-runoff relationship investigations, a major problem is that of determining rainfall excess, or its corollary infiltration. The laboratory phase of this research was concerned only with impervious areas. The investigation into natural watersheds is using standard methods of hydrography separation and infiltration rate averaging.

INSTANTANEOUS UNIT HYDROGRAPH RESPONSE BY HARMONIC ANALYSIS

Dr. James M. Wiggert
Associate Professor of Civil Engineering
Department of Civil Engineering

Water Resources Research Center
Virginia Polytechnic Institute
Blackshurg, Virginia
August 1967

INSTANTANEOUS UNIT HYDROGRAPH RESPONSE BY HARMONIC ANALYSIS

Objectives

The aim of this study is to develop a method to predict runoff from rainfall using linear methods, specifically harmonic analysis. Fourier coefficients are determined by harmonic analysis from events (rainfall excess and runoff) of record. The coefficients are then applied to other rainfall excess events and the resulting computed runoff compared to the runoff of record.

The method is being applied to data compiled from a number of rainfall and stream gaging stations in the Detroit, Michigan area, where data were selected because they were in a physical state compatible with available computers.

Results

The research to date shows that the method has utility in that coefficients derived from one event produce reasonably good runoff values for another storm. This is particularly true if judicious selection of the descriptive storm is made. Such a statement is to be expected from unit hydrograph application experience.

Some difficulty is being experienced in proper determination of rainfall excess. As in any rainfall-runoff relation, the lack of understanding regarding the infiltration phenomenon is a handicap.

Present efforts are directed toward finding reasons for the behavior of the Fourier coefficients. A search is on for relations between the significant coefficients and physical characteristics of the watersheds. This phase is considered important for extension of the general results into a design method. An additional hydrologic application of the harmonic analysis technique is concurrently being studied. It appears that flood routing can be routinely accomplished within acceptable limits of accuracy. (Flood routing as used here being the name for computation of discharge at a point on a stream from given values of flow at an upstream location.)

TRAINING AND EDUCATION ASPECTS

OF THE

WATER RESOURCES RESEARCH PROGRAM

TRAINING AND EDUCATION ASPECTS OF
THE WATER RESOURCES RESEARCH PROGRAM

A. New Courses Developed

Accessory Minerals (Not Interdisciplinary)

Accessory minerals in sedimentary rocks and interpretations of provenance derived from accessory mineral suites.

Advanced Petrology (Not Interdisciplinary)

Major problems in the petrogensis of sedimentary rocks.

Biology of Fungi (Not interdisciplinary)

Advanced, detailed study of fungal cells, organisms, and populations.

Carbonate Petrology (Not Interdisciplinary)

Origin, occurrence, and diagenesis of carbonate sediments and their various classifications.

Crystal Chemistry of the Rock-Forming Minerals (Interdisciplinary)

Physical properties, chemical structure, and paragenesis of the common rock-forming minerals.

Crystal Structure Analysis (Interdisciplinary)

Theory and methods of crystal structure analysis.

Crystallography (Interdisciplinary)

Study of the external geometry and internal structureof crystals.

Decision Theory (Interdisciplinary in application, not content)

A theoretically oriented course in statistical decisions with some emphasis toward practical application.

Exploration Geophysics (Interdisciplinary)

Physical properties of the earth, instruments employed in their measurement, and procedures employed in exploring the lithosphere, which employ those instruments.

Decision Theory (Interdisciplinary in application, not content)

A theoretically oriented course in statistical decisions with some emphasis toward practical application.

Exploration Geophysics (Interdisciplinary)

Physical properties of the earth, instruments employed in their measurement, and procedures employed in exploring the lithosphere, which employ those instruments.

Fishery Management (Not Interdisciplinary)

The history, theory, and practice of fishery theories underlying fish production and the application of these theories in management of fishery resources.

Fishery Science (Not Interdisciplinary)

The principles of fishery science with emphasis on the fundamentals of fishery biology and population dynamics.

General Oceanography (Interdisciplinary)

Study of major aspects of oceans and ocean basins.

Geometries (Not Interdisciplinary)

Current quantitative approaches and application of computers to problems in earth science. Statistics and operations research, methods for analyzing all kinds of geologic measurements.

Introduction to Space Groups (Interdisciplinary)

Derivation of space groups and associated geometric structure factors and electron density formulas.

Introductory Mycology (Not Interdisciplinary)

A survey of the biology of fungi, emphasizing the morphology, classification, and reproductive cycles.

Pleistocene Geology (Interdisciplinary)

Provides a basic background in Pleistocene geology and stratigraphy. Especially concerned with periglacial effects.

Queueing Theory (Interdisciplinary)

To give an understanding of the underlying principles of queueing theory with applications to specific queueing models. Submarine Geology (Interdisciplinary)

Principles and practice of geologic and geophysical investigation of the deep sea, and geologic history of ocean basins and submarine topography.

X-Ray Crystallography (Interdisciplinary)

Theory, production, and interpretation of powder and single-crystal x-ray diffraction records.

New Staff Members Added (none receive support from P. L. 88-379 funds)

Barrett, J. P.,Ph. D., Sampling

Bloss, F. D., Ph. D., Crystallography-Mineralogy

Bollinger, G. A., Ph. D., Seismology

Connelly, B., M. S., Stochastic Process

Costain, John K., Ph. D., Geophysics

Dahlberg, Michael, Ph. D., Fishery Biology

Gibbs, Gerald V., Ph. D., Crystallography-Mineralogy

Goldston, E. F., B. S., Soil Science

Good, I. J., Ph. D., Statistics

Grender, Gordon C., Ph. D., Petrology, geologic data processing

Hackett, James E., Ph. D., Geohydrology, environmental geology (appointment shared with Center for Urban and Regional Studies)

Hall, Monte R., B. S. Electron Microprobe and X-Ray Technology

Paterson, R. A., Ph. D., Botany (Aquatic Mycology)

Pratt, Richard M., Ph. D., Oceanography, Submarine Geology

Richardson, Glenn, M. S., Soil Science

Ribbe, Paul H., Ph. D., Crystallography-Mineralogy

Robinson, Edwin S., Ph. D., Geophysics

White, Harlin E., Ph. D., Forage Crops Wolfe, Dale D., Ph. D., Crop

Ecology Woodruff, John M., M. S., Crop Ecology

Staff Members Employed to Replace Those Who Retired, Died, or Moved

Caskey, J. S., Ph. D., Chemical Engineering

Chu, J. C., Ph. D., Chemical Engineering

Cibulka, J. J., Ph. D., Sanitary Engineering

Fricke, A. L., Ph. D., Chemical Engineering

Kirk, Paul, Ph. D., Botany

Randall, C. W., Ph. D., Sanitary Engineering

New Research and Training Facilities Other than Research Equipment Items

Mineral Constitution Laboratory. New building for geological sciences, embracing approximately 62,500 square feet of floor space. New cold-press hydrothermal laboratory.

Interdepartmental, Interuniversity or Regional Agreements Consummated with Respect to Improved Research and Training Capabilities

Annual allotment supports a research project in the Civil Engineering Department of the Virginia Military Institute at Lexington, Virginia. No formal agreement has been entered into between the universities. General operating procedures have been developed between the principal investigator and the Director of Water Resources Research Center. This informal agreement has worked very satisfactorily during this past fiscal year. Next year this same informal arrangement has been agreed upon between the University of Virginia at Charlottesville and the Water Resources Research Center.

B. Student Enrollment

	No. Enrolled	No. Graduating
Juniors	111	0
Seniors (Bachelor's degree candidates)	83	75
Master's degree students	101	48
Doctoral degree students	94	24
Postdoctoral degree students	2	0

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

Category of Students	No. Using Equipment, Supplies, etc.
Undergraduates	14
Master's students	9
Doctoral students	7
Postdoctorate students	0

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

Category of Students	Scientific Discipline	Number
Undergraduates	Arts and Sciences	1
	Engineering	1
Master	Civil Engineering	2
	Geohydrology	2
	Ichthyology	1
	Sanitary Engineering	1
Doctoral	Chemical Engineering	1
	Civil Engineering	1
	Engineering	1
	Ichthyology	1
	Limnology	2
Postdoctoral		0

E. Employment Status of 1966-1967 Graduates in Water-Related Fields

Category of 1.966-67 graduate by degree obtained	No. Employed in Water Related Positions in:				No. ret for	No. entr mil sere	No. unempl or unkwn
	Federal Agencies	State Agencies	Col. and Univ.	Oth er such			
Bachelor	7	10	0	7	20	8	23
Master	5	7	0	11	14	6	5
Doctoral	2	0	9	2	0	6	5
Total	14	17	9	20	34	20	33

F. Type of Employment of 1966-67 Graduates in Water-Related Fields

Cat. of grad by degree obtained	No of Graduates engaged in water-related work in:						
	University or College			Agcy or pvt wtr resources research	Oper and mgmt	Planning	Other wtr re sources work
	teach prim	resrch prim	resrch and teach				
Bachelor	0	3	0	0	21	0	0
Master	0	7	0	1	13	2	0
Doctoral	2	2	1	1	7	0	0
Total	2	12	1	2	41	2	0

PUBLICATIONS AND THESES

Publications

Wills, George B.
1967. Approximate matrix methods for multicomponent mass transport in membranes. Transactions of the Faraday Society, No. 531, Vol. 63. Pages 579-583.
Based on project A-002-Va.

Shanholtz, Vernon 0. and J. B. Burford
1967. Computer systems for the reduction and analysis of hydrologic data. ARS-41-132.
Based on project A-009-Va.

Knapp, John
1967. The economics of urban drainage. Third annual American Water Resources Conference. San Francisco. 15 pages. Based on project A-011-Va.

Wills, George B.
1966. Optimized models for multicomponent transport phenomena in aqueous solutions.. Virginia Academy of Science, Vol. 17. Based on project A-002-Va.

Evrard, T. 0.
1967. Translocation of nutrients in chara vulgaris, a nonvascular aquatic plant found in Virginia's waters. Bulletin 5. Water Resources Research Center. Pages vii + 85.
Based on project A-003-Va.

Sutton, David L.
1967. Analyses for simazine in fish and water sample from treated ponds. Northeastern Weed Control Conference. Volume 21. Page 541. Based on project A-010-Va.

Sutton, David L., and S. W. Bingham
1967. Some effects of simazine and dequat on the movement of C140, or its metabolities. Northeastern Weed Control Conference. Vol. Z1, pages 552-555.
Based on project A-010-Va.

Simmons, George
1966. The occurrence of Branchiura sowerbyi beddard in Claytor Lake, Pulaski County, Virginia. Virginia Journal of Science 17(4), pages 141-142.

Simmons, George
1967. Limnetic carbon assimilation in two Virginia reservoirs. Association of Southeast Biologists 14(2), pages 40-41. Based on project A-012-Va.

Theses

Koch, Ellis
1967. Bedrock control of rainfall-runoff relations in the Peak Creek Watershed, Pulaski and Wythe Counties, Virginia. *M. S.* Thesis, Carol *M.* Newman Library, Virginia Polytechnic Institute. Pages 48. Based on project A-004-Va.

Glennon, James M.
1967. Effect of biological pretreatment on the lime demand of digester supernatant liquor. M. S. Thesis, Virginia Polytechnic Institute. Pages 68.
Based on project A-001-Va.

Yeh, Hsin-Hsing
1967. Removing phosphates from digester supernatant liquor and optimizing the process with particle nucleation techniques. M. S. Thesis. Virginia Polytechnic Institute. Pages 77. Based on project A-001-Va.