PROCEEDINGS OF UNIVERSITY SEMINAR ON POLLUTION AND WATER RESOURCES

Volume IX 1975-1978

PROCEEDINGS OF UNIVERSITY SEMINAR ON POLLUTION AND WATER RESOURCES

Volume IX 1975-1978

Edited by
George J. Halasi-Kun
and
Kemble Widmer

COLUMBIA UNIVERSITY
in cooperation with

U.S. DEPARTMENT OF THE INTERIOR,
GEOLOGICAL SURVEY

The New Jersey Department of
Environmental Protection
Bureau of Geology & Topography

BULLETIN 75 - C

CONTENTS

INTRODUCTION

In the past three academic years, the program of the Seminar has been concentrated, besides the international and interstate aspect of the water resources problem, on the basic data collection and geodetic survey, including its interrelation with hydrology. The ninth volume is dedicated not only to oceanography and saline water but also to water resources data collecting and to some pollution problems. The entire tenth volume is devoted to the various problems of the geodetic and land surveying in connection with mapping, tidal water, basic data collection and especially the needs of the New York City-Philadelphia area. The eleventh volume is again pollution oriented handling not only water quality but also research in water resources.

Since 1975, the "Annual Meeting in Washington, D.C." has been held in the Cosmos Club with the U. S. Geological Survey as host, where each year a review of the world situation in water resources planning is the topic.

The most important activities of the Seminar besides its regular meetings were as follows:

On Sept. 21-25, 1975 in Reston, Va. the International Symposium on Computer-assisted Cartography was held and one paper was delivered on water resources oriented data bank.

In the spring and fall of 1976, two different teams of scientists from Hungary, sponsored by the U.N., visited the "Land Oriented Reference Data System" of N. J. Bureau of Geology and Topography to learn more about the water resources data bank. This system has been in operation since 1974 with the assistance of the Seminar. The visits were feasibility studies as to how to apply the system also in Hungary.

In the summer of 1976, the members of the Seminar were asked to write entries for the international "Encyclopedia on Earth Sciences, Vol. XVIII - Geohydrology and Water Resources" as they did in 1972 by contributing 20% of the articles in the "Encyclopedia on Earth Sciences, Vol. IV-A - Geochemistry and Environmental Science." (See introduction to Proceedings, Vol. V.) To date, our members committed themselves or wrote over sixty entries (25% of the volume).

On February 14-15, 1977, a "Seminar on Issues before the United Nations Water Conference" was organized in New York City with the assistance of the Seminar to prepare fifty-five participants from fifty-four countries for the United Nations Water Conference in Mar del Plata, Argentina in March 14-25, 1977. Five of our members delivered lectures to assist the United Nations in their effort.

In June 1977, the representative of Arizona State University visited the N. J. Bureau of Geology and Topography to inspect the previously mentioned data bank and its applicability to Arizona.

On August 15-19, 1977 in Baden-Baden, F. R. Germany, three members at the Conference of the International Association for Hydraulic Research, and one member at the University, Ghent, Belgium, delivered papers on water resources oriented data bank systems. Researchers from Belgium and Netherland were especially interested in the presentation at Ghent University because they are working on a similar system after they had received information about the data bank in 1974, and they wanted further details on how the system improved since then. The paper has been delivered as a supplement to the report of 1974 at the request of the University Ghent.

On August 23-25, 1977, the Geodetic Survey and Cadastre Offices of the State of Lower Saxony and the Geodetic Institute of Techn. University, Brunswick, both in F. R. Germany, were visited to gain information about the water resources mapping based on geodetic survey.

From Sept. 14, 1977 to Nov. 22, 1977, the National Academy of Sciences initiated international research exchange programs between the United States and Yugoslavia and also between the United States and Hungary. The Chairman of the Seminar was nominated as a fellow of the National Academy of Sciences to exchange ideas about water resources oriented data bank including hydrology of smaller watersheds and karst hydrology. The program generated ten lectures in Yugoslavia and six presentations in Hungary at various universities and national Academies of Science. As a further result of the trip, there were eleven articles prepared in English by Hungarian and Yugoslavian scientists for publication. In the joint program, five articles were delivered in English, German, Hungarian and Yugoslavian by members of the Seminar for publication in scientific journals of those countries. During this visit, the Water Data Banks in Zagreb, Yugoslavia and that of VITUKI in Budapest, Hungary were visited. Both centers had been informed in 1975 about the environmental data bank (LORDS) of N. J. Bureau of Geology and Topography. Finally, an exchange of scholars with fellowships, publications, and a joint research program in soil mechanics and geohydrology was initiated with the involvement of three universities in the United States (Columbia, Rutgers and Fairleigh Dickinson) and the Hungarian Academy of Sciences, Yugoslavian Academy of Arts and Sciences including Techn. Universities in Budapest, Miskolc in Hungary, and the Universities Zagreb and Sarajevo in Yugoslavia.

In the spring of 1978, two teams again visited the operating data bank of New Jersey in Trenton to check operational procedure and details of the system in order to organize similar information centers. The first team came in May of 1978 from Techn. University Stuttgart, F. R. Germany and the second team came in June of 1978 from the Techn. University Lisbon, Portugal.

Finally, the editors of the Proceedings wish to express their appreciation to all members contribution articles and lectures for the past three years. The publications were made possible only by the generous help and cooperation of the U. S. Department of the Interior-Geological Survey and the State of New Jersey, Department of Environmental Protection.

George J. Halasi-Kun
Chairman of the University Seminar
on Pollution and Water Resources
Columbia University

FEDERAL SALINE WATER CONVERSION PROGRAM

A STATUS REPORT

by

GEORGE F. MANGAN, Ph.D.

U.S. Dept. of the Interior, Office of Water Research
and Technology

(1976)

The federal saline water conversion program was authorized in 1952 as a $2 million 5-year program to develop new or improved low-cost methods for producing fresh water from sea or brackish water. It was soon obvious that $2 million dollars and 5 years was simply not adequate to make much of an impact on the problem. In 1955 the Congress extended the program to 10 years and increased the amount authorized to be appropriated from $2 million to $10 million.

The early success of the program led Congress in 1958 to pass Public Law 85-833 authorizing the construction and operation of not less than five demonstration plants in order that cost data could be obtained for the more promising desalting approaches.

The first plant was a one-million gallon per day distillation plant built at Freeport, Texas using the vertical tube technology. A second million gallon per day plant was built at Point Loma in California and used multi-stage flash distillation. A third plant was a 250,000 gallon per day brackish water plant using a newly invented membrane process called electrodialysis. It was located at Webster, South Dakota and treated a 1700 ppm water reducing the salinity to 300 ppm. A fourth plant, of one-million gallon per day capacity, was built at Roswell, New Mexico for demonstrating the distillation cycle with vapor compression. The fifth plant, a 200,000 gallon per day plant, was built at Wrightsville Beach, North Carolina, for the conversion of sea water using a freezing process. With the exception of the freezing plant the plants met their design criteria. The freezing plant was apparently built too soon without enough background data and could not be called a successful operation.

The electrodialysis process has since become a major process for the desalination of brackish water. The multi-stage flash process has become the leading process for the desalination of sea water.

The Point Loma multi-stage flash distillation plant was operated for approximately two years. When the Cuban government cut off the water supply to our Navy Base at Guantanamo Bay it was suggested that the quickest way to get an alternate source of water to the base would be to take the Point Loma plant and move it to Cuba. The Navy accepted the suggestion and in exactly five months the plant was moved from California to Cuba and started producing water. The plant has since been expanded and is now producing about 2.1 million gallons a day. It's on stream about 96 percent of the time and provides all of the water supply for the Navy base.

After the multi-stage flash distillation plant was moved from Point Loma to Cuba another plant was built in San Diego to demonstrate a multi-stage flash multi-effect distillation process. The plant was named the Clare Engle, after the late Senator from California. In that plant a performance ratio of 22-to-1 was achieved, the highest performance ratio achieved by any distillation plant. For every pound of steam delivered to the plant, 22 pounds of product water were produced. An additional test unit built by the Office of Saline Water is a section of a 50-million gallon per day multi-stage flash plant that has provided data for the design of all the large multistage flash plants constructed at this time.

The final construction of major size is located at Fountain Valley, California, where in cooperation with the Orange County Water District of Southern California, the OWRT constructed a module of a 15 million gallon per day combination vertical tube evaporator/multi-stage flash plant. The fresh-water production of that plant will be about 3 million gallons per day. It is expected that data from the plant will give industry the basis for the design of multi-million gallon per day plants using the combination process.

Probably the most exciting accomplishment of the Federal saline water conversion research program has been the development of an entirely new process known as reverse osmosis. In concept, it is a relatively simple process and involves separation of dissolved salts from water by means of a membrane which is permeable to water but impermeable to the dissolved salts. When pressure is applied to an aqueous salt solution interfacing with a semi-permeable membrane, fresh water diffuses through the membrane leaving a concentrated salt solution behind. The flux of water through the membrane is a function of the osmotic pressure of the solution and the applied pressure.

That such a separation is possible was first demonstrated by Professor C.E. Reid at the University of Florida in the late 1950's. Prof. Reid, supported by the Office of Saline Water, was able to effect a separation of salt from water by using a cellulose acetate membrane. Although he achieved separation, the volume of fresh water he was able to drive through the membrane was so small that the process could not be considered competitive with other desalination processes. In 1960 Loeb and Sourirajan at UCLA were able to modify the cellulose acetate membrane to produce a membrane which had salt rejection properties and a flow rate sufficient that reverse osmosis could be considered a candidate process for desalination. Loeb and Sourirajan's work was supported by the State of California's Sea Water Conversion Program.

In the years since 1960 the Office of Saline Water funded intensive research on reverse osmosis. The program was initially directed toward developing an understanding of the mechanism by which the membrane separated salt from water. The experimental program involved studies of the relationship of the chemical and physical properties of cellulose acetate to its effectiveness in water transport and salt rejection, with the Loeb and Sourirajan membrane as the basic model. The results of the research programs were sufficiently encouraging to justify a development effort in the design, construction and testing of reverse osmosis pilot plants.

The first reverse osmosis system configuration was a simple plate and frame arrangement. The development of the frame was a rather challenging engineering problem because of the necessity for a support that would withstand the pressures that were applied against the membrane. If the support were too dense, it would retard the flow of water through the support. If the support were too porous the membrane could rupture through the pores. Adequate support materials were developed but the plate and frame soon dropped out of the picture because of the high costs of the supports, the high cost of the pressure vessels, and the general poor efficiency of the design.

A second configuration was the tubular configuration in which the membrane was put on the inside of a tube. The first tubes were actually hollow fiberglass fishing rods which were subsequently improved to withstand higher pressures. Today, tubular reverse osmosis systems are available off the shelf.

Another design is a spiral-wound configuration consisting of membrane envelopes of two layers of membrane separated by a porous, incompressible backing material. These envelopes together with brine side spacer screens are wrapped around a water collection tube and housed in carbon steel pipes. The pressurized brine flows axially along the brine side spacer screen. Pure water flows through the membrane into the porous backing material and then to the product collection tube in the center (Fig. 1).

Another significant development in reverse osmosis membrane technology was the development of hollow fine fiber membranes. The use of hollow fine fiber membranes eliminates the need for a porous support since the fibers can withstand high pressures and function both as desalination barriers and as pressure containers. In 1967, the Dupont Company introduced polyamide hollow fine fibers to commercial brackish water application. The fibers while providing approximately 90% rejection of salt had very low fluxes, about 0.1 gallons per square foot of membrane surface per day (gfd). Since then the company has improved water fluxes of the fibers to about 2.0 gfd. Dow Chemical Company has developed hollow fine fibers from cellulose triacetate polymer. These fibers provide fluxes up to 4.0 gfd in brackish water desalination (Fig. 2).

In an operating hollow fiber reverse osmosis unit, the fibers are placed in a pressure vessel with one end sealed and the other open to a product water manifold. The salt water, under pressure, flows on the outside of the fibers and the product water flows inside the fibers to the open end where it is collected at the product water manifold.

Although the flow rate through the hollow fine fiber (1-4 gfd) is quite low when compared to the flow rate of the spiral wound membranes (10-20 gfd), a large amount of membrane surface can be enclosed in a small pressure vessel. For example, a unit that is eight inches in diameter and approximately four feet long, can contain more than an acre of membrane surface. Thus, if the flow rate through these membranes is only a little more than a gallon per square foot per day, a single unit will produce upwards of 1,000 gallons of product water daily.

While each of the above described reverse osmosis membrane configurations has unique advantages, economic considerations have favored construction of reverse osmosis plants based on spiral wound and hollow fiber designs. Except for specialized applications such as industrial waste treatment, tubular reverse osmosis plants have not been competitive with the spiral wound or hollow fiber configurations because of high capital costs.

Until very recently the reverse osmosis process found principal application in the treatment of brackish water and industrial wastes. Application of the process to sea water desalination was greatly hindered by two constraints: 1) The availability of membranes capable of the extremely high salt rejection required for sea water desalination; and 2) The high cost of high pressure equipment. Sea water could be desalinated but only through an expensive two-stage system.

However, just within the last two years, several sea water membranes which appear to be suitable for commercial use have been developed. These include Dow's cellulose triacetate hollow fine fiber and Dupont's polyamide hollow fine fiber. Over the past two years, pilot plants with capacities up to 25,000 gpd equipped with these membranes have undergone seawater evaluation tests and have consistently produced product water of less than 500 ppm. The plants are operated at pressures of 800-1,000 psi.

Just last month the ROGA Division of Universal Oil Products reported that they have been able to produce, on a commercial scale, a flat sheet polyamide membrane capable of desalinating seawater in a single stage. The membrane has exhibited single-stage seawater capability when tested at an applied pressure of 1,000 psi. The performance shows an average membrane flux of 20.3 gal/ft^2/day and salt rejection of 96.46%. The membrane is processed dry and is wet-dry stable. It is also reported to be stable over a wide pH range and at high tempreatures. On the basis of these results the future prospects for the application of reverse osmosis technology to the desalting of seawater look very promising.

Since the saline water conversion program was first authorized in 1952, about 275 million dollars have been spent. During the period 1968-1973 expendi- tures were at the rate of about $22 million per year. Appropriations for the program began to decline in 1974. In 1973 the appropriation for the saline water conversion progam was $26.8 million; in 1974 it was $3.6 million. Also, in 1974 the functions of the Office of Saline Water which administered the saline water conversion program and the Office of Water Resources Research which administered the Water Resources Research Act of 1964 were consolidated into a new Office of Water Research and Technology. In 1975 the appropriation for saline water conversion research and development of the Office of Water Research and Technology was approximately $5.9 million. In 1976 it is expected to be around $4 million.

The Department of the Interior has relinquished ownership of the five demonstration plants I described earlier, and is in the process of closing down the Wrightsville Beach, North Carolina and Roswell, New Mexico test facilities which have been operated since early in the Saline Water Conversion Program. Personnel administering the saline water conversion program have declined from a high of 158 in 1973 to currently about 22 people on the OWRT staff devoting full time to saline water conversion research and development activities.

Why the decline in Federal saline water conversion research and development activities? According to an administration spokesman, the Office of Saline Water was one of those programs in the Federal government which set out to achieve an objective which it largely achieved and the time had come for a change of mission. The program developed a whole new technology of reverse osmosis for desalting of brackish water, opening up new planning alternatives and new ways of dealing with brackish water supplies. Also, under the saline water conversion program the technology of distillation of water was carried to a very advanced state. Both reverse osmosis and distillation are now based on commercially available technology. These factors led Dr. Wm. S. Butcher, the current Director of the Office of Water Research and Technology, to make the following statement:

"This means the mission has been accomplished to a large extent and so the saline water program now is moving on to a state where it's supporting what I would call a mature industry, newly mature perhaps, and there's more maturity yet to come. But now our saline water conversion program is serving an established industry, not trying to develop one, and this is the reason why it's appropriate for this now to fall back to its place in the whole spectrum of water technologies. We believe in the Office of Water Research and Technology it will be folded into an appropriate place."

"The old development is over. It has been achieved and I think great credit should be given to the former Office of Saline Water as it now goes on to a new phase, dropping back in level of funding, because its mission is considerably changed and appropriately so. I don't know how many programs in the Federal government you can say have stopped when they have achieved their mission. I feel stopping or altering a program in the Federal government is extremely difficult. The saline water program just shifted gears to a new level which I believe is an appropriate level."

The Federal government will continue some saline water conversion research and development activity under the OWRT programs. In the 1976 budget there is a request for an appropriation of approximately $4.0 million for saline water research, water reuse and technology transfer programs that could be considered as part of the new direction for the old saline water conversion research program.

However, there do not seem to be any large size demonstration plants, test modules, or large pilot plant testing facilities envisioned in future programs. Any development activities will probably be carried out at contractors' facilities.

For the immediate future the OWRT research program in saline water conversion will be directed to the following objectives:

1. Improving reverse osmosis membranes - to make them more resistant to fouling and biodegradation, improve their water flux and salt rejection, and increase their compaction resistance.

2. Improving the efficiency of reverse osmosis systems by minimizing boundary layer effects by both physical means (equipment design) and chemical means (scale inhibitors, solubilizers, etc.).

3. Improving feed-water pretreatment systems by developing methods to prevent fouling, plugging, polarization, depletion, or other mass transfer limiting phenomena.

4. Identifying inefficiencies in freezing desalination processes and developing design modifications to improve process economics.

5. New desalting technology. To assure that opportunity will remain available for the introduction of new ideas and concepts into the saline water conversion research program, a limited amount of research funds will be

allocated for the evaluation and limited investigation of novel desalination processes.

6. Investigation of the technical and economic feasibility of adapting seawater conversion technology to other water resource problems of significant national interest.

In fiscal 1977 the Office of Water Research and Technology plans to initiate investigation of processes, components, systems, and techniques for treatment to allow recycling of municipal, agricultural, and industrial water supplies. We have a valuable national resource in the technology developed under the saline water conversion programs and it should be adapted to appropriate purposes.

However, hardware availability is only one element of the water reuse equation. Institutional obstacles to the adoption of water reuse as a water quality strategy and in extending the utility of water supplies may pose a greater constraint than technical feasibility. Consequently, the OWRT program will also initiate studies seeking answers to social, economic, and legal concerns which may hinder widespread adoption of water reuse as part of a total water management strategy.

The coupling of the hardware research programs of the former OSW with the broader water resource programs of the former OWRR in the new Office of Water Research and Technology provides the mechanism for a total rather than fragmented approach to water resource problems such as those expected to be encountered in the water reuse field. This kind of problem solving approach is what was envisioned when the functions of the two programs were combined.

For the short term future we have program plans, appropriation requests, and administrative mechanisms to maintain a national program in water resources research including saline water conversion research.

Also, the Federal government will be in the saline water conversion business through the construction of a 100 million gallon per day brackish water plant as part of the solution to the problem of salinity in the Colorado River. When the plant is constructed it will be the world's largest desalting plant.

The U.S. Government became involved in that activity because of salinity increases in the lower Colorado from high salinity irrigation return flows originating in the Wellton-Mohawk Irrigation District adjacent to Yuma, Arizona. These return flows, which can peridically exceed 4,000 ppm of total dissolved solids, increase the salinity of the Colorado to the extent that the Mexican Government complained that the water became too saline for irrigation in the Mexicali Valley. Following negotiation, corrective measures were agreed to by the U.S. and Mexico including the construction of a large brackish water desalting plant of up to 100 million gallons per day capacity to treat the Wellton-Mohawk irrigation return flows. Due to the feed salinity, it has been decided that the 100 mgd plant could be based on either reverse osmosis, electrodialysis, or a combination of the two. To facilitate process selection, a brackish water test facility has been constructed in Yuma to conduct extensive pretreatment studies on the Wellton-Mohawk drainage water and to permit membrane units to undergo evaluation on a side-by-side basis. I believe that at the present time four systems are undergoing tests - the Dow and Dupont hollow fine fibers systems, the ROGA spiral-wound system, and the Ionics electrodialysis sytem. The Bureau of Reclamation which is managing the project predicts that evaluation of desalting systems and final selection of suppliers may extend through mid-1977. Testing at Yuma is expected to be completed about mid-1978 with construction commencing shortly thereafter.

As far as the long term future of Federal desalination research programs is concerned, the crystal ball is very cloudy. Legislation has been introduced in the Senate (S.1301) which would combine the two separate pieces of legislation that OWRT now administers (the Water Resources Research Act of 1964, and the Saline Water Conversion Act) into a single legislative authorization. The Senate Interior Committee has not yet acted on the legislation and is planning to canvass the desalting programs before it decides what course of action to take. Among its options are to endorse S.1301, write a different piece of legislation, or do nothing. The latter course will cause problems because the Title II authority of the Water Resources Research Act expires this year and the saline water conversion program requires authorization on an annual basis. In the House no counterpart to S.1301 has yet been introduced.

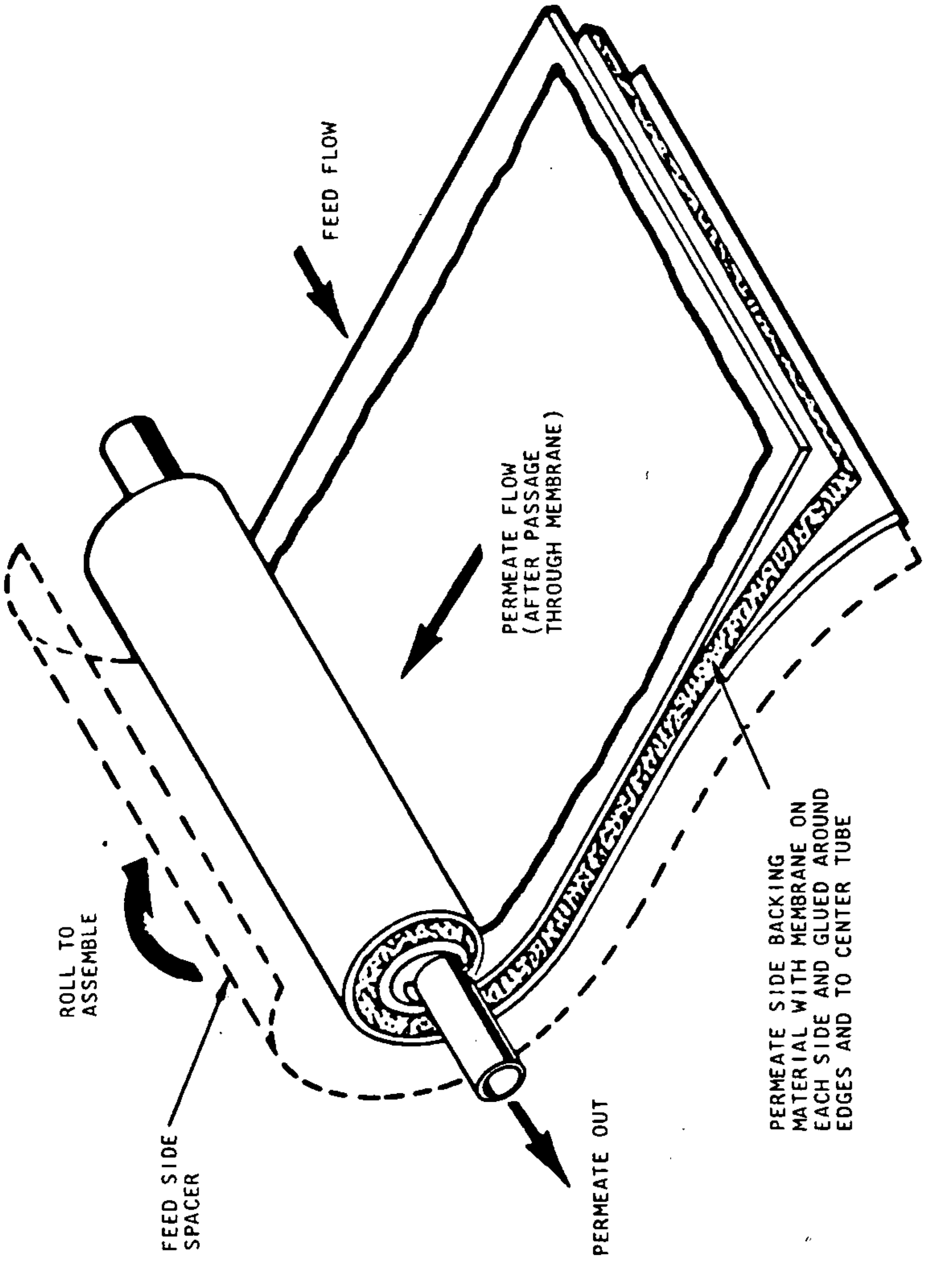
It appears that the lack of action by the Senate and the House is a manifestation of uncertainty in the Congress as to the role of the Federal government in the water resources research field.

In the 50's and 60's Congress supported Federal water resources research programs on the basis that those programs were supportive of Federal water development projects. The objective of the saline water conversion program was to provide low-cost desalting technology for large scale desalting projects that would be needed when the demand on the Nation's surface and ground water resources, particularly in the Southwest, exceeded the developable supply. We are now in the mid-70's and the forecasts of the early 50's about overpopulation, water crises, and so forth have failed to materialize. Large water development projects cannot be justified, and Congressional interest in water resources research has lessened considerably. Research programs must relate to some current Federal interest to get high priority consideration in the Congress and at the moment, water resource development is quite low on the Congressional interest list.

What is the future for water resources research? There will probably be a backing off in some of the programs as we have witnessed in the saline water conversion program. Except for the Colorado River salinity control program there are no really large scale water development projects on the horizon, and supportive research and development is not needed. There will probably be some research and technology for future needs but the mechanism by which that research will be accomplished is uncertain.

The most recent legislative development in the saline water conversion program is bill HR-1599 introduced by Congressman Harold T. Johnson of California in January 1976. The bill would authorize a $6.47 million dollar appropriation for the fiscal year 1977 saline water conversion program. Hearings on this legislation will be held on the 27th of February 1976.

Legislative activity is evidence of Congressional interest in maintaining a national saline water conversion research program. The future of that program and other water resources research programs rests on the strength of Congressional convictions of the need for such programs.



SPIRAL WOUND REVERSE OSMOSIS

Figure 1.

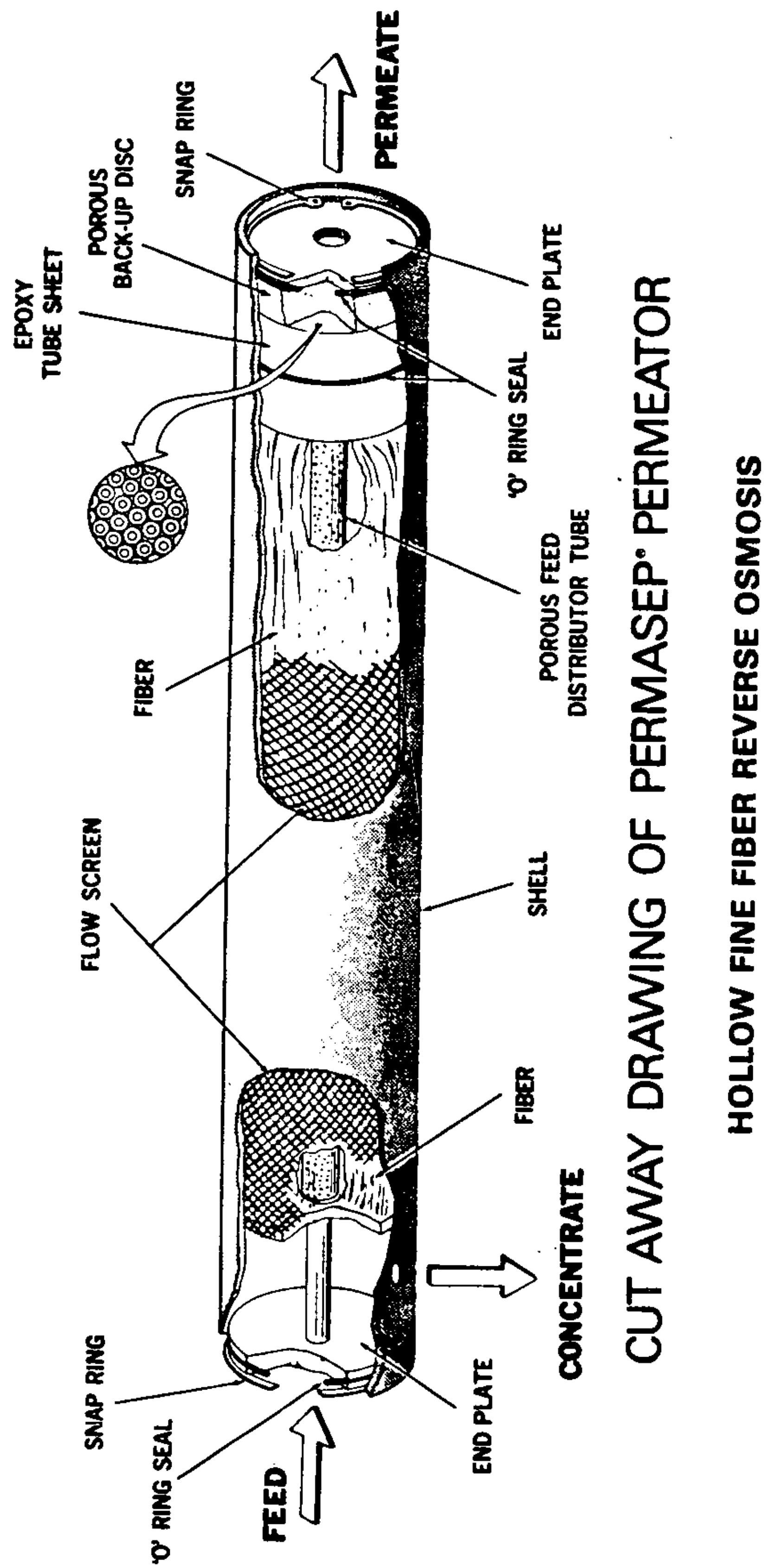

PERMEATE
SNAP RING
POROUS BACK-UP DISC
EPOXY TUBE SHEET
END PLATE
'O' RING SEAL
POROUS FEED DISTRIBUTOR TUBE
FIBER
FLOW SCREEN
SHELL
FIBER
CONCENTRATE
SNAP RING
'O' RING SEAL
FEED
END PLATE
CUT AWAY DRAWING OF PERMASEP® PERMEATOR
HOLLOW FINE FIBER REVERSE OSMOSIS

Figure 2.

SALINITY MANAGEMENT AND THE DEVELOPMENT OF THE COLORADO RIVER BASIN: A MULTIDISCIPLINARY PROBLEM WITH INTERNATIONAL IMPLICATIONS

by

WILLIAM S. BUTCHER, Ph.D.

U. S. Dept. of the Interior, Office of Water Research and Technology

(1976)

Introduction

The Colorado River is situated in the southwestern United States and extends 1,400 miles from the Continental Divide in the Rocky Mountains of north-central Colorado to the Gulf of California (Fig. 1). The river is a water and power resource that supports the needs of 17 million people. The Colorado River Basin covers an area of 254,000 square miles, approximately one-twelfth of the continental United States. The Colorado River Basin includes parts of seven states: Arizona, California, Colorado, Nevada, New Mexico, Utah and Wyoming.

The Colorado River rises high on the Continental Divide at altitudes of over 14,000 feet, and flows generally southwestward, leaving the United States at an elevation of about 75 feet above sea level. The Colorado River Basin is composed of a complex of rugged mountains, high plateaus, deep canyons, deserts, and plains. Principal physical characteristics of the region are its variety of landforms, topography, and geology. There are numerous regulating reservoirs along the river's 1,400 mile length including the major regulating reservoirs Lake Mead (Hoover Dam) and Lake Powell (Glen Canyon Dam).

The Colorado River Compact of November 1922 divides the entire Basin into two parts, the Upper Basin and the Lower Basin. These basins are separated at a point on the river in northern Arizona known as Lee Ferry, which is located 1 river mile below the confluence of the Paria and the Colorado Rivers and is approximately 17 miles downstream from Glen Canyon Dam. The purpose of the Compact is to provide for equitable division and apportionment of the use of the waters of the Colorado River System and for legal, political, institutional, and hydrological purposes.

The Colorado River Compact defines the Upper Basin as the part of the Colorado River Basin within and from which water naturally drains to the Colorado River System above Lee Ferry and the Lower Basin as that part of the Basin within and from which waters naturally drain into the Colorado River System below Lee Ferry.

The Upper Colorado Region encompasses about 45 percent of the drainage area of the Colorado River Basin and includes parts of Arizona, Colorado, New Mexico, Utah, and Wyoming. The Lower Colorado Region embraces parts of Arizona, New Mexico, Nevada, Utah, and California.

Basin Hydrology

The most universally used index of the Basin's water yield is the "virgin" flow of the Colorado River at Lee Ferry, Arizona. Annual flows vary widely. Figure 2 indicates that the virgin flow at Lee Ferry has ranged between about 5.6 and 24 million acre-feet per year since 1896 with a long-term average of about 15 million acre-feet. However, during the historical period of low flow from 1931 to 1964, this flow averaged only 12.9 million acre-feet per year. Legal apportionment of annual beneficial consumptive use calls for 7.5 million acre-feet of the natural flows of the Colorado River to each of the Upper and Lower Basins, while 1.5 million acre-feet has been allocated to Mexico. Since the projected water demands of the Colorado River Basin greatly exceed the most conservative estimates of supply and since the legal entitlements of the Upper and Lower Basin States and Mexico exceed the long-term annual virgin flow, the approximate 2.0 million acre-foot shortfall or 13 percent variation from the long-term average is of vital importance.

Salinity Impacts

The Colorado River flows for most of its length through arid and semiarid regions of the United States and Mexico. The great river and its tributaries accumulate the solution products of (1) erosion and weathering, (2) irrigation return flows, (3) municipal and industrial wastes, and (4) various point sources such as springs and wells. From headwaters to mouth, a distance of nearly 1,400 miles, the salinity of the river progressively increases.

At the headwaters, the average salinity (concentration of total dissolved solids) in the Colorado River is less than 50 ppm and progressively increases downstream until, at Imperial Dam, the present modified condition is 865 ppm. (See Table 1.) Projections of future salinity levels without a control program suggest that values of 1,200 ppm or more will occur at Imperial Dam by the year 2000. One projection used in the Lower Colorado Region Comprehensive Framework Study foresees such a level being reached by 1980. Should these increases in salinity levels occur, the agriculture in the Imperial, Coachella, Gila, and Yuma Valleys would be further threatened. Also, a poorer water quality would be diverted to the Metropolitan Water District of Southern California and the Las Vegas Valley Water District, causing further economic losses to the very large block of domestic water users in California and Nevada.

The concentrations of total dissolved solids in the lower mainstem of the Colorado River are approaching or are beyond threshold damage limits for some uses. Great concern and a sense of urgency to halt the rise have been expressed by those who depend upon the river as a lifeline. The concern extends to Mexico and has become an important aspect of relations with that nation.

In the United States, the total damages attributable to salinity in the Colorado River System for 1973 are about $53 million per year. By the year 2000, these damages will amount to $124 million per year if control measures are not applied. These economic impacts are based on recent studies by the Bureau of Reclamation, which estimated total direct and indirect losses of about $230,000 per ppm increase in salinity at Imperial Dam. The estimates of damage do not include effects below 500 ppm for municipal and industrial water supplies and 750 ppm for agricultural use. The damages arise in agriculture from decreased crop yields, increased leaching requirements, increased management costs, and application of various adaptive practices. In the municipal and industrial sector, the detriments arise primarily from increased water treatment costs, accelerated pipe corrosion and appliance wear, increased use of soap and detergents, and decreased potability of drinking water.

International Aspects of Colorado River Salinity

The 1944 Treaty for the Utilization of Waters of the Colorado and Tijuana Rivers and of the Rio Grande allotted to Mexico 1,500,000 acre-feet annually "...of the waters of the Colorado River, from any and all sources...."

TABLE 1.

Present modified quality of water. Colorado River (Average annual values, 1941-1968).

Station	Concentration Tons/Acre-foot	mg/l
Near Glenwood Springs, Colorado	0.42	306
Near Cameo, Colorado	0.60	442
Near Cisco, Utah	0.91	671
Lees Ferry, Arizona	0.84	619
Grand Canyon, Arizona	0.93	682
Below Hoover Dam, Arizona-Nevada	1.03	760
Imperial Dam, Arizona-California	1.18	865

Of the total, approximately 1,360,000 acre-feet annually are delivered to Mexico in the limitrophe section of the Colorado River (the section of the river between the United States and Mexico) upstream from Morelos Dam. The remaining approximately 140,000 acre-feet annually are delivered at the Southerly International Boundary, 17 miles to the south, and in the limitrophe section of the river below Morelos Dam.

The 1944 Water Treaty contains no specific provisions regarding the quality of water the United States may deliver to Mexico, and Mexico and the United States have had differing interpretations of the intent of the Treaty as it may affect water quality. The Treaty does provide for the settlement of differences with respect to the interpretation or application of the Treaty, and Minute No. 242 of the International Boundary and Water Commission constitutes such a settlement.

The delivery of Treaty waters to Mexico began in 1950 with the completion of Morelos Dam, Mexico's major diversion structure on the Colorado River. Eleven years later, two events occurred to make water quality a serious issue between the two countries. There were delivered to Mexico above Morelos Dam highly saline drainage waters pumped by the Wellton-Mohawk Irrigation and Drainage District from an aquifer that underlies the District. These waters, initially averaging 6,000 ppm TDS, were pumped to maintain ground-water levels below the crop root zone. In addition, excess flows which Mexico had received prior to 1961 came to a near end in that year. These flows had diluted the more saline drainage waters that were then being discharged to the river below Imperial Dam with the result that the quality of water delivered to Mexico above Morelos Dam was very nearly the same as that used in the Lower Colorado River Basin of the United States.

The effect of these developments was to increase the salinity of Colorado River waters made available to Mexico at the Northerly International Boundary from an annual average of about 800 ppm TDS to nearly 1,500 ppm TDS in 1962.

In a note dated November 9, 1961, Mexico formally protested that "...the delivery of water that is harmful for the purposes stated in the Treaty constitutes a violation of the Treaty" and that "any contamination of international water by one of the riparian countries that cause damage or loss to the other riparian party is in itself an act clearly and specifically condemned by International Law...." Mexico continued to press its case thereafter.

In response to the Mexican protest, the United States began in 1963 to alter river operations to reduce the salinity of Colorado River water delivered to Mexico. By 1965, a 5-year agreement was reached by the two Governments, referred to as Minute No. 218 of the International Boundary and Water Commission (IBWC).

This Minute, which became effective on November 16, 1965, provided for practical measures to further reduce the salinity of waters reaching Mexico. Under the Minute, each country reserved its legal rights. The measures consisted of the construction and operation of a 12-mile-long channel known as the Main Outlet Drain Extension to enable the United States to discharge Wellton-Mohawk drainage waters to the Colorado River either above or below Morelos Dam (see Fig. 3), and the installation and operation of additional drainage wells in the Wellton-Mohawk area to make possible selective pumping. During periods when scheduled deliveries to Mexico were the Treaty minimum of 900 cfs the United States discharged all WelltonMohawk drainage below Morelos Dam, amounting to about 50,000 acre-feet per year. These bypass waters were replaced by other waters, largely from above Imperial Dam. By the end of 1971, these operations, coupled with a gradual improvement in the quality of Wellton-Mohawk drainage water, had reduced the average annual salinity of waters made available to Mexico to about 1,245 ppm TDS, with monthly averages varying from 1,105 to nearly 1,500 ppm TDS.

Meanwhile, Mexico concluded that it would not use waters with salinity greater than about 1,240 ppm TDS (1,300 ppm, Mexican count) in the Mexicali Valley and asked the United States under terms of Minute No. 218 to bypass an additional 40,000 to 75,000 acre-feet of Wellton-Mohawk drainage flows annually. The effect was to further reduce the average salinity of waters diverted by Mexico at Morelos Dam in 1971 to about 1,160 ppm TDS.

Before Minute No. 218 was to have expired on November 15, 1970, the United States proposed a new 5-year agreement to further reduce salinity. The United States offered to bypass additional volumes of Wellton-Mohawk drainage water and to substitute equal volumes of better waters to reduce the average annual salinity of waters delivered to Mexico at the Northerly International Boundary to about 1,140 ppm TDS, subject to increases in salinity at Imperial Dam. This salinity would approximate that of waters delivered to Mexico above Morelos Dam if all United States projects below Imperial Dam were operating in salt balance. The administration of President Diaz Ordaz of Mexico considered the proposal constructive, but decided to leave the matter to the administration of President Echeverria, who took office in December 1970. Minute No. 218 was therefore extended for one year.

In 1971 and early 1972, the Governments exchanged several proposals in an attempt to reach an agreement, extending Minute No. 218 in November 1971 for another year so that the discussions might continue. After further conversations in early 1972, Mexico requested a prompt, permanent settlement.

The Presidents of the United States and Mexico met and issued a joint communique on June 17, 1972. With this communique the search for a solution entered another phase. President Nixon assured President Echeverria of his desire for a definitive, equitable and just solution to the problem, and indicated he would designate a special representative to develop a solution and to submit a report to him. Once approved by the United States Government, the report would be submitted to President Echeverria for his consideration and approval.

The President, on August 16, 1972, designated as his Special Representative former Attorney General Herbert Brownell, Jr. He was assisted by an Interagency Task Force comprised of representatives of the Department of State; Department of the Interior; Department of Defense (Corps of Engineers); Environmental Protection Agency; Council on Environmental Quality; Office of Science and Technology; Office of Management and Budget; Domestic Advisory Council; and U.S. Section, International Boundary and Water Commission. The seven-state Committee of Fourteen also met and consulted with Mr. Brownell and advised him during his deliberations.

To immediately further improve the quality of water delivered to Mexico above Morelos Dam, the two Governments approved a new Minute, No. 241, signed July 14, 1972. It provided for the bypass of 118,000 acre-feet of Wellton-Mohawk drainage waters annually without charge against Mexico's guaranteed Treaty allotment, more than twice the rate of the United States bypass under Minute No. 218, and their replacement by other waters from above Imperial Dam and from wells on the Yuma Mesa. The operations under Minute No. 241 reduced the average annual salinity of waters made available to Mexico from 1,245 ppm TDS in 1971 to 1,140 ppm TDS for the year ending June 30, 1973.

The provisions and operations for bypassing waters, described in the preceding paragraph, without charge against Mexico's guaranteed Treaty allotment was with prior notice to and consent of the Colorado River Basin States.

In addition to the United States operations under Minute No. 241, Mexico requested the United States to bypass without replacement the remaining drainage waters from the Wellton-Mohawk Irrigation and Drainage District to the Colorado River below Morelos Dam. This additional bypass amounted to about 100,000 acre-feet annually. This further reduced the average salinity of water diverted by Mexico at Morelos Dam from 1,160 ppm TDS in 1971 to less than 1,000 ppm TDS for the year ending June 30, 1973.

Upon completion of the study for solution of the salinity problem, Mr. Brownell presented his recommendations to President Nixon. After acceptance of the recommendations by the United States Government, the President appointed Mr. Brownell as Special Ambassador for the purpose of negotiating an agreement with Mexico.

At the conclusion of negotiations, operations under Minute No. 241 were terminated by provisions of a new agreement between the United States and Mexico, designated Minute No. 242, and approved on August 30, 1973. Minute No. 242 is recognized by both governments as the permanent and definitive solution of the salinity problem on the Colorado River.

The Agreement with Mexico

At the conclusion of negotiations, the joint recommendations of the Special Representative of President Nixon, Ambassador Herbert Brownell, Jr., and the Secretary of Foreign Relations of Mexico, Lic. Emilio O. Rabasa, were approved by the Presidents and incorporated in Minute No. 242 of the International Boundary and Water Commission, United States and Mexico. The Minute entitled "Permanent and Definitive Solution to the International Problem of the Salinity of the Colorado River" was formally approved by the two Governments on August 30, 1973.

Among other things the Minute provides that the United States shall adopt measures to assure that the approximately 1,360,000 acre-feet of the Treaty water annually delivered to Mexico upstream of Morelos Dam have an average salinity of no more than 115 ppm ± 30 ppm over the annual average salinity of Colorado River water arriving at Imperial Dam. It further provides for the United States to deliver to Mexico on the land boundary at San Luis and in the limitrophe section of the Colorado River downstream from Morelos Dam approximately 140,000 acre-feet annually with a salinity substantially the same as that of waters customarily delivered there. As a part of the measures required to assure the quality control at Morelos Dam, the Minute provides that the concrete-lined Main Outlet Drain Extension (M.O.D.E.) be extended from Morelos Dam to the Santa Clara Slough in Mexico at United States expense.

Those provisions of the Minute that are dependent for their implementation on construction of works or on other measures which require expenditure of funds by the United States became effective upon notification by the United States to Mexico of the authorization by the United States Congress of such funds. This authorization was encompassed in Public Law 93-320, enacted June 24, 1974, and notification was given to Mexico on the same day.

Colorado River Basin Salinity Control Act (P.L. 93-320)

Public Law 93-320 authorizes the construction, operation, and maintenance of certain works in the Colorado River Basin to control the salinity of water delivered to users in the United States and Mexico. Title I of the Act provides for programs downstream from Imperial Dam to implement the provisions of Minute No. 242 and Title II provides for programs upstream from Imperial Dam.

Title I of the Act authorizes three major features: (1) a desalting complex, (2) a new concrete-lined canal or lining of the presently unlined canal to replace the first 49 miles of the Coachella Canal, and (3) protective and regulatory gound-water well fields.

Included in the desalting complex are structural measures consisting of: (1) a membrane-process desalting plant of 104 million gallons per day capacity with a pretreatment plant and the necessary appurtenant works to treat Wellton-Mohawk Division, Gila Project drainage water, (2) the extension of the concrete-line bypass drain from Morelos Dam to Santa Clara Slough in Mexico, and (3) replacement of an existing metal flume in the Main Outlet Drain Extension with a concrete siphon. Nonstructural measures consist of: (1) an irrigation efficiency improvement program in the Wellton-Mohawk

Division to minimize the quantity of drainage return flow by accelerating a cooperative program of irrigation management services and providing Federal cost-sharing assistance for on-farm irrigation system improvements, (2) an irrigable acreage reduction program in the Wellton-Mohawk Division to eliminate potential increases in drainage return flows associated with additional development, and (3) acquisition of land, if needed, in Painted Rock Reservoir to permit a change in operational releases to minimize infiltration in the Wellton-Mohawk Division. As compensation to the Cocopah Tribe of Indians for rights-of-way for project features, the Act provides for ceding approximately 340 acres of Federal land to the Tribe in Sections 25, 26, and 27, Township 9 south, Range 25 west, Gila and Salt River Meridian, Arizona.

In connection with the reconstruction of the Coachella Canal, the Act provides, as a nonstructural measure, for the acquisition of land on the Imperial East Mesa which receives, or has been granted a right to receive, water from Imperial Irrigation District's capacity in the Coachella Canal. Approximately 4,200 acres of land are involved.

The capacity of the protective and regulatory ground-water well fields authorized by the Act is 160,000 acre-feet per year within 5 miles of the Arizona-Sonora boundary, which quantity is consistent with Minute No. 242. As a nonstructural measure, it authorizes the acquisition of approximately 23,500 acres of land or interests therein within 5 miles of the Mexican border on the Yuma Mesa.

The objectives of the P.L. 93-320 program are to reduce the salinity of water delivered to Mexico, more efficiently utilize water resources, and manage ground-water withdrawal.

Desalting complex objectives are to meet an annual average salinity differential of Colorado River waters delivered to Mexico as provided in Minute 242, conserve 132,000 acre-feet per year of water resources by desalting irrigation return flows now being wasted, preserve interstate harmony through utilization of most of the return flows thereby freeing an equal amount of water for use in the United States, preserve international harmony by providing means to meet an international agreement, and to enhance development of membrane desalting technology.

The objective of lining the Coachella Canal is to conserve for beneficial use an additional 132,000 acre-feet of Colorado River water now being lost annually through canal seepage. The salvaged water will be credited to the United States for the purpose of delivering water to Mexico as a replacement for the bypassed Wellton-Mohawk drain water on an interim basis until such time as the Secretary of Interior does not meet all the water delivery requests of the California agencies holding Colorado River water rights up to a total of 4.4 million acre-feet per year. After the desalting plant is in operation, any credits from the savings due to Coachella Canal lining would be used to offset past debits, credit against brine discharge from the desalting plant and accumulate credits to offset future brine discharges. Public Law 93-320 provides that credits of the water saved by the lining of the first 49 miles of the Coachella Canal will commence upon completion of the lining and will terminate the first year that the Secretary of Interior delivers mainstream Colorado River water to California in an amount less than the sum of the quantities requested by (1) the California agencies under contracts made pursuant to Section 5 of the Boulder Canyon Project Act (45 Stat. 1057), and (2) Federal establishments to meet their water rights acquired in California in accordance with the Supreme Court decree in Arizona vs. California.

The objectives of the Protective and Regulatory Ground-water Pumping Plan are to manage and preserve United States groundwater resources for the benefit of the United States, and to provide water deliveries to Mexico, thereby conserving upstream Colorado River water. The underflow of ground water to Mexico caused by Mexican pumping will be reduced, and thus a valuable water resource will be protected. A substantial portion of the pumped water will be delivered to Mexico in satisfaction of Treaty requirements. This will not incresase delivery of water to Mexico, but will maintain delivery at the amounts specified by the Treaty and maintain water deliveries across the land boundary at San Luis at approximately 140,000 acre-feet per year as provided in Minute No. 242.

Title II of P.L. 93-320 provides for programs upstream of Imperial Dam necessary to stabilize the salinity of the Colorado River. The law provides for the construction, operation, and maintenance of four salinity control units as the initial stage of the Colorado River Water Quality Improvement Program. These are: the Paradox Valley Unit in southwestern Colorado, where efforts will remove as much as 180,000 tons of salt annually from the Delores River; the Grand Valley Unit near Grand Junction, Colorado, which will remove about 200,000 tons of dissolved salt from saline irrigation return flows; the Crystal Geyser Unit, a point source contributor in east-central Utah, where control of the geyser will remove 3,000 tons of salt annually from the river system; and the Las Vegas Wash Unit near Las Vegas, Nevada, which will remove an estimated 138,000 tons of salt from saline flows entering Lake Mead. These combined efforts will improve the salinity at Imperial Dam by over 48 ppm.

Studies have progressed on each of these units to such an extent that should funds be provided, construction of the initial units could begin during 1977.

Yuma Desalting Plant

The Desalting Plant authorized by P.L. 93-320 has been sited in a bend of the Wellton-Mohawk drain about four miles west of Yuma, Arizona (see Fig. 4).

During the past year special emphasis was placed on the evaluation of pretreatment of the drain water prior to desalting. This is a "first" in desalting technology and is required for Wellton-Mohawk drain waters due to the high concentration of carbonates and other dissolved substances that tend to plug up membrane filters (see Fig. 5).

The plant will be sized for 104 million gallons of water per day. However, the operating production will be about 94 million gallons per day most of the time. This is necessary to permit routine maintenance without interrupting normal production. It will produce 97,000 acre-feet per year of desalted water with a salinity of 250 ppm. The desalted water will be mixed with about 25,000 acre-feet of bypassed drainage water to produce 122,000 acre-feet per year of 860 ppm water delivered to the Colorado River above Morelos Dam. This water will be mixed with the Colorado River water so that the flow measured at the Northerly International Boundary will have an annual average salinity of not less than the Colorado River entering Imperial Dam, + 115 ppm ± 30 ppm. Fig. 6 depicts the relationships of these various flows.

The reject water from the plant, averaging about 42,000 acre-feet per year and 9,100 ppm total dissolved solids, will be conveyed to the Santa Clara Slough via the proposed 53-mile extension of the Main Outlet Drain. This extension will constitute the first construction of Title I features. The first phase of this construction, a half-mile long siphon, is scheduled to begin this fiscal year. The desalting plant is scheduled to be online by December 1981.

Also, a program to reduce the quantity of irrigation return flow entering the drain is being implemented. Through the cooperation of the Department of Agriculture's Soil Conservation Service, the Wellton-Mohawk Valley Natural Resource Conservation District, and the Bureau of Reclamation, on-farm water systems improvements will be achieved by updating gravity irrigation systems on about 20,000 acres and by converting to pressure systems on about 4,000 acres. It is anticipated that through on-farm and distribution system improvements, in conjunction with the use of a computerized program to determine when to irrigate and how much water to apply, an irrigation efficiency of 60 to 70 percent can be achieved. Irrigation management techniques are currently being applied to about 14,000 acres of farmland in the Wellton-Mohawk area. It is planned to include 30,000 acres during this fiscal year, 48,000 acres in 1977, and 60,000 acres by 1978. By using these new water management techniques, nearly 50,000 acre-feet reduction of return flows could be accomplished.

Water Resources and Quality

In the short-term period of 10 to 20 years, the net program effect will be gradually improved water quality at the expense of some water loss (up to 112,000 acre-feet per year) from the river system. Downstream reductions in salinity and hardness will result in savings in the costs of cleaning compounds, water softening, appliances, plumbing fixtures, boilers, food processing, and a host of other municipal and industrial applications that require good quality water. Long-term agricultural benefits of water quality improvement will accrue to irrigation by increased crop production and lower costs of food production to the United States and Mexico.

In the long term, additional water quality improvement must consider the augmentation of water supply to the basin to also increase the availability of water.

Future development in the southwest will be decided by the availability of water for agricultural, municipal, and industrial purposes. Controlling the salinity of the Colorado River to maintain it at a quality suitable for beneficial uses requires the implementation of structural and nonstructural measures in a setting in which extremely complex social, legal, and economic issues abound.

The technological solution which I have described appears to be a high cost solution. However, within the range of possible alternative solutions it is the politically feasible solution which promises the greatest protection to the rights of the parties involved.

The solution did not come easily and required a multidisciplinary effort with major contributions from the engineering, physical, biological, and agricultural sciences.

The political decisions required statesmanship of the highest order. The politcal and economic stakes in the Colorado Basin are high and every action bearing on water rights affects the region's economic and social future and the tenor of the U.S. relationship with our good neighbor to the south.

Literature Cited

U.S. Bureau of Reclamation, Final Environmental Statement, Colorado River Basin Salinity Control Project Title I, 1975.

U.S. Bureau of Reclamation, Draft Environmental Statement, Colorado River Water Quality Improvement Program, 1976.

U.S. Environmental Protection Agency, The Mineral Quality Problem in the Colorado River Basin, Summary and Appendices Report, 1971.

Lopez, Jr., Manuel, Overview of Salinity Problems on the Lower Colorado River, Technical Proceedings, 3rd Annual Conference National Water Supply Improvement Association, 1975.

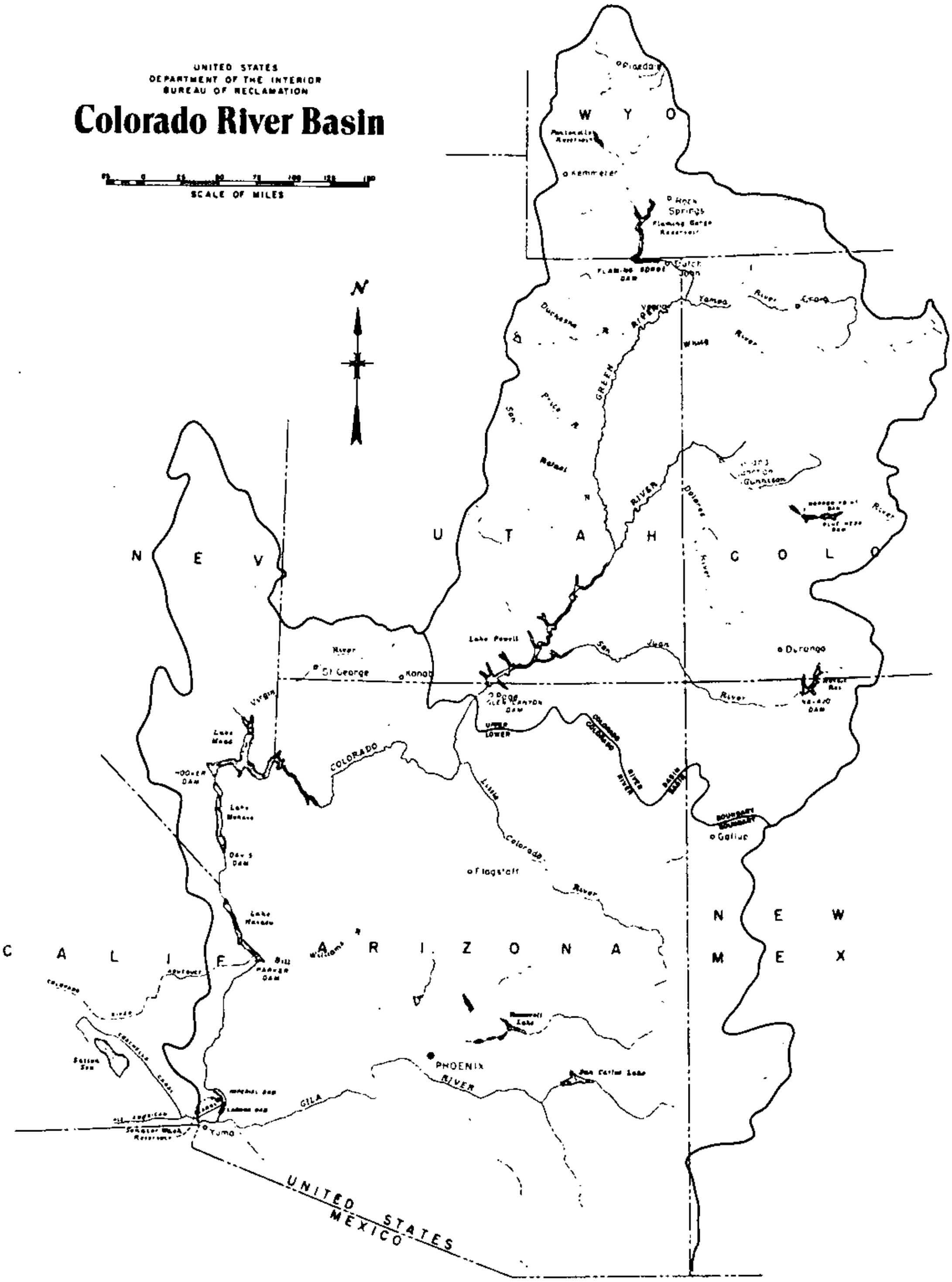
Maletic, John T., Current Approaches and Alternatives to Salinity Management in the Colorado River Basin, Proceedings of the 15th Annual Western Resources Conference at the University of Colorado, July 1973.

Editors comment (May 1977):

FIRST SIX WELLS DRILLED FOR U.S.-MEXICO SALINITY CONTROL AGREEMENT

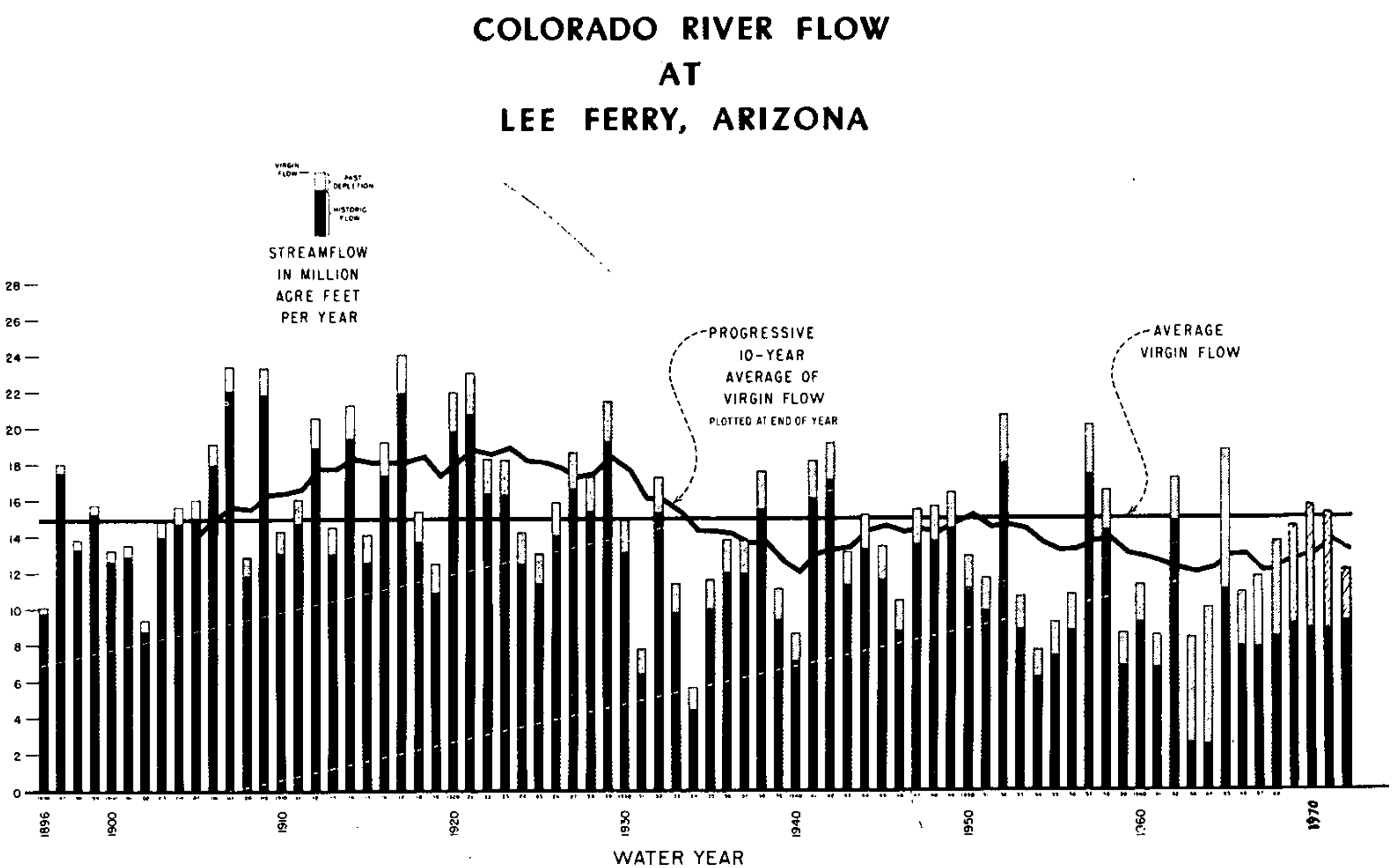
The 1973 agreement with Mexico to control the salinity of Colorado River waters entering that country also established a protective and regulatory ground-water pumping program for a strip of land along the border in the vicinity of San Luis, Arizona. Each country is to limit pumping to no more than 160,000 acre-feet annually from a designated area extending 5 miles from each side of the Arizona-Sonora boundary. The United States will be able to supply from its share of the ground water most of the 140,000 acre-feet historically delivered as treaty water to Mexico across the border. A smaller portion of the pumped water will be available to Arizonans for agricultural and other uses.

Drilling has been started on the last of the six wells of the Protective and Regulatory Pumping Unit under a $586,000 contract by Dreiling, Inc., Holly, Colorado. This initial phase of the planned 25 to 35 unit well field is expected to be in operation by 1978.



Map of Colorado River Basin.

Figure 1



Colorado River flow at Lee Ferry, Arizona..

Figure 2

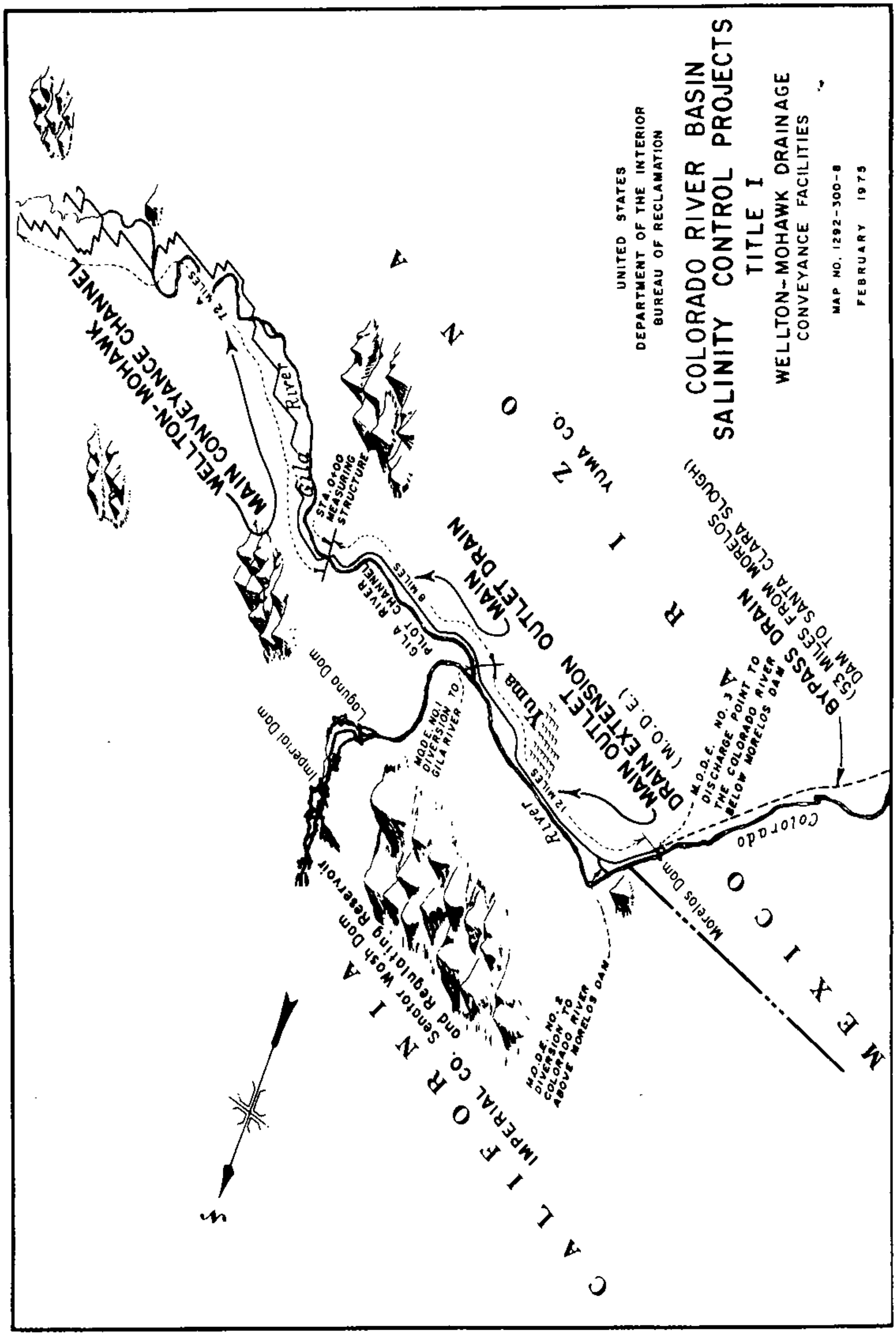

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLORADO RIVER BASIN
SALINITY CONTROL PROJECTS
TITLE I
WELLTON-MOHAWK DRAINAGE
CONVEYANCE FACILITIES
MAP NO. 1292-300-8
FEBRUARY 1975
WELLTON-MOHAWK
MAIN CONVEYANCE CHANNEL
12 MILES
Gila
River
STA. 0+00
MEASURING
STRUCTURE
A R I Z O N A
YUMA CO.
MAIN
OUTLET DRAIN
8 MILES
GILA RIVER
PILOT
CHANNEL
MAIN OUTLET
DRAIN EXTENSION
(M.O.D.E.)
Yuma
12 MILES
River
BYPASS DRAIN
(53 MILES FROM MORELOS
DAM TO SANTA CLARA SLOUGH)
M.O.D.E. NO. 3
DISCHARGE POINT TO
THE COLORADO RIVER
BELOW MORELOS DAM
Colorado
Morelos Dam
M E X I C O
Laguna Dam
Imperial Dam
MODE NO. 1
DIVERSION TO
GILA RIVER
Senator Wash Dam
and Regulating Reservoir
IMPERIAL CO.
C A L I F O R N I A
M.O.D.E. NO. 2
DIVERSION TO
COLORADO RIVER
ABOVE MORELOS DAM

Figure 3

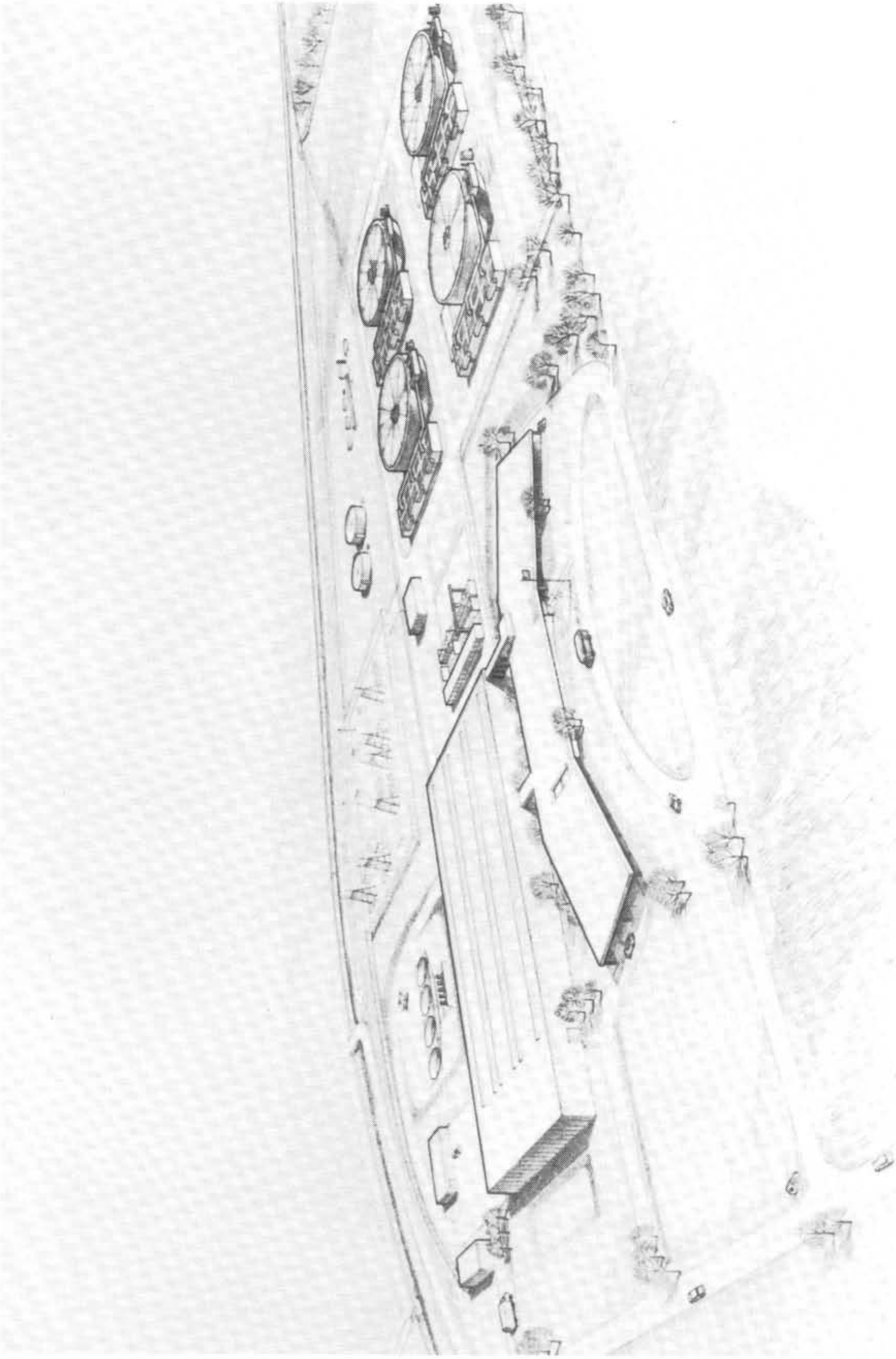


Figure 4

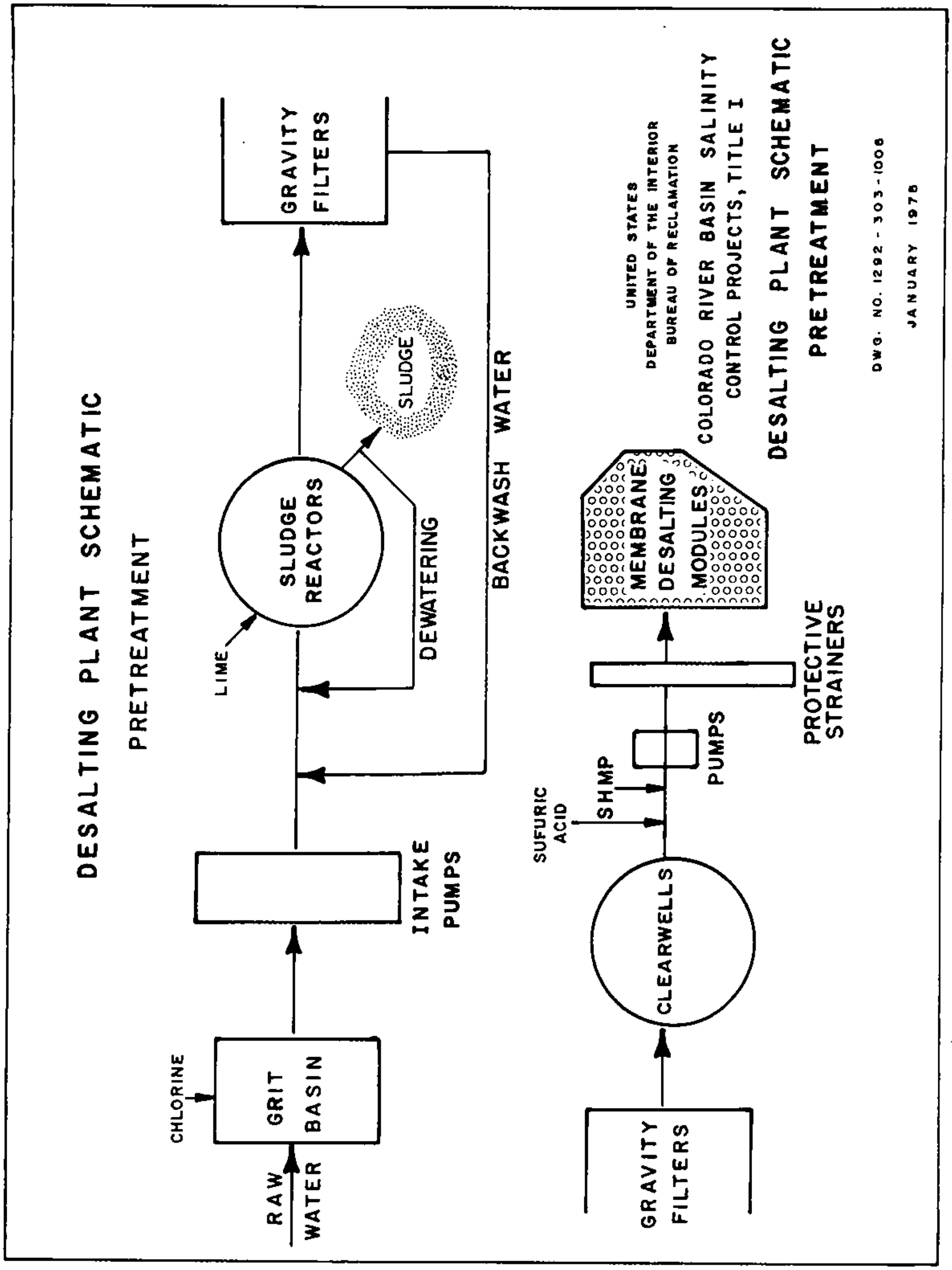
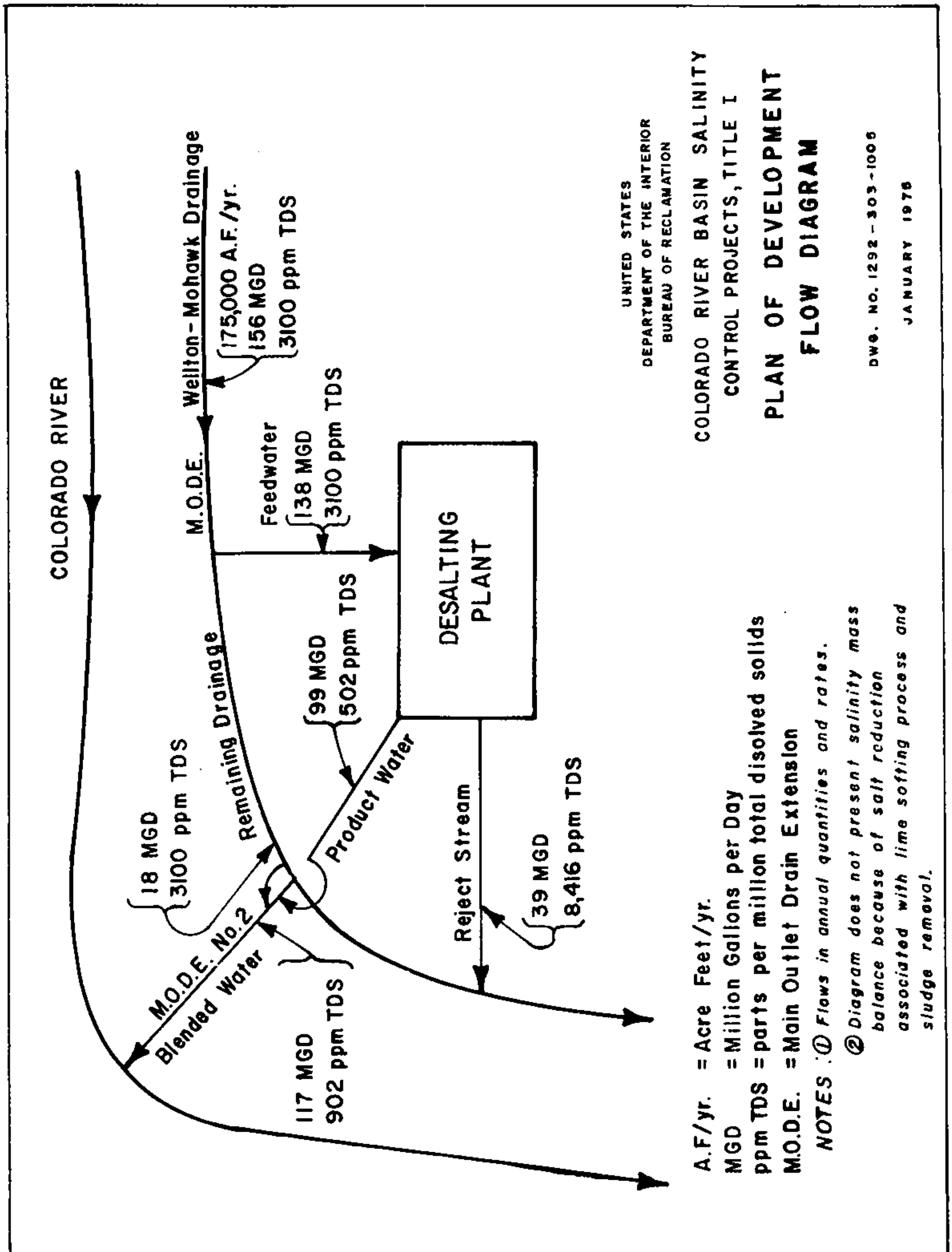

DESALTING PLANT SCHEMATIC
PRETREATMENT
RAW WATER
CHLORINE
GRIT BASIN
INTAKE PUMPS
LIME
SLUDGE REACTORS
SLUDGE
DEWATERING
BACKWASH WATER
GRAVITY FILTERS
GRAVITY FILTERS
CLEARWELLS
SUFURIC ACID
SHMP
PUMPS
PROTECTIVE STRAINERS
MEMBRANE DESALTING MODULES
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLORADO RIVER BASIN SALINITY
CONTROL PROJECTS, TITLE I
DESALTING PLANT SCHEMATIC
PRETREATMENT
DWG. NO. 1292 - 303 - 1006
JANUARY 1975

Figure 5



COLORADO RIVER
Wellton-Mohawk Drainage
175,000 A.F./yr.
156 MGD
3100 ppm TDS
M.O.D.E.
Feedwater
138 MGD
3100 ppm TDS
DESALTING PLANT
99 MGD
502 ppm TDS
Product Water
Remaining Drainage
18 MGD
3100 ppm TDS
Reject Stream
39 MGD
8,416 ppm TDS
M.O.D.E. No.2
Blended Water
117 MGD
902 ppm TDS
A.F./yr. = Acre Feet/yr.
MGD = Million Gallons per Day
ppm TDS = parts per million total disolved solids
M.O.D.E. = Main Outlet Drain Extension
NOTES: ① Flows in annual quantities and rates.
② Diagram does not present salinity mass balance because of salt reduction associated with lime softing process and sludge removal.
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLORADO RIVER BASIN SALINITY CONTROL PROJECTS, TITLE I
PLAN OF DEVELOPMENT
FLOW DIAGRAM
DWG. NO. 1292-303-1005
JANUARY 1975

Figure 6

PLAN NACIONAL HIDRAULICO (1973)

(MEXICAN NATIONAL WATER PLAN)

by

ING. GERARDO CRUICKSHANK, M.S. IN C.E.,

Under Secretary
Department of Water Resources
Government of Mexico

Mexico's industrial development and rapid population growth have led and will continue to lead in the future to an increasing total and per capita demand for water that creates a drain on available resources for future needs.

To the problems derived from the amount of available water resources there is added that of the growing pollution of the rivers, oceans, and other bodies of water that makes the utilization of this resource increasingly difficult and constitutes a serious threat to the future welfare of the population.

Although the average annual rainfall in the country is 780 millimeters per year, its distribution is very irregular, since it is concentrated within a rainy season of a few months and much of it falls in areas that are only lightly populated. The location of population and economic development centers is inversely related to the availability of water, since the southeastern area, which accounts for only 7% of the total land area of the country, has 40% of the water resources and 8% of the population, while the central highlands and northern mesa have 60% of the population, comprise 50% of the national territory, and have only 12% of the resources just mentioned.

Mexico has been overcoming obstacles to development, and the creation of an agricultural infrastructure has made it possible to sustain a high rate of economic growth. The revolutionary movement of 1910 began the agrarian reform and revindicated the nation's property rights over land and water. Multiple-use hydraulic works have been constructed throughout the country, and have made it possible to satisfy vital needs for food and services. However, this development process has not brought an even distribution of progress among all the country's inhabitants, all its regions, or all sectors of the economy; there has been a noticeable and persistent tendency to unjust distribution of the benefits of economic growth. Futhermore, the necessity of importing capital goods for development needs has led to deficits in the balance of payments and a growing foreign debt.

In order to achieve a balanced development of the economy, the present administration has established the following objectives:

1. Improved distribution of the national income,

2. Reduction of our dependence on foreign centers,

3. Achievement of the highest possible development rate compatible with economic and social stability.

The scarcity and unequal seasonal and regional distribution of water are obstacles to the utilization of such resources and require constantly growing investments to meet demands. At the same time, the time that must elapse between the conception of new hydraulic works projects and the moment when they begin operations is becoming increasingly longer. As Mexico's available water resources grow scarcer and more difficult to exploit, efforts to achieve greater efficiency in utilizing these resources and in setting priorities become increasingly important.

Water resources planning is particularly complex due to the fact that water is used by practically every sector of the economy, whose development must be considered as a whole. It would be mistaken to try to isolate problems and regions from this Frame of reference.

Mexico's investments in water matters will be necessarily increased in the future, and their impact on the environment, the economy, and the social situation of the country will be of great importance in the coming decades.

To give added agility to the planning process, the Ministry of Water Resources undertook the task of drawing up the National Water Plan, based on information provided by studies and accumulated experience in the country.

The National Water Plan is oriented to fulfill the following objectives:

i) Formulation and establishment of a systematic process of planning utili- zation of water resources for the rational selection of programs, projects, and policies under this heading that will best contribute to achieving the objectives of national socioeconomic development.

ii) Formulation of policies related to water use and control, with recommen- dations for pertinent institutional measures.

iii) Formulation of alternative programs for short, medium, and long-term development of water resources, including a preliminary identification of projects.

iv) Design of an information system that will cover immediate needs and assure a flow of data for systematic planning.

v) Establish a systematic program of basic and advanced training that will meet complementary personnel requirements in every area and activity included in the plans, programs, and projects for utilization of water resources.

In order to provide for international advisory services in some important aspects of the Plan as well as to make Mexico's own experience and that acquired during future work available to other countries, it was considered pertinent to reach an agreement with the United Nations Development Program (UNDP).

Executive agency for the technical assistence provided by UNDP will be the World Bank, in order for the Plan to provide a solid framework of reference for future credit programs for hydraulic works financing.

The National Water Plan's development organization is structured so as to assure adequate communication channels among the different national and international departments and organizations participating in the program.

The Board of Directors, whose members include the Director of the National Finance Institution (Nacional Financiera) and the Secretaries of the Presidency and of Finance and Public Credit, and which is headed by the Secretary of Water Resources, is the highest authority in charge of issuing general directives on research and executing policy decisions.

The Consultative Council, made up of 3 national and 3 foreign experts, is responsible for evaluation of reports and for making observations and recommendations which are then submitted to the consideration of the Board of Directors.

The World Bank, in its role of executive agency, provides consultation on matters related to the elaboration of the project.

In order to guarantee communication and coordination between work performed by the Plan and that carried out by other departments, a board of Under Secretaries and General Directors from the Ministry of Water Resources and a Coordination Committee composed of personnel from other government departments were formed.

UNDP's contribution comprises pay of experts, equipment, seminars, and scholarships. The government, in turn, contributes everything necessary for setting up the working groups and carrying out Plan studies.

At the executive level, the Plan Commission, which I have the honor of heading, was set up. It includes working groups with both Mexican and foreign members that operate under a General Coordinator.

The nature of the problems involved in water resources availability and demand made it necessary to divide the working groups into those having a national and those having a regional approach.

Planning groups with a national approach will devote their efforts to analyzing the water demand for different uses and the availability and quality of water and soil resources, gathering and integrating information with a view to processing information that is relevant to Plan studies, to designing the necessary mechanisms for attacking planning problems common to the particular regions studied, and to coordinating the work of the regional approach groups. The last mentioned groups will act as a liasion between work undertaken by the Plan and that carried out by the Ministry of Water Resources and other organizations. They will make studies covering water demand for different uses and water availability in their respective areas, estimate water balances, and analyze already-existing regional studies.

The Frame of Reference group will be in charge of integrating and revising all information and studies of a diagnostic nature collected during recent decades in order to define the type of economic and social behaviour that may be expected in coming years and to make an explicit estimate of development needs and necessary strategies for reaching national development goals. These needs will be translated into specific water demands to be expected from each sector of activity by the Water Uses group.

The "Availability group" will determine water and soil resources and report on existing utilization plans and possible modifications to them. The comparison of demands with availability will show which aspects of existing hydraulic utilization should be modified or whether new systems must be created.

Water resources development planning, in the form just described, can be carried out by means of different policies that in turn imply alternative programs composed of various specific projects. The choice of policies, programs, and projects must be consistent. The Evaluation group will define the criteria for assuring such consistency and will establish the Plan's communication flows within the national Frame of Reference.

The Technology group will be in charge of information, analysis techniques, and training program problems, and will participate in the analysis of projections regarding technology to be employed in the future. Its basic function will be one of providing support for the other groups of the Plan.

The method of study allows for both a national and a regional approach. The first approach analyzes the aggregate of variables that describe national socioeconomic development and problems that are common to the various regions of the country.

At the regional level, a homogeneous approach may be taken to the wide range of problems resulting from the needs, restrictions, and potentialities that are characteristic of each region, and an analysis made of the manner in which they interact with the variables examined at the national level.

Almost all the phases of the process described above are currently in existence in the Ministry of Water Resources. One of the aims of the NWP is to provide an explicit framework for all states and to bring isolated activities into harmony with the rest, in order to orient all action in water resources matters towards fulfillment of the overall objectives of national development.

The National Water Plan will use as a basis for determining the socioeconomic situation, the existing studies and information that have been carried out or gathered by government departments and agencies, from which the aspects of water resources that are related on the national or regional levels to development will be derived.

During this stage, special importance must be given to a diagnosis of the social and economic situation that will be made on both national and a regional scale and will take into account the dynamic nature of the development that has occurred in recent decades, analyzing the evolution of the supply and demand of goods and services and the factors that have motivated or hindered the development of various sectors of the economy and favored present patterns of distribution of income.

The diagnosis will be the basis for projections to be made in accordance with the tendencies noted in order to obtain an up-to-date picture of the future, and, in general, of future situations that may be expected to result from different development policies and goals. In this way, objectives, goals, and policies for each region and for the country as a whole may be established and a forecast made of the variables that will prove relevant in planning for utilization of water resources that will provide the foundation for subsequent stages of the process.

The study of the availability and use of water resources is one of the activities carried out by the Ministry of Water Resources. In this respect, the objective of the National Water Plan lies fundamentally in establishing the manner in which these problems are linked to the socioeconomic panorama and to alternative development plans that facilitate a clear analysis of possibilities and plans for utilization of water resources that can lead to the achievement of national objectives or to the solution of regional problems.

The formulation and integration of regional programs has for some years been one of the activities of the Ministry of Water Resources. The National Water Plan will culminate this task by working out regional integration programs that cover every sector of activity and fall within the frame of reference of national development. Not all the regions of the country have been equally well studied, in some cases because available technology offers no possibilities of utilization of resources, and in others, such as the humid zones, because of the inherent difficulties they present for development purposes in general.

In short, the definite results that will derive from the activities of the National Water Plan include:

o Formulation and institutionalization of the planning process, including the generation of projects.

o Formulation of a body of policies congruent with the programs and a preliminary selection of projects, taking into account the economic, social and ecological aspects.

o Determination of an adequate information system for the planning process, and elaboration of a basic and advanced training program for complementary personnel.

This briefly described plan has served to orient the elaboration of a detailed work program that is already in execution. The plan working group will carry out two iterations of the process described, the first of which will be completed by the end of this year.

Next, I will give you a broad description of water resources planning in Mexico.

The 6.5% growth rate of Mexico's gross national product is fairly high in comparison with that of other countries. Nevertheless, the present administration considers that from the social point of view the growth rate has not been particularly satisfactory.

One of the basic objectives of the economic strategy set forth by President Luis Echeverria in his inaugural address on December 1st. 1970, is "winning the collective welfare".

The President also declared on that occasion that: "For the Federal Executive branch, to govern shall be to make an equitable distribution of the fruits of redoubled efforts; to see to it that the more fortunate regions and groups contribute to the development of those which have been left behind."

A national water plan must contribute to increasing exports and to reducing the inflationary pressures that have become so evident throughout the world. It is within this new shared development strategy that the National Water Plan must operate.

Mexico's annual population growth rate of 3.5% and its urban growth rate of over 5% are among the highest in the world. This implies an accelerated increase in demands for goods and services that constitutes a serious problem, particularly when we recall that within certain limits the costs involved in satisfying those demands are spiralling upwards at a dizzy rate.

Imbalances have arisen that have threatened to detain the progress of the economy.

The sectoral imbalance is reflected by the fact that the product generated by each active worker in the agricultural and livestock sector is 4 times less than the average per capita product of our economy. A new strategy with social content that is directed more to making a fair redistribution of income than to achieving high growth rates has been adopted.

Outwardly, agricultural and livestock sector growth has been sufficient to meet foreign and domestic demands. Since 1966, however, it has suffered a noticeable drop that calls for increased investments in this sector and in the development of water resources in particular.

Balanced growth requires an export growth rate of about 12% and an agricultural and livestock sector growth rate of about 5%. The demand for resources resulting from this growth must therefore be met, and they may be expected to increase if there is a rise in exports.

Industrial development at an annual rate of more than 8% brings with it a growing need for the material and services employed in production, including such natural resources as water. On the other hand, the geographic concentration of industrial activity is unquestionably accompanied by an intense industrialization process and by problems directly related to water that have to do less with the quantities consumed than with industrial pollution of the element.

To maintain GNP growth at the annual actual rate of 6.5% (the rate used in Plan projections) therefore demands great emphasis on the measures the new administration is already beginning to take: reducing dependence on foreign centers, establishing favorable relations with foreign investment and technology, increasing the coverage provided by Socal Security to the rural population, improving education programs, and adopting family planning policies.

The National Water Plan considers that the economic foundation provided for this new strategy makes it a strategy of social content in which growth rates serve to facilitate an equitable distribution of progress.

Development generates demands for resources, among them water. Naturally, both the water utilization plans that are proposed for the purpose of satisfying regional needs and the institutional and administrative framework within which these plans operate influence the water demand. Other important factors are regional aspects such as climate, and control measures such as tariffs and regulation of the type of wastes that may be disposed in bodies of water.

The use made of water in a specific activity depends on the technology that is employed. In forcasting water demands, the possibilities of technological development and its possible effects on the use and reuse of water as well as the difficulties confronting the adoption of a new technology must be taken into account.

NWP studies of water use intend to analyze present utilization of this resource in various activities and to predict possible future alternatives for socioeconomic development. They also intend to provide the tools that will make it possible to estimate water demands that will arise from specific water utilization schemes in a given area, taking into account all the factors that influence demand.

It has been estimated that of the 390 billion m^3 of runoff both in withdrawal and in available consumption, total withdrawal in 1970 was 111 billion m^3, of which 30.4 billion were consumed. While 68% of the withdrawal corresponded to electric power generation, agriculture accounted for 95% of the consumption. These percentages will probably continue to apply in 1980, even if total withdrawal rises to 210 billion and consumption to 60.4 billion m^3. Both in withdrawal and in consumption the water needs of industry and the population are less than 5% of the totals for 1970 and 1980.

During the decade of the seventies, some two million hectares should be irrigated. This, together with the 4.5. million already in existence, would make our irrigated land reach the figure of around 6.5 million hectares. Simultaneously, the potable water demands of cities, particularly Mexico City, must be met.

It is possible that, in the future, fish hatcheries and nurseries will require important quantities of water and that both this activity and tourism will impose restrictions on the quanity of water used. River navigation, another of the possible uses of water, has never been very important in Mexico, but it might develop in the northeastern and southeastern regions of the country.

A basic idea of regional water problems may be gained by making a rough balance between uses and availabilities. Three of the regions of the country have already either exhausted the available resources of runoff or will have done so by 1980. This calls for thought concerning possible solutions such as the desalinization of sea water in the Peninsula of Baja California or the transportation of important volumes of water from other basins to that of the Valley of Mexico. Other regions, on the other hand, consume 10 percent or less of their available runoff even when they use enormous quantities of water. Such is the case of the basins of the Balsas, Papaloapan, Grijalva and Usumacinta Rivers, all of which have important hydroelectric installations, programmed for enlargement in the future.

Among the uses made of water, its urban-industrial usage and in the generation of thermoelectric energy cause important contamination problems. A rough index of regional pollution problems can be reached by dividing the regional share of the gross national product by the region's available run-off that might assimilate waste. This index allows us to divide the Republic in two parts: that north of parallel 19, with problems of pollution, and the area south of the same parallel, which together with the

Yucatan Peninsula comprise a zone singularly free of these problems. This index is all too general and does not take into consideration very important aspects of the evaluation of pollution problems such as the industrial makeup of each region. The vertical bars represent concentrations of biochemical demand for oxygen as well as concentrations of solids produced by the wastes from urban-industrial activity. Thus, in the Papaloapan area, where the general index showed fewer pollution problems than in the northwest or the Gulf region, there are really greater problems due to the fact that the majority of its industrial activity is related to the food industry, one of the activities leading to greatest pollution. The two upper lines in each column shows the increase in wastes to be expected if potable water and drainage is supplied to 100 per cent of the population by 1980. At present, taken on a national level, 65 percent of the urban population recieves these services.

If the water used for cooling in thermoelectric plants were to be flushed directly into surface waters, an increase in temperature of less than 3°C would be registered in all regions except the Valley of Mexico, where there would be an increase of 65°C.

Naturally, although these withdrawal, consumption, and pollution indices provide a general idea of some regional problems, they are not sufficient to carry out local studies of the demands within each region. One of the activities of the National Water Plan consists in studying the factors affecting demand and in designing tools that will allow us to estimate the water demand corresponding to different uses to which it might be put.

Surface water, ground water, and precipitation are the resources available to satisfy the before-mentioned needs.

The average annual precipitation of 780 mm is equivalent to 1500 billion cubic meters per year. This precipitation shows a marked imbalance and varies from less than 150 mm in the Baja California Peninsula to over 4,000 mm in the upper part of the Grijalva and Usumacinta River Basins. Sixty per cent of the country receives a precipitation that is less than 700 mm and is consequently considered arid, which means that it is impossible to obtain profitable crops from it in any given year unless it is irrigated.

With the data available today, some modifications have been made in Emberger's aridity index, adjusting it in a reasonable way to the true conditions of pluviometric deficiency in the country, except in the northwestern part of Yucatan where the index is powerless to delimit the semi-arid zone that exists there. According to this index, the country is divided into the zones appearing in the illustration.

As may be observed, the greater part of the territory is arid or semi-arid with the exception of the southern Gulf and Pacific coasts and the Grijalva-Usumacinta region.

Nearly 75% of the rainfall is consumed by evaporation and the remaining 25% produces an annual average runoff of 390 billion cubic meters. The arid part of the country and the Yucatan Peninsula provide 10% of the total runoff, the Central Pacific, the Balsas, and the Gulf regions another 30% and the remaining 60% of the runoff is supplied by the Isthmus of Tehuantepec, the Papaloapan and Grijalva-Usumacinta regions, which occupy 12% of the total national territory.

The quantity of water actually available depends on the annual variation in this runoff, on the possibilities of replenishing water supplies, on the evapotranspiration potential, and on the storage capacity of the reservoirs.

At present, the total storage capacity is 120 billion cubic meters, representing 30% of the mean annual runoff. Regional availability is shown in the illustration. It might be mentioned that 55% of this capacity is contained in a small number of reservoirs on the Grijalva, the Balsas and the Bravo Rivers.

The figure shows the percentage of storage as related to the runoff. The Bravo and Central Lerma regions are the best controlled, followed by the northwestern and northern catchment area regions.

As to their function, the reservoirs in arid and semi-arid zones are used mainly for irrigation, whereas in the humid zones the dams are used for power generation and flood control.

Mexico is a mountainous country, and only 30% of the territory has slopes of less than 25%. It is estimated that only some 35 million hectares have an agricultural potential, and of these, only 14 million can be irrigated. At this time, 4.4 million hectares are under irrigated cultivation and 10.4 million are dependent on rainfall.

In making our diagnosis, we have studied the Ministry's investments in irrigation and some of its effects, which I shall attempt to show you.

In 1926, the Government began a policy of agricultural development based mainly on the irrigation of farmlands. A study shows that almost the entire amount of the investment made by the Ministry of Water Resources was channeled toward irrigation, and that the proportion of federal investment decreased in the period from 1959 to 1970.

In the Ministry of Water Resources, increasing importance has been given to investment in small scale irrigation works which are aimed both at increasing agricultural production and at contributing to the economic development of certain underdeveloped regions. It is also worthwhile to mention the growing concern of the MWR in works of social improvement through the provision of water for domestic, industrial, and municipal consumption.

These investments produced an increase in agricultural production from 3.68 billion pesos (1970 prices) in 1950 to more than triple the amount in 1970 when production reached the figure of 11.4 billion pesos, representing respectively 22 and 31 per cent of the total national agricultural production for the period. Also, irrigation has contributed most conspicuously to the diversification of agricultural production, where we see a changeover from a single crop, which was cotton in 1950, to seven different products that are being cultivated today. Furthermore, the domestic demand for agricultural products has been satisfied, and the changeover has contributed to the generation of surpluses available for export which, in turn, bring in the funds necessary for the development of other sectors of our economy. Indeed, cotton, sugarcane, tomatoes, and wheat have recently played an outstanding role in the balance of trade. It is estimated that 75% of all agricultural exports (which constitute 30% of total exports) come from the zones that have been irrigated by the Ministry of Water Resources.

In the beginning, investments in irrigation were directed toward those regions from which the greatest return was anticipated, thereby producing a notable increase in agricultural production by means of the preparation of irrigated lands in areas considered arid or semi-arid, where without irrigation it was impossible to obtain any agricultural production. These zones are located in the north of the country and comprise three quarters of the total irrigated crop land. It is from these regions that we have obtained an important part of our products for exportation.

A further important part of the investments was channeled toward regions in which the greater part of the country's population is concentrated and which corresponds to the central zone of the High Plateau. A fifth of the irrigated lands come from all other regions and constitute around 5 per cent of the total.

In general, the greater part of the investment has been directed to structural works for irrigation, ignoring to some extent the complementary aspects such as research and agricultural extensionism, as well as the marketing of the products. This has caused a decrease in the efficacy of the measures taken, for, in the specific case of the ex-post evaluation of Zone IV in the State of Michoacan, it was discovered that the benefit-cost relationship that might have been obtained by complementary investments would have been notably larger than those that have actually been perceived.

Another effect of investment in irrigation has been its contribution, together with that of other investments of social importance, to attracting inhabitants from neighboring regions, thereby retaining the rural population that otherwise would have emigrated to other zones or toward the cities, creating poverty belts and other related problems. However, a large part of the capital generated in the regions, thanks to public investment, has not been invested in the same region in other economic sectors or in small and medium industries that could serve to diversify a local economy, and this indicates the relatively scarce participation of private capital in regional development.

On the other hand, a certain effect of concentration of income has been observed among persons who, having capital and/or technical knowledge, exploited the agricultural potential, thus becoming the principal beneficiaries of the development brought about by public spending. For this reason, the Ministry of Water Resources is laying greater emphasis on complementary investment that will lead simultaneously to more effective returns on investments and a better distribution of the income generated by such investments.

In Mexico as in other countries of the Third World, people do not have a clear understanding of how to look for a better future. Uncertainty and hesitation hamper the solutions of the basic problems of the community. This makes us consider that planning is not only constrained to economic variables but should also take into account social and political aspects in order to change the attitude of men and structures. This change does not admit palliatives. The allocation of resources is stressed without trying to achieve an equitable distribution. To increase production without an adequate distribution among countries, regions, and social groups is a dangerous "boomerang" for the privileged countries and groups that have enjoyed, until now, most of the benefits of human development.

Planning cannot be an exclusive task either of the government or of private enterprise. The fundamental idea of every plan should be to promote the formation of a new social conscience in the community regarding prosperity and welfare. It would not be possible to achieve this objective unless all sectors of society are moved towards a new mentality. This new attitude will blend the willingness to perfect into the desire for equity, justice, and human solidarity.

THE UNANSWERED CHALLENGE: PLANNING TO MEET THE TOTAL WATER RESOURCE NEEDS OF AN URBANIZED STATE

by

ROCCO D. RICCI, M.S. in C.E.
Commissioner

New Jersey Department of Environmental Protection

The concept of resource management has changed over time. During the past several years we have witnessed fundamental shifts in the assumptions underlying resource management and how it is practiced. Too often "management" was exploitation under an assumed name. It means development without regard to its impact on other resources.

Today that has changed. The environmental movement signified a new awareness among the public that resources are finite, that it is socially undesirable to despoil and waste them. Early on it seemed that environmentalists wanted to stop using all resources, perhaps in reaction to the developers' seeming desire to do the exact opposite. Most reasonable people in both camps probably would agree that a balance someplace in between is desirable (although exactly where is the subject of much debate). It is the role of government to develop a balanced program of adequate protection and development responsive to the needs of society as a whole.

Most teachers, regulators and practitioners in the water resource field probably would agree that creating such a balanced program for water resources requires management of the entire water cycle and should be approached holistically. They would agree that major efforts should be put into planning to make certain that decisions in water quality do not impact adversely upon water supply or flood plain management issues (and vice versa) both in the short and long terms. Total water resource management is sound theory and should be a basic tenet of any water resource management program.

However, there is a large gap between the accepted theory of water resource management and its practice. Based upon my own personal professional experience in private practice as well as federal and state service, I find there are several basic impediments to achieving the goal of total resource management: fragmented organizational responsibility in the regulating and implementing agencies; the attitude of professionals who limit their vision to that part of the water cycle for which they have responsibility, and a failure by these professionals to recognize the need for assessment of their proposed actions on other environmental and social issues. The environmental movement and the National Environmental Policy Act (NEPA) have forced our professionals to articulate many issues which were previously either ignored or inadequately presented for public debate. In my judgment, our profession, although it accepts the theory of resource management, has not provided the leadership to see to its implementation.

Our regulatory and operating agencies have grown to meet their immediate needs and purposes without concerted efforts to integrate the water supply issues with the water quality or flood shed management issues. As a result, we have organized with relatively narrow objectives, thus creating institutional impediments to effective total water resource management.

Today the Federal Government has set forth much of the basic framework for water resources management in the United States. This is certainly true for water pollution control and potable water, but less true for water supply and flood plain management.

The U.S. Environmental Protection Agency has primary federal water pollution control authority under the Federal Water Pollution Control Act, and has potable water authority under the Federal Safe Drinking Water Act. The thrust of these statutes, and the agency's mission pursuant to them, is water quality.

The U.S. Department of Interior and the U.S. Army Corps of Engineers share the authority for water supply projects through the construction of dams and reservoirs, stream dredging and diversion.

The U.S. Department of Housing and Urban Development and the Army Corps of Engineers share flood plain management authority--HUD administering flood plain delineation under the National Flood Insurance Program and the Corps engaging in engineering analysis, flood plain delineation, planning and construction of flood control facilities.

Thus, the institutional problem at the Federal level is apparent, and to some degree states suffer from this same diffusion, with water pollution control and water supply in different departments, and in different units within the same department. While the scale of the problem is smaller the difficulties in achieving unified management are the same--the institutions are fundamentally deficient for carrying out total water cycle management.

However, even the proper institutional framework is not sufficient. The complexity of the issues we face, and its resulting specialization, compound this problem. The manager must organize his own resources, such as budget and personnel, to respond effectively to the demands of his increasingly complex duties. As a matter of survival, the practitioner looks narrowly toward accomplishing the shortterm tasks with which he is charged; he is frequently hard put to do more.

There also is a need to overcome the biases of bureaucrats who have performed their limited tasks for one portion of the water cycle for many, many years and sometimes are uncomfortable with change, with the need to deal with different disciplines, and with the need to solve more comprehensive problems with a limited amount of supporting data. There is a similar need for change in attitude and scope of vision in the private sector.

New Jersey, to a large degree, does not have the institutional problems at the State level; all water resources functions are in the Division of Water Resources within the Department of Environmental Protection. Even so, the department is just starting to deal with water resources in a total management framework. While we are developing this management system to deal with issues in a systematic way, we still must make day-to-day decisions to solve short-term problems. We are attempting to do so with a feel for long-term goals rather than being able to rely on real long-term plans. It is not the best way to do business, but today it's the only way we have.

New Jersey, it is often said, is a laboratory for solving problems which will confront other urbanized parts of the United States in the decades to come. Our evolving management approach to water resources is the direct result of the seriousness of our water supply, water pollution control and flood shed protection problems. It has been increasingly clear that total resource management in our urbanized State is not a subject only for the halls of a university but is something which must be applied in practice. A few specific projects should serve to illustrate the interrelationship of the various phases of the water cycle in our State and to highlight a number of the issues which must be solved today without having all the necessary planning data.

In the area surrounding the Borough of Princeton, there is a regional sewerage authority which is responsible for the treatment of wastewater without any statutory responsiblity for water supply or land management. Yet, major issues in this area relate to the environmental impact on water supply and land use of the proposed interceptors and waste treatment facilities.

This project, which is still under review, presents two alternatives to the abatement of existing pollution problems in an upstream watershed. One alternative is to convey all waste in the area to a central treatment plant. The other proposes several treatment facilities in the service area.

The one plant approach would deplete the upstream areas of some base stream flow in the summer. Discharge to the streams either at the three upstream locations or downstream will lower the groundwater table. However, even if clearcut knowledge existed on these environmental management problems, the most controversial aspect of this project, in my opinion, is the concern over secondary impact. There is concern that building an interceptor across undeveloped land will induce land speculation which in turn will result in accelerated development and the degradation of the watershed.

This project is illustrative of a water pollution control plan which has been developed over a ten year period. The resource management concerns have involved land use, construction of waste treatment facilities in excess of readily available water supply for the area, and evaluation of intangible social values. The issues are extremely complex and require a weighing of factors which are not readily quanti- fiable.

The Passaic River Basin in northern New Jersey graphically illustrates the complexity of, and need for, total water resource management. Water is intensively used and reused in the Passiac Basin. One hundred mgd of the potable surface water supply is withdrawn below sewage treatment plants discharge points. Under drought conditions the flow at Little Falls would be almost entirely treated sewage effluent from upstream areas. This base flow will increase from approximatley 75 mgd at present to a significantly larger figure in the future as the result of further diversion of upstream groundwater through municipal collection systems after planned high levels of treatment.

There are various proposals to divert or impound part of this flow at the confluence of the Passaic and Pompton Rivers for water supply. A major diversion at this point is currently under review and is one of the last remaining major blocks of water which can be developed in this part of the State. It is the first time that a proposed diversion in New Jersey has been evaluated on the basis of considering surface stream quantity and quality effects. While large investments are being made in waste treatment facilities, we also must consider the effects of water quality resulting from the diversion of substantial amounts of water, since intensive water use compounds water quality problems. Reuse of water requires high levels of waste treatment as well as highly efficient treatment of the potable water supplies. Such intensive water use is indicative of intensive development. In the Passaic Basin many developed areas are flood prone, and development in the upper parts of the watershed have changed flood hydrology and increased flooding potential.

For many years now, the U.S. Army Corps of Engineers has been attempting to develop a flood control program for the Passaic Basin. To date, none of the proposals have had widespread public support because of the diversity of interests involved. We have been successful in obtaining the authorization for a new Corps study to evaluate both structural and nonstructural solutions to flooding in the Basin. Study of the alternatives will consider water supply quality and flood shed management practices. Most importantly, we have taken the lead by establishing the Passaic River Citizen's Task Force to work with local, State and Federal governments to solve a problem which everyone acknowledges to be serious.

The Passaic Basin, which I have discussed briefly, is probably the finest example that I could give in promoting the need for total water resource management in a State which is densely developed and makes intensive use of its available water supply.

These examples are indicative of the types of problems which are encountered on a day-to-day basis; they are not isolated situations. They demonstrate the need to solve today's problems while looking to the future. We have taken some significant steps forward but it is difficult to be completely satisfied with the progress which has been made to date. The State Water Supply Master Plan and Areawide Water Quality Management Plans for the entire State are being developed concurrently. These efforts are being coordinated with each other as the foundation for our total resource management program. The following are several of the major areas to be covered in the Water Supply Master Plan:

a. The plan will enable the State to decide upon the right mix of water supply projects to meet developing needs;

b. A data base and information system will be developed which can be used by the decision-makers for evaluation of trends and evolving problem areas;

c. Programs will be evaluated for the development and protection of our groundwater resources;

d. A major effort will analyze the institutional, fiscal and legal impediments to implementing water supply master plan recommendations;

e. The development of drought contingency plans, interconnection and water conservation programs are high on our list of required outputs;

f. The plan will develop procedures to assess the total water balance (surface and groundwater) throughout the State. The techniques will be demonstrated with six sub-basins, and recommendations will be made for programs to effectively manage both water quality and quantity.

The Areawide Water Quality Management Plans should provide specific answers to several water quality problems during the first two to three years of development. In particular we are concerned about such things as the effects of non-point sources, introduction of toxic and carcinogenic materials into our streams and groundwaters, the development of effective industrial pretreatment programs, protection of our groundwater recharge areas, and the development of a statewide sludge management program to enable us to recycle what is a valuable resource. In our coastal plains, we are attempting to identify areas with a good potential for future recharge of highly treated waste effluent.

In my judgment, there is unquestioned need for total water resource planning, especially in a state like New Jersey where we have intensive water use in our urbanized areas, vast groundwater resources, large agricultural needs, and extremely dense population. The issues are becoming more complex, and the longer we delay the more difficult the puzzle will be to solve. We must take a hard look at the manner in which government establishes and implements water resources policy with the goal of moving, as quickly as possible, toward real total water resource management.

METHODS FOR ESTIMATING OF WATER POLLUTION LOAD FROM PARTICULAR LAND USES ASSOCIATED WITH STROM RUNOFF (1978)

by

LADISLAV MICHNA, M.S. IN C.E.

Columbia University Seminar on Pollution
and Water Resources

I. INTRODUCTION

The nationwide significance of water pollution caused by storm-generated discharges was first identified in 1964 in the United States Public Health Services publication on the "Pollutional Effects of Stormwater and Overflows from Combined Sewer Systems." Congress, in recognizing this problem, authorized funds under the Federal Water Pollution Control Act of 1965 and following legislation for the research, development, and demonstration of techniques for controlling this source of pollution. The 1972 Amendments placed new and stronger emphasis on pollutant loads associated with different land uses generated by storm runoff. This type of water pollution is of major significance in the areawide water quality control planning under section 208 of P.L. 92-500, since the estimation of "non-point" source pollution loading depends largely upon future projections of land use.

A number of published information (1), (2), (3), (4), (5), (6), confirms generally that the storm runoff generates different types of pollutants and that urban runoff contains more pollutants than runoff from suburban, rural, agricultural or forest land use. However, estimates of annual losses of sediment and nutrients from rural areas tend to stagger one's imagination. Approximately four billion tons of sediment are washed into United States streams each year (7).

The objective of this paper is: (a) to present a literature review related to "non-point" sources of pollution, (b) to discuss some existing methods for estimating storm related pollutant loads, and (c) to present numerical examples for estimation of pollutant loads associated with land use practices.

II. Literature Review

Loehr (8) summarized comparative magnitudes of pollutants from nonpoint sources. Characteristics of pollutants in storm runoff from urban, semi-urban and rural watersheds in West Lafayette, Indiana, are summarized in the following table:

Parameter* mg/1	Urban		Semi-urban		Rural	
	mean	range	mean	range	mean	range
BOD_5	35.4	2.5-146.0	10.3	4.0- 20.0	4.0	1.8- 6.6
COD	138.0	22.0-369.0	93.2	35.0- 176.0	32.0	18.0- 52.0
SS	224.0	20.0-824.0	955.0	86.0-2720.0	244.0	17.0-646.0
VSS	56.0	0.0-168.0	96.0	15.0- 190.0	37.0	4.0-102.0

*Parameters defined in glossary.

Weibel, et al. (19) investigated the fluctuations of pollutant parameters in Cincinnati stormwater runoff with seasonal changes. They found that there is no pronounced change in the parameters, with the possible exception of BOD. Burm and Vaughan (9) found a definite rising trend exists during the warmer summer months for both fecal and total coliforms. Land use is another factor affecting storm runoff quality.

Palmer (10) concluded that in highly urbanized and densely populated watershed would produce heavily polluted storm runoff, and would be but slightly less objectionable to receiving waters than the overflow from combined sewers.

Whipple, et al. (11) indicated the effects of antecedent conditions on pollutant loadings for a storm event are not well defined. They cast considerable doubt on the reality of the assumption that pollution from runoff increases with time elapsed since previous rainfall. De Filippi and Shih (12) report, for short duration storms, pollutant concentration has a characteristic, initial high peak, followed by an abrubt falloff. Peak concentration does not always coincide with the highest flow rate, but in general, concentration tends to increase with increasing flow rate. Long-duration rainfall is characterized by higher total flow with lower peak concentration than short-duration, high-intensity storms. Consecutive rains result in decreased peaks.

A summary of BOD concentration and pollution loads associated with storm runoff in non-urban areas is shown in Table 1.

III. METHODS FOR ESTIMATION OF POLLUTION LOADS

Several methods have been proposed to estimate storm runoff loads, for both urban and non-urban areas, for long-term as well as short-term predictions.

A. Detail Simulation Methods

In this approach, the physical process of rainfall, runoff and water quality is modeled and analyzed. The approach has the best potential for success when the data base is very extensive such that calibration and verification of the models is possible. These models usually require the use of digital computers. The following models have been mostly used in the water quality management plans.

1 STORM (13)

1.1 Description

The Storage, Treatment, and Overflow Model (STORM) of the U.S. Army Corps of Engineers is designed primarily for evaluating the stormwater storage and treatment capacity required to reduce untreated overflows below specified values. The model can simulate hourly stormwater runoff and quality for a single catchment for several years. Five water quality constituents can be computed for different land uses: suspended and settleable solids, biochemical oxygen demand, nitrogen, and phosphorus. Computations of treatment, storage and overflow proceed on an hourly basis by runoff volumes and pollutant mass balance. If the hourly runoff exceeds the treatment capacity, the excess runoff is put into storage. If the storage capacity is also exceeded, the excess runoff becomes untreated overflow. If the runoff is less than the treatment capacity and water is in storage, than the excess treatment capacity is utilized to diminish the storage volume.

The computer program is written in Fortran IV and the output includes hourly precipitation for a single raingage and various summaries of the stormwater runoff and quality analysis for selected storm events. These include the duration and amount of rainfall, the time and amount of treatment, the amount of overflow to receiving waters, and averages for all selected events. Runoff amounts are defined in inches and pollutant quantity in pounds.

1.2 STORM Input Data

STORM requires the following input data: Area of drainage basin, percent of total area of each land use group, average per cent imperviousness of each land use group, runoff coefficients for per- vious and impervious areas, feet of gutter per acre for each land use group, depression storage available on impervious areas, treatment rate, hourly rainfall, daily rate of dust and dirt accumulation per 100 feet of gutter for each land use group, pounds of pollutants per 100 pounds of dust and dirt, and street sweeping frequency and efficiency.

1.3 Evaluation of STORM Model

The model is suitable for the continuous simulation of stormwater runoff and quality from a single urban catchment. A significant weakness of the model is its inability to simulate dry-weather flow. Limitations on accuracy of the runoff computations are imposed by the simplified rainfall-runoff formulation, particularly the assumptions of a constant infiltration loss rate during rainstorms, a constant evaporation rate between rainstorms, and immediate runoff of the hourly rainfall excess. The last approximation would reduce model accuracy as the catchment site increases and the time of concentration of the runoff becomes longer than one hour.

The stormwater quality relationships are based on empirical formulations which have been tested on very limited data and whose accuracy has not been sufficiently established. It is therefore not possible to estimate their accuracy for application to areas where no records of concurrent urban stormwater runoff and quality are available for calibration purposes.

The model apears to be useful, however, for analysis of rainfall records to determine critical runoff-producing events and for general planning purposes to estimate the relative magnitudes of required storage and treatment capacities to reduce stormwater overflows to the receiving waters.

2 SWMM (13)

2.1 Description

The Stormwater Management Model (SWMM) is one of the most comprehensive mathematical models available for the simulation of storm and combined sewerage systems. It computes the combined storm and sanitary runoff from several catchments and routes the flows through a converging branch sewer network. Both dry-weather and stormwater quality for suspended and settleable solids, biochemical and chemical oxygen demand, coliform bacteria, phosphorus, nitrogen, and oil and grease are computed for each modeled catchment and routed through the sewerage system. The computer program is written in FORTRAN IV for an IBM 360/370 computer and is organized into an executive block (MAIN) and four computerational blocks (RUNOFF, TRANSPORT, STORAGE and RECEIVE) which may be used separately or in any combination to simulate the entire urban drainage area.

2.2 SWMM Input Data

The input data requirements for SWMM are extensive and include: rainfall data antecedent dry days, subcatchment descriptions including area, overland flow width, slope, roughness coefficients, infiltration rates, percent imperviousness; land use, population data, street sweeping frequency and number of passes, soil erosion data, pollutant loading and generation factors, sewer layout, shapes, dimensions, slope, roughness, specifications of flow control devices, Infiltration data, dry weather flows, catch basin data, treatment and storage facility data, tidal variations, water surface elevations and areas, water depths and roughness coefficients for receiving waters, and receiving water boundary conditions.

2.3 Evaluation of SWMM Models

The SWMM model is one of the most complete and widely used mathematical models available for the assessment and planning of storm and combined sewerage systems. Consideration of both wastewater flows and qualities is an important aspect of evaluating needed treatment facilities and the impact of sewage effluents on receiving waters. This is also one of the few models which include cost computations. The computation of the costs of overflow storage and treatment level is valuable aid to the engineer-designer.

The program includes an option to suppress the water quality computations and perform the flow simulations alone. This can save considerable computer time if water quality computations are not needed. The model shows satisfactory accuracy for catchment areas ranging in size between 5 and 2200 ha (13 and 5700 acres).

The model is very complex and poorly organized in documentation which makes it difficult for the user to implement.

3 HSP (13)

3.1 Description

The Hydrocomp Simulation Program is also one of the most comprehensive mathemetical models for the simulation of both rural and urban catchments. The water flow computations are based on the Stanford Watershed Model which was the first comprehensive mathematical model of catchment hydrology. The program is formulated for the continuous simulation of water flow and quality from several catchments and routing in converging branch sewer and open channel networks. Catchment moisture and water quality are accounted for during periods of no precipitation, so the model can be used for continuous simulation of several years. Special features are included for the simulation of impoundments and diversions, including the flow of water over spillways and through hydroelectric turbines.

3.2 HSP Input Data

Input requirements are extensive and include: Precipitation data, Evapotranspiration data, Temperature, Streamflow and parameters needed for calibration such as: infiltration, depression storage, soil moisture storage, snow parameters, channel characteristics, watershed segments, etc. Determination of these parameters requires considerable user skill and experience, since not all can be measured directly.

3.3 Evaluation of HSP Model

HSP is most suited for runoff modeling of urban and non-urban catchments where detailed continuous simulations are required. Comparison between measured and computed runoff for selected storm events have produced generally good agreement.

HSP is not suited for systems where treatment processes must be simulated or where pressure flow and surcharging are significant factors.

Drawback: The user must contract with Hydrocomp International, Inc., for routine application of the program. Information is not published which would allow estimates of computer execution times as a function of problem size.

4 AGRUN (13)

AGRUN (Water Resources Engineers) is a revised version of the RUNOFF block of the Stormwater Management Model which can be used to estimate runoff quantity and quality from agricultural lands. AGRUN has not been extensively tested, and potential users are cautioned accordingly.

Note:

Many other urban runoff models have been described in the literature (15) and are too numerous to enumerate here. A multiplicity of techniques are available by which to estimate non-point source pollutional discharges, each with specific advantages and disadvantages. The following described methods can be used as "first-cut" techniques in evaluating the water quality problems within short time and resources available and yet should provide sufficient technical information for wastewater management planning.

B. Desk-Top Methodology Method

Michna (16) describes two approaches for the "First-cut" determination of the pollution loads associated with different land use activities as follows:

a. Base flow non-point input approach

b. Rainfall-Runoff approach

1. Base Flow (Steady State) Non-point Input Approach

Steady state pollutant loads are the result of both natural conditions, as occur in land areas unaffected by man's activity, and perturbances to the natural state caused by land use activities. The pollutants may enter the surface waters through ground-water inflow and/or interflow. The steady state loads will be quantified by analyzing the measured pollutant concentrations and flows under steady state flow conditions, e.g., samples collected at the selected storm-sampling sites before and after the storm. Thus, if sufficient data were available, one can construct for each sampled parameter (e.g. BOD, SS, COD, etc.) a graphical plot of unit load (pounds concentration per area per time) versus unit flow (cfs per area), for each land use activity (agriculture, forest, etc.)

Examining the curves in Figure 1, one can expect increasing mass discharge (unit load) from increasing land use activity and one would also expect that the higher stream flow per unit of land area would yield higher unit loads. From the graphical plot, the estimation of pollution loads associated with the specific land use activity during non-storm conditions can be made.

For areas where known point sources are identified, the pollutant concentrations expected from those point sources and flows should be subtracted from the steady-state flow concentrations to yield the steady-state non-point source concentrations most likely associated with the surrounding land use activity.

2. The rainfall-runoff approach is proposed for the storm runoff effect pollution load estimation. Available water quality rainfall and stream-flow data can be used to establish the functional relationship between the pollutant load, the land-use types, and rainfall characteristics. The functional relationship permits conversion of these rainfall statistics to runoff load statistics, e.g., rainfall, streamflow and water quality are examined. There are several techniques (17, 18) available that employ parameters and assumptions which are usually statistically divided. These techniques have the advantage of relative ease of verification and application, and are much less costly to apply than the mathematical modeling methods.

   Again, in this approach, the rainfall is used as an input unlike the output is set of pollutant loads for a given set of land uses. Figures 2a and 2b give a schematic picture of the Rainfall-Runoff Approach.

   The total input of the pollutant for each sample and for each parameter into the receiving stream can be found by multiplying the pollutant concentration by the measured flow. This number (rate) is plotted versus time for the duration of each storm. The curve is also called "Pollutograph" and the area under this curve is the total volume of the pollutant which entered the receiving stream during the storm. Dividing this total volume by the acreage of the drainage area gives the volumes of pollutant per acre generated by the storm for that particular land use type.

C. Direct Method (20)

Direct Method is based on estimating the average mass discharge rate as the product of the average concentration in the runoff, and the average quantity of runoff. That is, if $\overline{W}_o$ is the long term average mass discharge rate from an overflow point, then

$$\overline{W}_o = \overline{c}\ \overline{C}_v\ \overline{I}_t A \quad . . . . \quad (1)$$

where: $\overline{c}$ is the average concentration (mg/l)

$\overline{C}_v$ is the average runoff coefficient (unitless)

$\overline{I}_t$ is the average rainfall divided by the period of averaging, T (in/hr)

A is the drainage area in acres.

This equation assumes that the random variables $\overline{c}$, $\overline{C}_v$, and $\overline{I}_t$, are uncorrelated. An analysis of runoff coefficients presented in Figure 3 indicates that a relationship exists using population density as a measure of the degree of imperviousness. For low and medium population densities, a mean of 0.3 ± 0.15 seems reasonable, and results in approximately a two-fold uncertainty. The average concentration ($\overline{c}$) can be obtained from (20) for selected U.S. cities.

The Direct Method may be applied in the following steps:

1. Identify a drainage area (A) in acres with sewer overflow.

2. From the demographic inventory, estimate a population density (persons/acre) for each urban drainage area.

3. Estimate a mean runoff coefficient $\overline{C}_v$ for urban drainage area. Figure 3 or alternate techniques may be used.

4. Obtain the average annual rainfall from the weather bureau.

5. Convert average annual rainfall, V, to average hourly intensity, $\overline{I}_t$. $\overline{I}_t = {}^{V}/_{t}$

6. Calculate average annual runoff, $\overline{Q}_o$ (cfs) = $\overline{I}_t$ (${}^{in}/_{hr}$) $\overline{C}_v$ A (acres)

7. Estimate the average annual load discharge (lbs/day) for a particular pollutant (BOD_5, SS, etc.), from equation (1).

D. Example Application

To illustrate the use of the Direct Method, an example is presented.

A hypothetical South River Basin has an annual rainfall of 40 inches/year. Approximately 10 square miles of the total 20 square mile area of Anytown is sewered with combined sewers. The remaining area is unsewered and the existing sewage treatment plant can not handle any stormwater.

The population density of the combined sewer area is 20 persons per acre.

Estimate the total untreated load flows in lbs/day which flow directly to the South River from the urban unsewered area.

Solution.

A = 10 square miles = 6,400 acres (unsewered)
$\bar{I}_t$ = 40 inches/year = 0.00457 inches/hr.
Population density = 20 persons/acre
From Figure 3, the runoff coefficient at 20 persons per acre is $\bar{C}_v = 0.42$.
The average stormwater overflow from Anytown
$\bar{Q}_o = 0.00457 \times 0.42 \times 6{,}400 = 12.28 = 12.3$ cfs
Assuming $\bar{c} = BOD_5 = 25$ mg/l (equivalent to secondary treatment) then the average annual BOD load is:
$\bar{W}_o = 5.4$ (conversion factor) $\times 25 \times 12.3$
$\bar{W}_o = 1{,}660.5$ lbs/day

IV. RELATIONSHIP TO OTHER NATURAL RESOURCE INVENTORIES

The coordination of land use and water quality analysis must be emphasized for the overall evaluation of a water quality management plan. As a minimum the following information should be available:

A. DRAINAGE AREA AND SUBAREAS

The drainage area under investigation should be clearly identified on a map of suitable scale. Drainage areas may be further broken down into subareas to more precisely identify major land use categories or topographic characteristics.

B. LAND USAGE

The most common subdivisions of land use are:

residential (urban, suburban, rural, single, multi-family, etc.)
commercial
industrial
agricultural
forest
open lands and parks, etc.

C. POPULATION DENSITY AND INCOME

Population density information (people per ha) can be utilized for evaluating residential areas.

D. CLIMATE

Because of the nature of storm water runoff studies, climatic conditions is an important parameter. The temperature, wind velocities, evaporation, precipitation (storms, duration and intensities) should be about the climatological data.

E. TOPOGRAPHY

Topographic information is very difficult to present for smaller local areas since typically topographic maps are prepared for rather large areas and are not easily reduced to a satisfactory scale.

F. PERVIOUS AND IMPERVIOUS AREAS

Pervious and impervious areas play an extremely important role in the runoff rates from various areas. This information is typically gathered from aerial photographs. Street areas and length of curb can be handled in the same manner.

G. SPECIFIC SAMPLING SITES INFORMATION

For the selected storm sampling sites the following data should be added:

- Ownership
- Municipality
- Average slope
- Drainage area
- Soil Texture
- Soil type
- Crop Cover
- Fertilizer
- Depth to Groundwater
- Geology

V. SUMMARY

As the Nation's point source pollution control program nears the end of its first stage, it is becoming more apparent that "trade-offs" must be made between more advanced treatment of continuous point sources and control of nonpoint source pollution.

Among diffuse sources of pollution, stormwater runoff (concentration from different land uses) has been identified as one of the major contributors to water pollution.

Brief literature review of some existing studies demonstrating the non-point water pollution problems due to storm-runoff from different land uses has been presented in this paper.

The principal purpose of 208 studies is the local development of cost effective areawide wastewater management plans for initial and longer term water quality control. Numerous point, non-point sources may have to be assessed, in many cases with little or no direct data. Therefore, the immediate problem facing the 208 planner is to define the appropriate technical steps and procedures which are to be considered in order to evaluate the water quality problems within the time and resources available and yet which will provide adequate technical information for wastewater management planning.

Three methods which can be used by the 208 planner for water quality assessment have been described in this paper.

The Direct Method can be used for rough estimate of the magnitude of urban waste loads due to storm-runoff on an annual average basis. This method should be used as a preliminary tool when no sampling information is available. The numerical example and step-by-step procedure for application of this method is presented.

The Desk-Top Methodology Method can be applied to estimate the wastewater loads from different homogeneous land use due to storm-runoff, if storm water sampling data is available. The method should be used again for an approximate estimate of the wastewater loads.

The Direct Method and the Desk-Top Methodology Method should be used in the early stage of the planning process when one is interested in a gross assessment of relative loads and impacts on water quality at various sources.

The Simulation Methods described in this paper are computer-based mathematical tools. The user must know how they work, what they do, and what they do not do, and also how costly they are. The selected model must be calibrated-verified, and adequate input data must be collected. If data is not there, or if adequate funds for data collection are not provided, the use of a complicated model may be ruled out. All of these models are in use and undergoing continued change and updating. They are excellent tools to analyze sets of alternatives for selection of the best wastewater management plan.

IV. REFERENCES

1. Whipple, W. Jr., et al, "Unrecorded Pollution from Urban Runoff," J.WPCF, Vol. 48, pp. 809-996, May 1976.

2. Whipple, W. Jr., et al, "Characterization of Urban Runoff," Report of Water Resources Research Institute, Rutgers University, New Brunswick, New Jersey, September 1976.

3. Wadleigh, C.H., "Wastes in Relation to Agriculture and Forestry," U.S. Department of Agriculture Pub., No. 1065, Washington, D.C., 1968.

4. Bensow, R.O., "The Quality of Surface Runoff from a Farmland Area in South Dakota During 1969," Technical Report, State University of South Dakota, 1970.

5. Weidner, R.B. et al, "Rural Runoff as a Factor in Stream Pollution," J.WPCF, Vol. 41, pp. 335-514, March 1969.

6. USEPA, "Methodology for the Study of Urban Storm Generated Pollution and Control," EPA-600/2-76-145, pp. 233-257, August 1976.

7. USEPA, "Quantification of Pollutants in Agricultural Runoff," EPA-660/2-74-005, pp. 6-47, February 1974.

8. Loehr, M.D., "Characteristics and Comparative Magnitude of Non-point Sources," J.WPCF, Vol. 46, pp. 1899-1872, August 1974.

9. Burm, R.J., and Vaughan, E.D., "Bacteriological Comparison Between Continued and Separate Sewer Discharges in Southeaster Michigan," J.WPCF, Vol. 38, pp. 400-409, March 1966.

10. Palmer, C. L., "Feasibility of Combined Sewer Systems," J.WPCF, Vol. 35, pp. 162-173, February 1963.

11. Whipple, W. Hunter, J.V., and Yu, S.L., "Characterization of Urban Runoff-New Jersey," Report, Water Resources Research Institute, Rutgers University, New Brunswick, New Jersey, 1976.

12. De Filippi, J.S., and Shih, C.S., "Characteristics of Separate Storm and Continued Sewer Flows," J.WPCF, Vol. 43, pp. 2013-2058, October 1971.

13. USEPA, "Areawide Assessment Procedure Manual," EPA-600/9-76-014, Vol. II, Appendix A, pp. 9-69, July 1976.

14. USEPA, "Short Course Proceedings-Applications of Stormwater Management Model," EPA-600/2-77-065, pp. 4-93, March 1977.

15. Huber, W.C., "Modeling for Storm Water Strategies," APWA Report, Vol. 42, No. 5, May 1975.

16. Michna, L., "Desk-top Methodology for Estimation of Pollutant Loads Associated with Land Use Practices, "Working Paper 3.2.1, Delaware 208 Study Areas, N.J.D.E.P., Division of Water Resources, Trenton, New Jersey, August 1977.

17. USEPA, "Loading Functions for Assessment of Water Pollution from Non-point Sources," EPA-600/2-76-151, pp. 29-262, May 1976.

18. USEPA, Nationwide Evaluation of Combined Sewer Overflows and Urban Stormwater Dischargers," EPA-600/2-77-064a, Vol. I, pp. 7-76, September 1977.

19. Weibel, S.R., Anderson, R.J., and Woodward, R.L., "Urban Land Runoff as a Factor in Stream Pollution," J.WPCF, Vol. 36, pp. 914-924, July 1964.

20. USEPA, "Areawide Assessment Procedure Manual," EPA-609/9-76-014, Vol. I, pp. (2-55) - (2-59), July 1976.

GLOSSARY

Agricultural Land - Land in farms regularly used for agricultural production. The term includes all land devoted to crop or livestock enterprises; for example, the farmstead lands, drainage and irrigation ditches, water supply, cropland, and grazing land of every kind in farms.

Base Flow - Stream discharge derived from groundwater sources. Sometimes considered to include flows from regulated lakes or reservoirs. Fluctuates much less than storm runoff.

Baseline Sample - A sample collected during dry-weather flow (i.e., it does not consist of runoff from a specific precipitation event).

Basin - The term "basin" means the streams, rivers, tributaries, and lakes and the total land and surface water area contained in one of the major or minor basins defined by EPA, or any other basin unit as agreed upon by the state(s) and the Regional Administrator.

BOD_5 - Five-day Biochemical Oxygen Demand: A standard test for the amount of oxygen utilized in aerobid decomposition of a waste material during a five-day incubation at a specified constant temperature.

Calibration - The procedure of assigning values to the uncertain or unknown parameters in simulation model and adjusting them until model predictions correspond acceptably closely with observed prototype behavior.

Catch Basin - A chamber or well, usually built at the curb line of a street, for the admission of surface water to a sewer or subdrain, having at its base a sediment sump designed to retain grit and detritus below the point of overflow.

Concentration - The quantity of a given constituent in a unit volume or weight of water.

Curb Length - The distance of a single street curb, or the length of one side of a street or other thoroughfare. Distinguished from streetlength which normally represents two or more curb lengths.

Design Storm - A selected rainfall pattern of specified amount, intensity, duration, and frequency which is used as a design basis.

Detention Time - The theoretical time required to displace the contents of a tank or unit at a given rate of discharge (volume divided by rate of discharge).

Dilution Ratio - The ratio of the quantity of combined sewer overflow or storm sewer discharge to the average quantity of diluting water available after initial mixing at the point of disposal or at any point under consideration. This is not only used with respect to sewer overflows but also it is used for any point or nonpoint sources of pollution.

Direct Runoff - The water that enters stream channels during a storm or soon after. It may consist of rainfall on the stream surface, surface runoff, and seepage of infiltrated water.

Dissolved Solids (DS) - The total amount of dissolved material, organic and inorganic, contained in solution in water or wastes.

Distributed Load - A consistent load which enters the receiving water over a considerable distance, as in the case of groundwater seepage, rather than at a point as with a sewer outfall.

DO - Dissolved oxygen, the amount of gaseous oxygen dissolved in a liquid sample.

Drainage Basin - A geographical area or region which is so sloped and contoured that surface runoff from streams and other natural watercourses is carried away by a single drainage system by gravity to a common outlet or outlets; also referred to as a watershed or drainage area.

Fecal Coliform - Fecal coliform are indicators of human and animal pollution and are expressed as numbers of bacteria per volume of sample.

Feedlot - A relatively small, confined land area for raising and fattening cattle.

Frequency of Storm (Design Storm Frequency) - The anticipated period in years which will elapse, based on average probability of storms in the design region, before a storm of a given intensity and/or total volume will recur; thus a 10-year storm can be expected to occur on the average once every 10 years. Sewers designed to handle flows which occur under such storm conditions would be expected to be surcharged by any storms of greater amount or intensity.

Hyetograph - An intensity-time graph for rainfall derived from direct measurements.

Hydrograph - A flow versus time graph derived from direct measurement.

Hydrological - Pertains to the branch of hydorology that treats surface and groundwater; its occurence and movements; its replenishment and depletion; the properties of rocks which control groundwater movement and storage; and the methods of investigation and utilization of groundwater.

Impervious - Not permitting penetration or passage (e.g., of water).

Industrial Waste - The liquid wastes from industrial processes as distinct from domestic or sanitary sewage.

Land Use - Differentiating the spatial arrangements and activity patterns of land areas.

Loading - The dry weight, in pounds, of some material that is being added to a process or disposed of.

Loadograph - A graph of pollutant load as a function of time over a defined period of time (pollutograph).

Mathematical Model - The characterization of a process or concept in terms of mathematics, which allows the manipulation of variables in an equation to determine how the process would act in different situations.

Point Source - "The term 'point source' means any discernible, confined and discrete conveyance, including but not limited to any pip, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation, or vessel or other floating craft, from which pollutants are or may be discharged."

Pollutant - "The term 'pollutant' means dredged spoil, solid waste, incinerator residue, sewage, garbage, sewage sludge, chemical wastes, biological materials, radioactive materials, heat, wrecked or discarded equipment, rock, sand, cellar dirt, and industrial, municipal, and agricultural waste discharged into water."

Pollution Parameters - The physical, chemical, and bacterial contaminants which can be quantified to indicate pollution levels.

Pollutograph - A graph of pollutant concentration as a function of time during a rainfall/runoff event.

Rainfall Intensity - The rate at which rain is falling at any given instant, usually expressed in inches per hour.

Reach - The smallest subdivision of the drainage system consisting of a uniform length of open channel or underground conduit. Also, a discrete portion of river, stream or creek. For modeling purposes a reach is somewhat homogeneous in its physical characteristics.

Recharge Basin - A basin provided to increase infiltration for the purpose of replenishing ground water supply.

Residential Density - The number of persons per unit of residential land area. Net density includes only occupied land. Gross density includes unoccupied portions of residential areas, such as roads and open space.

Simulation - Representation of physical systems and phenomena by computers, models and other equipment.

Steady-State - Quantities (e.g., inputs and solution) which do not vary with time (but may vary over space).

Stochastic - The property of being random with respect to time.

Storm Frequency - The time interval between major storms of predetermined intensity and volumes of runoff for which storm sewers and combined sewers, and such appurtenant structures as swirl concentrator chambers, are designed and constructed to handle hydraulically without surcharging and backflooding: e.g., a five-year, ten-year or twenty-year storm.

Storm Sewer - A sewer which carries storm water and surface water, street wash and other wash waters or drainage, but excludes sewage and industrial wastes (also called a Storm Drain).

Surface Runoff - Precipitation that falls onto the surfaces of roofs, streets, ground, etc., and is not absorbed or retained by that surface, thereby collecting and running off.

Total Dissolved Solids - The dissolved salt loading in surface and subsurface waters.

Total Solids - The solids in water, sewage, or other liquids. It includes the dissolved, filterable, and nonfilterable solids.

Ultimate Oxygen Demand - The total amount of oxygen that is utilized by bacteria in the decomposition of sewage. This includes both the carbonaceous BOD and nitrogenous BOD.

Urbanized Area - Central city, or cities, and surrounding closely settled territory. Central city (cities) have population of 50,000 or more. Peripheral areas with population density of 1,000 persons per acre or more are included.

Urban Runoff - Surface runoff from an urban drainage area that reaches a stream or other body of water or a sewer.

Water Quality - A term used to describe the chemical, physical, and biological characteristics or water, usually in respect to its suitability for a particular purpose.

Watershed - The region drained by or contributing water to a stream, lake, or other body of water.

Wet Weather Flow - A combination of dry weather flows, infilitration, and inflow which occurs as a result of rainstorms.

Table 1

AGRICULTURAL STORM RUNOFF--BOD CONCENTRATION AND LOADS

Reference	Study Area	Land Use Characteristics	Study Area Size	BOD during wet weather		
				Range of Concentration (mg/l)	Average Concentration (mg/l)	Annual Load (lb/acre/year)
Whipple (11)	Six Mile Run	65% Farms 17% Residential	10.8 mi^2	0.4-10.0	3.2	46
Whipple (11)	Big Bear Brook	57% Farms 13% Residential	9.0 mi^2	0.4-22.0	2.6	6.0
Weidner (5)	Coshocton, Ohio	Crop land (corn, wheat)	1.5 - 303 acres	Corn Wheat 2.9-7.2		Corn 27.5-120 Wheat 3.7-15.5
Weidner (5)	Ripley, Ohio	Apple orchard Farm	5 acres 5 - 75 acres	 9.6-322	8.4	3.7 5.5 - 606

The study concluded the following:

1. Improved farm practice may decrease pollution load reaching streams.
2. Solid losses are proportional to BOD, COD, phosphate and total nitrogen.
3. BOD losses increase as runoff volume increases.

The BOD values are average for six farm sites that were mainly used for animal production.

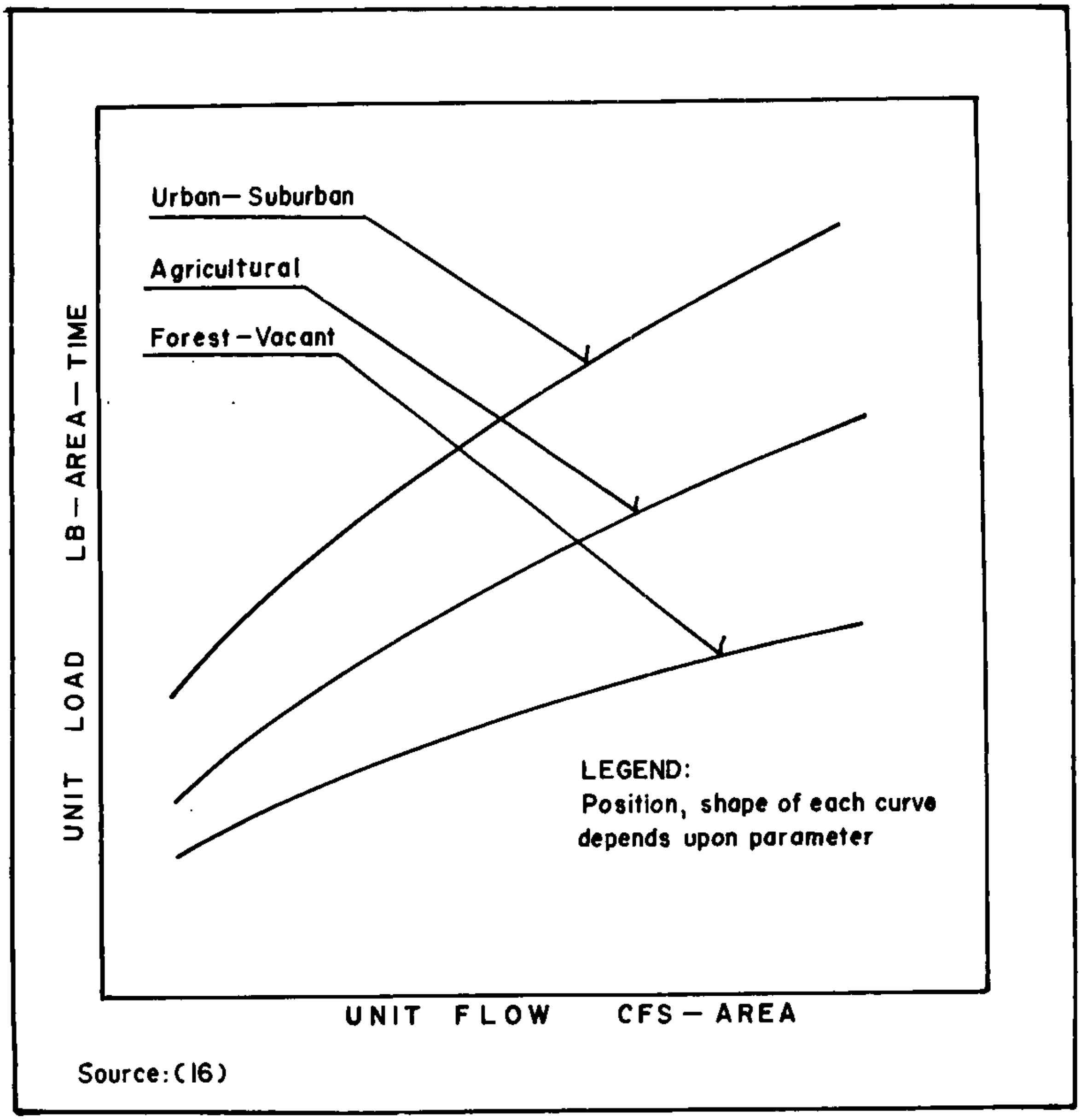


FIGURE I.

ANTICIPATED DISTRIBUTION OF THE UNIT LOADS FOR THE STEADY STATE NONPOINT SOURCES CONCENTRATIONS.

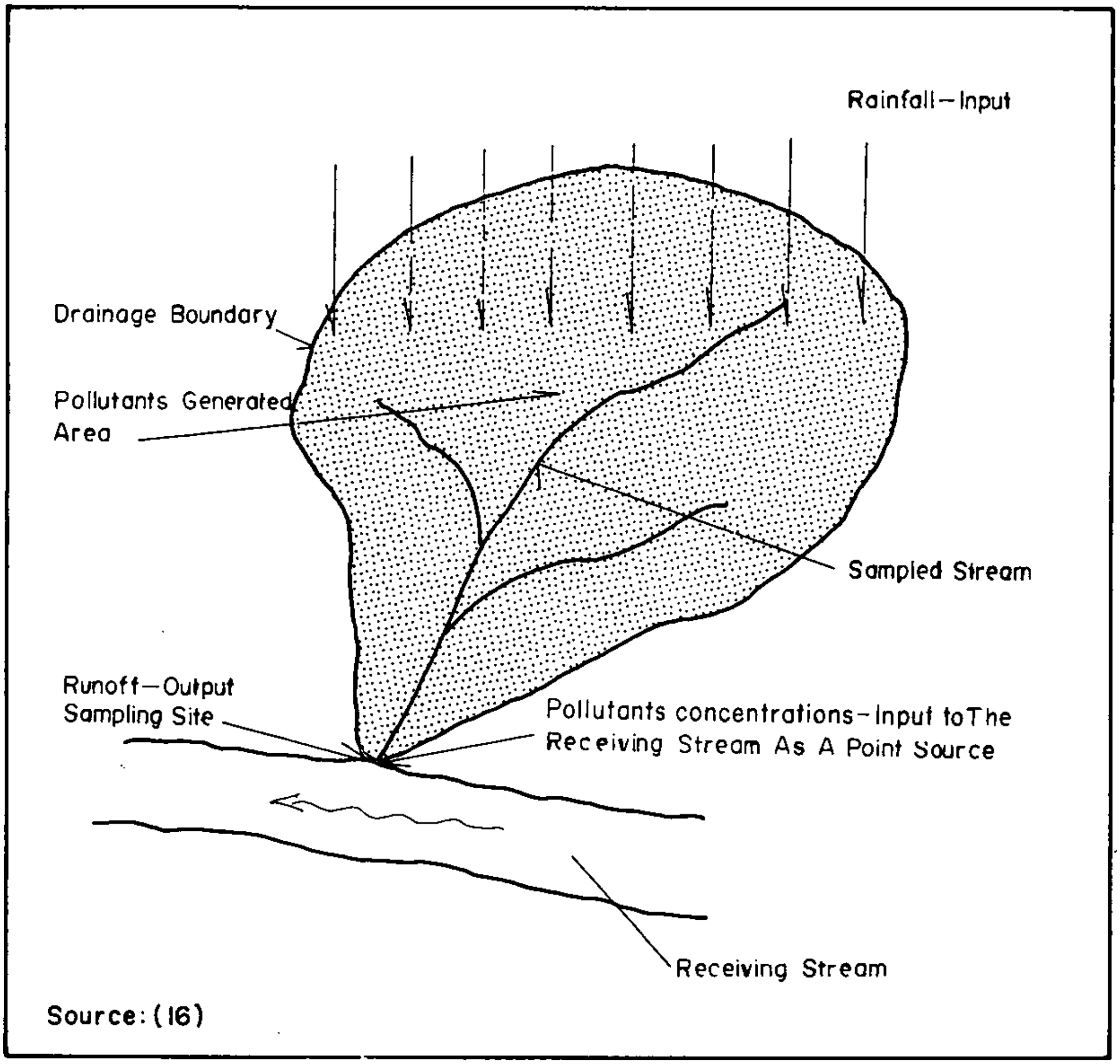
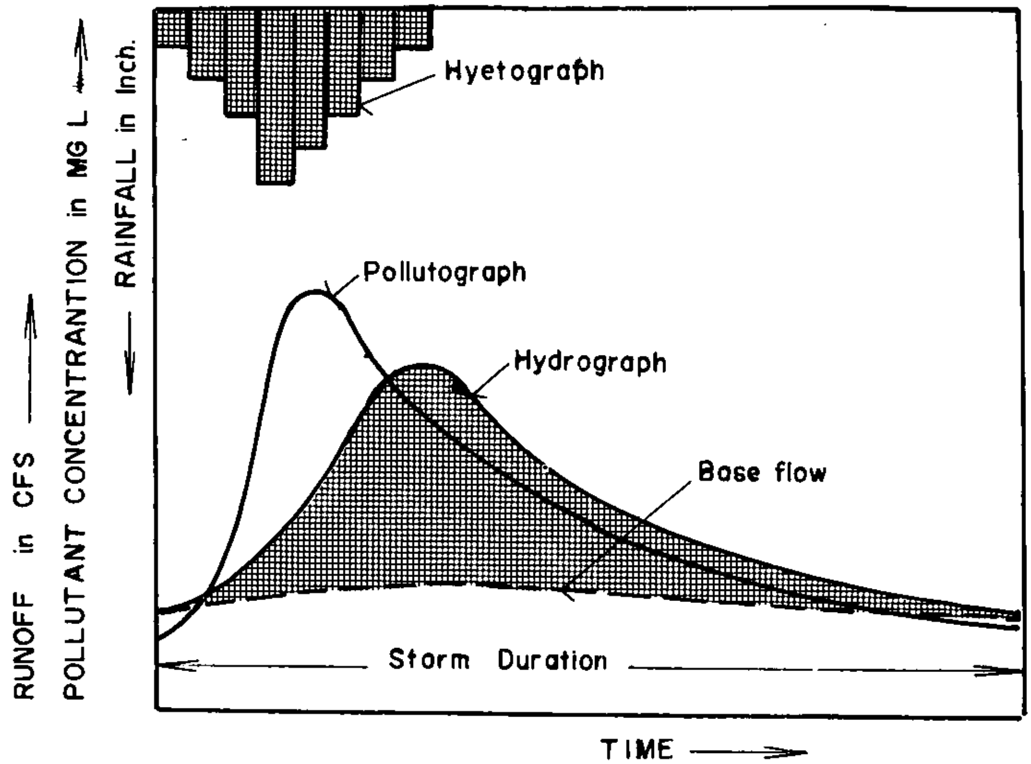


FIGURE 2a.

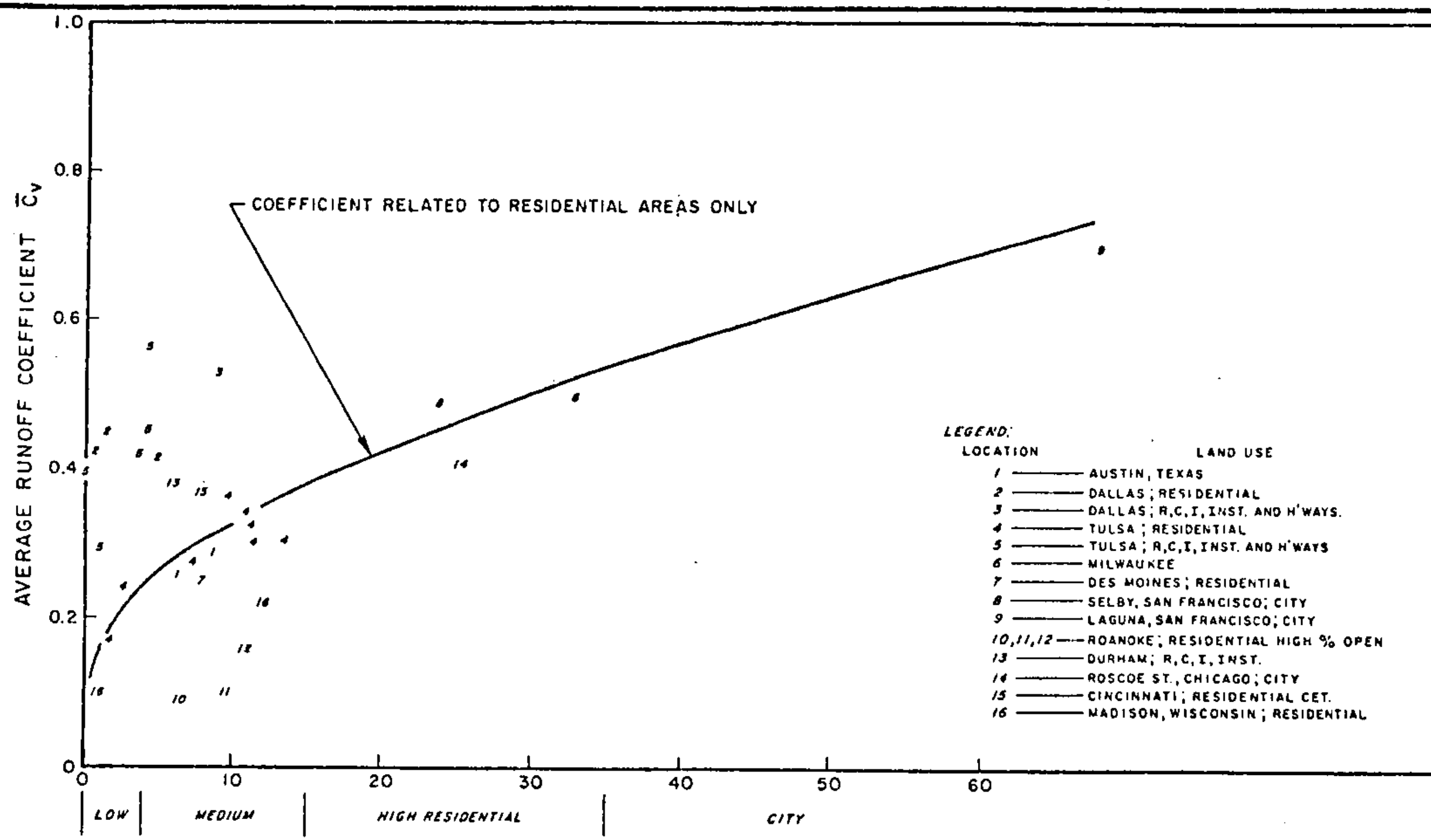
STORMWATER POLLUTANTS GENERATED AREA



Source:(16)

FIGURE 2b.

POLLUTOGRAPH-HYDROGRAPH CURVES FOR RAINFALL-RUNOFF APPROACH



SOURCE: (20)

FIGURE 3.
RUNOFF COEFFICIENT RELATED TO POPULATION DENSITY

HEADLAND-BAY BEACHES ALONG THE WESTERN SHORELINE OF CAPE COD BAY, MASSACHUSETTS

by

WARREN E. YASSO, Ph.D.

Department of Science Education
Teachers College, Columbia University*
New York, New York 10027

* On special assignment as Program Director for Education, National Sea Grant Program, National Oceanic and Atmospheric Administration

ABSTRACT

Computer analyses of the plan shapes of three, similarly oriented, headland-bay beaches along the western shoreline of Cape Cod Bay, Massachusetts, were based on data from large-scale maps. Shapes of all three beaches are closely approximated by logarithmic-spiral curves.

In confirmation of earlier results from Sandy Hook, New Jersey and beaches near San Francisco, California, the log-spiral centers for the three beaches are in close proximity to associated headlands. There is also a progressive decrease in spiral angle, , from Duxbury Beach, on the north (α=63.2°) through Manomet Beach (α=40.5°) to Sagamore Beach, on the south (α=31.9°).

The entire western shoreline of Cape Cod Bay has a similar composition of heterogeneous Pleistocene sediments. Therefore, it is assumed that southward progressive decrease of spiral angle, , is a unique example of the effect of southward progressive narrowing of the angular sector from which erosionally significant waves, generated in the long fetches north of Cape Code Bay, can approach the beaches. Consequently, it is hypothesized that the larger the angular sector from which erosionally significant waves can approach a headland-bay beach, the larger will be its characteristic spiral angle.

INTRODUCTION

A headland-bay beach is a beach lying in the lee of a headland subjected to a predominant direction of wave attack (Yasso, 1965). Such headlands may be relatively erosion-resistant natural materials like rock masses or glacial debris. Or, they may be man-made structures like groins or the termination of a sea wall. It is assumed that a headland blocks the direct attack of predominant waves on the lee shoreline. However, refracted and diffracted waves do impinge on the lee shoreline thereby causing its erosion. In special cases, reflected waves may also play a part in the process of erosion.

The planimetric shapes of headland-bay beaches in the vicinity of San Francisco, CA., were investigated using U.S. Geological Survey topographic maps as a data base. A computer curve-fitting procedure revealed that plan shapes of Bodega Bay, Drakes Beach and Limantour Spit of Drakes Bay, Bolinas Bay and Halfmoon Bay were closely approximated by logarithmic spiral curves (Yasso, 1965 and in press). In four of the five shorelines, the log.-spiral center was found to lie in close proximity to the adjacent headland. This finding lent support to the hypothesis of refraction/diffraction control of waves by each headland. However, there was no uniformity, or north-south trend, in log.-spiral characteristic angle, α, for headland-bay beaches near San Francisco (Table 1).

There are many variables, such as differing rock types of headlands and lee coasts, initial orientation of coastal segments, and tectonic movements involved in the origin of plan shapes of California beaches. Therefore, a simpler coastal situation was sought in which fewer variables might be operative in determining the curvature of headland-bay beaches. The search was rewarded by discovery of three large, similarly oriented, headland-bay beaches along the western shoreline of Cape Cod Bay. Location of the three beaches (Duxbury, Manomet and Sagamore) is shown by the detailed map of Figure 1. Associated headlands on the north side of each beach are composed of

Table 1

Beach Name	Spiral Angle, α (degrees)
Bodega	42.4
Drakes	85.6
Limantour Spit	82.2
Bolinas	65.0
Halfmoon	41.3

resistant glacial debris. These are also labeled in Figure 1. An inset map gives the general configuration of Cape Cod and adjacent landmass of Massachusetts.

DATA COLLECTION AND COMPUTER ANALYSIS

Data for plan curvature of the three Cape Cod Bay beaches were obtained by superimposing a fine-mesh, Cartesian grid over the oldest available, large-scale maps of the beaches. Coordinate values of closely spaced points along the shoreline were obtained. Computer processing of the data was performed as described in Yasso, 1965 (p. 711-712).

RESULTS OF COMPUTER ANALYSIS

Plan shape of each of the three beaches is closely approximated by a log-spiral. As an example of goodness of fit, a comparison of plan position between the actual shoreline and best-fitting log.-spiral was calculated for 38 data points spaced at roughly equal intervals along the entire Sagamore Beach shoreline. The mean distance, measured at right angles to the actual shoreline, between the two curves is 31.2 meters. This is a slightly better fit than was obtained for log.-spiral approximations to headland-bay beaches near San Francisco.

Of greater importance is confirmation of the positional relationship between the log.-spiral center and associated headland for each headland-bay beach. This was first stated as an hypothesis (Yasso, 1965) arising from the study of headland-bay beaches near San Francisco. As illustration, Figure 1 shows the best-fitting log.-spiral center is positioned in reasonable proximity to Green Harbor Pt., in the case of Duxbury Beach, and extremely close to the headlands associated with the other two beaches. A summary of base map and computer analysis information is presented in Table 2.

An unexpected result of the computed analyses is given in the last column of Table 2: there is a progressive decrease in spiral angle southward into Cap Cod Bay.

Incidental to the study described above, it was also found that plan shapes of beaches at the mouth of Plymouth Bay are closely approximated by log.-spirals. However, because of the difference in orientation of the Plymouth Bay and Cape Cod Bay beaches, the former are not discussed in this report.

Table 2.--Summary of log.-spiral analyses for selected beaches along the western shoreline of Cape Cod Bay, Massachusetts

SHORELINE SEGMENT	BASE MAP/DATE	GEOGRAPHIC COORDINATES OF LOG.-SPIRAL CENTER	SPIRAL ANGLE, α ALPHA (DEGREES)
Duxbury Beach	C.&G.S. Chart #245, 11/23/64	42°05'25"N, 70°35'50"W	63.2
Manomet Beach	U.S.G.S. Manomet Quad., 7 1/2', 1941	41°55'02" N, 70°32'26"W	40.5
Sagamore Beach	U.S.G.S. Sagamore Quad, 7 1/2', 1951	41°50'04"N, 70°32'06"W	31.9

INTERPRETATION OF RESULTS

The writer is not aware of any long-term record of wave height and direction in Cape Cod Bay. However, the configuration of the New England and Maritime Canadian coast suggests that waves from the North Atlantic Ocean are not the dominant source of wave energy in Cape Cod Bay. Waves entering Cape Cod Bay from long fetches to the North are considered to be the most erosionally significant along its western shoreline. Because of the presence of Cape Cod, there is a southward progressive decrease in the angular sector from which such waves can impinge on beaches analyzed in this study. That is, angular sector of wave approach for Duxbury Beach is oriented from roughly east to north whereas it is roughly northeast to north for Sagamore Beach. It is assumed that this change affects the configuration of headland-bay beaches in the study area. The result is a southward progressive decrease in the spiral angle of similarly oriented, headland-bay beaches along the western shoreline of Cape Cod Bay.

From the analyses and assumptions of this study, it is hypothesized that the larger the angular sector from which erosionally significant waves can approach a headland-bay beach, the larger will be its characteristic spiral angle. It is hoped that this hypothesis can be investigated for many headland-bay beaches in areas where wave data are available. It is also hoped that analyses of the shape of Cape Cod Bay beaches based on more recent maps will reveal any trends that might lead to long-term predictions of coastal erosion or deposition.

ACKNOWLEDGMENTS

The efforts of Joseph J. Pepenella in preparing Figure 1 and of Debra T. Hughes in typing the manuscript are greatly appreciated.

REFERENCES

Yasso, W. E., 1965, Plan Geometry of Headland-Bay Beaches: Jour. of Geology, v. 73, p. 702-714.

_____, in press, Headland-Bay Beaches, in Fairbridge, R. W. and Schwartz, M. L., Encyclopedia of Beaches and Coastal Environments. Stroudsburg, Pa., Dowden, Hutchinson, and Ross.

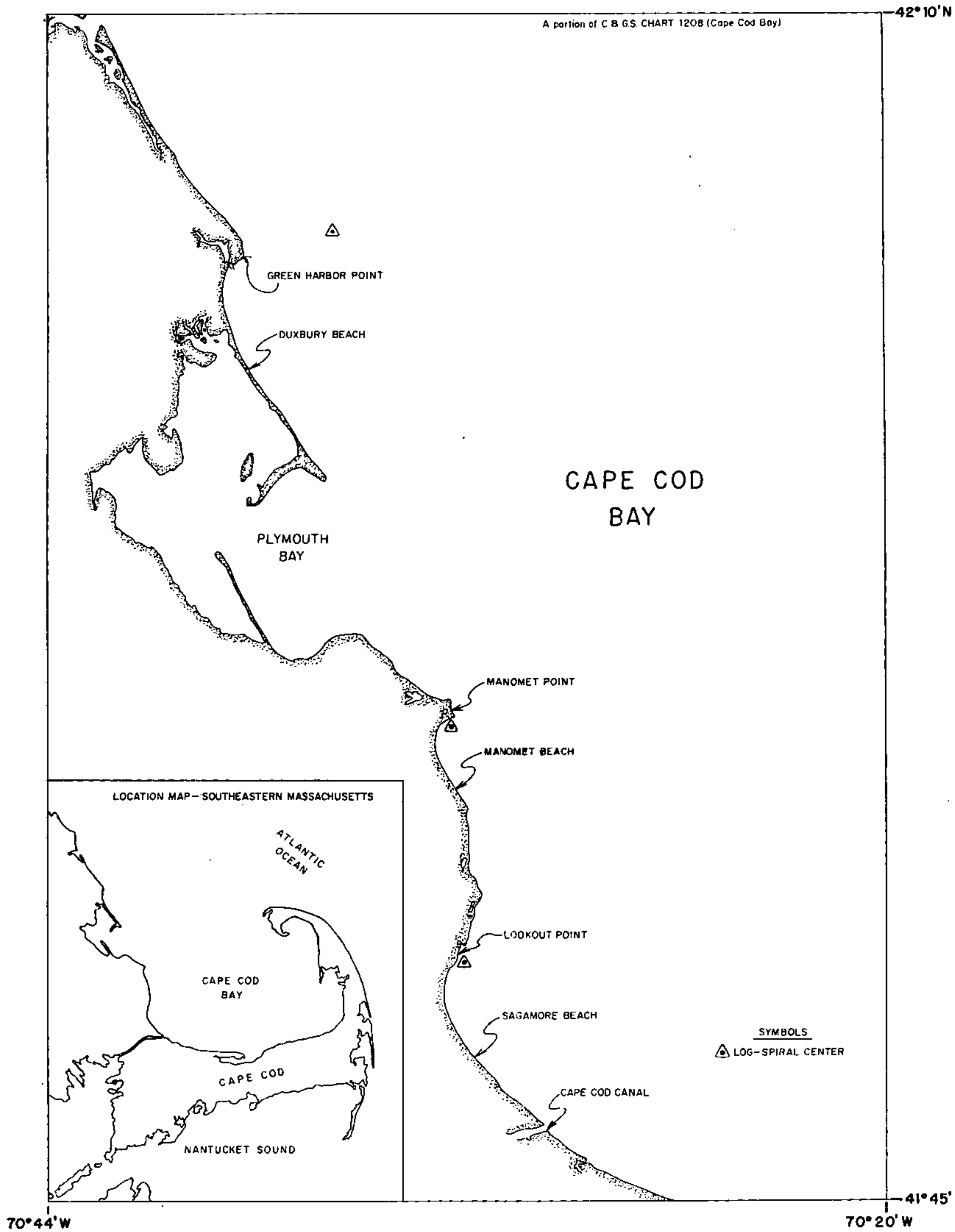


Figure 1. Western shoreline of Cape Cod Bay, Mass.

LAND ORIENTED REFERENCE DATA SYSTEM IN NEW JERSEY*

(LORDS)

by

DR. GEORGE J. HALASI-KUN

Chairman, Columbia University Seminars
on Pollution and Water Resources, New York
State Topographic Engineer of New Jersey

*Based on articles:

Halasi-Kun, G.J., "Land Oriented Water Resources Data System in New Jersey," Proceedings of the International Symposium on Computer-assisted Cartography, U.S. Census, Washington, D.C., September 21-25, 1975 pp. 388-409

Halasi-Kun, G.J., "New Jersey's Land Oriented Resource Data System--Environmental Data Collecting in Coastal Area," Proceedings of the International Association for Hydraulic Research, Baden-Baden, F.R. Germany, August 1977 (Vol. 3) pp. 235-242

INTRODUCTION

In choosing New Jersey for developing an environmentally oriented data bank system and for evaluating extreme surface flows in smaller areas, there were several considerations. It was felt that efficient environmental resources planning needs interdisciplinary data gathering concentrated in water interaction on the natural environment. To succeed in developing a model for a land-oriented water resources data bank, a region with a variety such as New Jersey seemed to be appropriate.

New Jersey is a state of contrasts in many respects. Not only is it one of the most densely populated regions of the world (400 persons per km^2 with an area of 20,295 km^2), sandwiched between two overpopulated metropolitan areas (New York City and Philadelphia), but 45% of its territory is still forest. The highly urbanized area has only two cities with a population over 100,000 inhabitants and accounts for 19% of the land. Some 27% of the region is agricultural with one of the highest per hectare dollar value for crops produced in the U.S. The transportation network, both highway and railroad, has the greatest traffic density in America. The chemical industry of New Jersey is one of the most developed in the U.S., however, its largest industry is still recreation related to the Atlantic Coast bathing beaches. The mineral industry, especially in dollar value of minerals produced per km^2 is within the top 16% of the U.S. Artificial and natural lakes, including swamps, occupy 9% of its surface and the territory of the state is bordered by fresh or salt water except the northern border.

Geologically, 60% of the region is underlain by Cretaceous or later sediments, which are primarily unconsolidated sands and gravels, including the area of the famous Pine Barrens Natural Park. Twenty percent of the state, the most densely populated part (over 10,000 persons per km^2) consists of Triassic shale and sandstone with Basalt flows or Diabase intrusions. The remaining 20% of the region is underlain by Precambrian Crystallines and early or middle Paleozoic limestones and shales.

The climate of the area is moderate with an average rainfall of 1200 mm/year. Periodically, severe droughts occur such as in the years 1961-1966 with an average rainfall of 800 mm/year. The extreme point rainfall intensity for 24 hours reaches 250 mm value in many parts of the state with a 2-5 years frequency. The northern half is characteristic for moderately high mountains (up to 600 m). On the other hand, the southern half is flat with less than 70 m above sea level. The whole area can be characterized as one of smaller rivers with a watershed less than 250 km^2 (except Delaware, Passaic and Raritan Rivers) and with many natural and artificial lakes. The evapo-transpiration and interception average 450-550 mm from the annual precipitation. The ground water availability indicator has a value from 0 to 450 mm yearly, depending on the permeability and storage capacity of the geological formations in accordance with the yearly precipitation.

Finally, the last but never the least reason in selecting the area for developing the data bank was the fine cooperation of the N. J. Bureau of Geology and Topography with the Columbia University Seminars on Water Resources by making available over 90,000 well records and other valuable land use, demographic, geologic and surface-flow data, and by materially supporting the whole project. Furthermore, the N. J. Department of Community

Affairs helped to develop the program as will be described in the "The Technique of the Data Bank."

BASIC PHILOSOPHY IN DATA COLLECTING

Environmental data collecting reflects the interaction of water on the natural environment. The inventory of natural resources is gathered from the viewpoint of their utilization by man. Since water and its quantity and quality are of utmost importance to life, the data bank is water resources oriented. It should give basic information about water quantity and quality in connection with surface streams including extreme values and ground water storage capacity based on permeability of the geologic subsurface. A climatic description of the area as primary source for water is also needed. Inasmuch as land use development is the source of demand for water, both for consumption and for treatment, it is necessary to identify current water distribution, sewage systems, treatment and polluting activities (point and area pollution). As additional information, an inventory of other natural resources--including geologic survey, land use, geographic description, together with areas utilized for transportation, historic sites and public spaces--is essential.

Man being in the center of any evaluation of the environment, updated demographic data are also an important part of the data bank. Demographic information, based on the latest census, gives area density, concentration of the population within each community, and each community boundary.

Finally, data collecting and its importance is governed not only by demographic and water resources information, but also by real estate values in land use. Taxation is an excellent indicator for defining the grade of importance of the area in question. Therefore, data from tax maps and locally maintained information, after being evaluated and computerized, should also be incorporated as part of the data bank. Tax considerations lead to the conclusion that the smallest land use unit for the data bank may cover 3 hectares in settled areas and 12 hectares outside the community. However, it was decided that 4 hectares should be the smallest cell of information, using 1:63,360 scale basic topographic maps for graphical consideration.

The itemized information of the data bank may be stored by computer, by MTST (magnetic tape/selectric typewriter), or by whichever method best fits the character of the gathered data. The advantages and disadvantages in the case of the New Jersey data bank will be discussed later.

AVAILABLE WATER AND EXTREME SURFACE FLOW VALUES

The most important part of an environmentally oriented data bank is the water resources inventory and the computation of the available water with its average and extreme values, including the ground water capacity of the area.

The various sophisticated methods such as those of unit hydrographs, flood frequency, log Pearson Type III curves, etc., give excellent values for larger areas. It is generally accepted that the available data can be interpreted with a workable accuracy only for a time no longer than twice that of the period of observation. This means that for computation of 100-year extreme flow it is necessary to have at least 50-year observations, which may be available for larger rivers in many regions but almost non-existent for smaller streams. The need for data on peak and lowest flow occurs at random and in emergency conditions; therefore, there are no collected data nor is there time to collect data for longer periods. Since these methods are based on probability, the curves at their lowest and peak value are less reliable. Extending the curves and forecast extreme values for periods twice as long as the observation can give a ±20-30% error. Further extension of any forecast makes the computations highly unreliable as estimates in regional planning. On the other hand, regardless of the size of the watershed, these methods give excellent average flow values for streams for which there is a shorter observation period or on data, but where conditions are similar to those of known and recorded watersheds. Analogous difficulties can occur with surface flow formulas using too many parameters. In general, they are based on probability computations and so the errors and deviations accumulate.

Despite these shortcomings, it can be efficiently evaluated and utilized with the help of local geologic survey and meteorologic conditions data, establishing correlation and similarities between permeability of the geologic subsurface and extreme values of the meteorologic records on one side, and the extreme flows from smaller watersheds with an area of less than 250 km^2 on the other side. For watersheds over 250 km^2 in area, the geologic and meteorologic conditions have less effect on extreme flows except in regions such as certain areas of Australia, midwestern United States, Soviet Union, etc., where greater uniformity of these factors prevail.

The approach in New Jersey utilized over 90,000 well records and 360 selected stream gaging station statistics gathered in the period 1945-1978 for the wells and 1882-1978 for the streams. Furthermore, historical flood data and point rainfall intensity observations for the period 1825-1882 were also taken into consideration.

The developed formula of peak and lowest runoff including the ground water capacity is described in detail by the author in "Computation of Extreme Flow and Ground Water Capacity with Inadequate Hydrologic Data in New Jersey," Proceedings of University Seminar on Pollution and Water Resources, Vol. V: 1971-1972, Bulletin 72-D, Columbia University, 1975.*

Based on the above principles and the publication, the surface runoff extreme values were computed and the results, organized by hydrogeologic regions, were put in the data bank with a value for an area of 2.5 km^2 (one sq. mi.). As a by-product of this method, the ground water capacity of the various hydrogeologic areas was also established. The recommended lot size for domestic wells and septic tanks is a result of the concept.

TECHNIQUE AND ORGANIZATION OF THE DATA BANK

The information system was originally conceived for the purpose of developing a methodolgy capable of continued revision that would permit the quick assembly of data relative to land use planning. It started in 1973 as LORDS

*Available through the N. J. Bureau of Geology & Topography

(Land Oriented Reference Data System) and the data were organized into 88 km^2 units to enable regional planning in a particular area or point problem solutions in the assumption that it can be affected by the available natural resources from a distance up to five miles. Therefore, any information from this particular area (88 km^2) will be needed for efficient planning decision. In the meantime, the data were organized in a form that should make it available quickly (10 to 15 min.) to the interested parties, in typed or book form, together with necessary special maps and films at a nominal price. Figures 1-17 are examples of maps and printed materials.

The data can be grouped as follows:

A. <u>Basic Maps:</u>

(a) "Atlas Sheet" 1:63, 360 (one inch to one mile) - 1600 km^2 per unit; consisting of 17 maps for the entire state.

(b) "U.S.G.S. Quad" 1:24,000 - 140 km^2 per unit; 174 topographic maps for the entire state.

(c) Aerial photo 1:24,000 - 140 km^2 per unit; 171 maps, renewed every four years.

B. <u>Semitransparent Maps in Scale of "Atlas Sheet"</u>:

(a) Drainage basins with all legally accepted surface flows including flood prone areas -- drainage divides are also indicated. Streamflow information, point of diversion, and points of potential pollution may be indicated on these maps in the future. (17 maps)

(b) Geologic maps. (17 maps)

(c) Water Service Areas and Public Water Supply with the political boundaries of the municipalities. Also indicated are the major water supply lines and surface water intake points. (17 maps)

(d) Sewage Service Areas and Sanitary Landfills indicating the public and semipublic sewage systems, and also the areas served by each sewage company, their main trunk lines, sewage treatment plants, including capacity, and used or abandoned sanitary landfill areas. (17 maps)

(e) Demographic Maps at present show not only the municipality boundaries, the average population density for the municipality, but also the main highways and urbanized areas where the population density is over 400 persons per km^2. (17 maps)

(f) Land Use Maps are based on 1972 aerial photos (1:24,000) and 1973 EROS Image Space Photos (altitude 250 miles or 400 kms) evaluation, and their classification complies with U.S.G.S. Circular 671 (1972): B. Anderson, "A Land Use Classification System for Use with Remote-Sensor Data" and with U.S.G.S. Land Use Data Analysis (LUDA). (17 maps which will be supplemented with computerized tax maps at a later date)

C. Semitransparent Maps in Scale of 1:24,000:

(a) Geodetic Control Survey Maps indicating all triangulation, vertical and horizontal monument locations (13,600 monuments). (85 maps)

(b) Wetland Maps (15% of the state) in scale 1:24,000, 1:12,000 or 1:2,400 as will be discussed in a later chapter in more detail.

D. Additional Semitransparent Maps of the State (1:250,000):

(a) Electrical Transmission Lines showing also the generating stations and switchyards.

(b) Oil Pipelines including refineries and tank farms.

(c) High pressure Gas Pipelines with gate stations.

(d) Bathymetric Map of the Outer Continental Shelf showing geologic cross-section, shipping lanes, cables, dump areas, protraction diagrams for leases, etc.

(e) Fisheries Resources Map of the Outer Continental Shelf with spawning areas, migration routes, fin fish winter and summer grounds and shellfish occurrence.

(f) Drainage Basin Map with outline and area of basins, extreme and average yearly rainfalls, locations of flow and water quality gaging stations.

E. The Basic Data Bank:

1. Basic Data

(a) Description of "Atlas Sheets" in book form, LORDS (Land Oriented Resources Data System) Bulletin #74 of N. J. Bureau of Geology & Topography, 1974. General information about the Atlas Sheet area is given as a descriptive tabulation with a uniform format containing such information as extreme surface flow, ground water capacity, recommended lot size for domestic wells and septic tanks, geographic, climatic, geologic information, references, etc.

(b) "Block" descriptive material on tape of MTST (magnetic tape/selectric typewriter) including some of the specific items from the Atlas Sheet summary, but giving data which apply specifically to the 88 km^2 area of the block. Each block description is stored individually. (246 blocks)

(c) "Block Semitransparent Map (1:63,360, 246 maps in each series). The series will be expanded to between ten and twenty multiparameter maps as data becomes available and is stored on Microfiche film. The following series are available: (1) drainage basin with flood prone areas; (2) geologic map with well records -- about one well per two km^2. The technical description of the wells can be found in the "Block" description (see E/1/6); (3) water supply with intakes, main distribution lines area served by the various companies including community boundaries and names of the companies; (4) sewage and sanitary landfills with the area served including trunk lines, sewage treatment plants with their capacity, active and abandoned sanitary landfills, indicating also community boundaries; (5) demographic map indicating urbanized areas (over 400 persons per km^2), communities by density of population based on 1975 consensus including main roads; (6) land use map evaluated in accordance with U.S. Geological Survey classification.

(d) Geodetic Control Survey monuments' description (13,600 monuments pertaining to triangulation, horizontal and vertical information) - sketches and description of each monument separately including their computerized data and geodetic control index map (1:24,000, 85 maps).

2. Supplementary Information:

(e) Aerial photo coverage (1:24,000 from 1961 and 1972, together with map collections covering the entire state from 1855 to 1978 (in easy reproducible form on polyester film, photo, overlay map or map form). This is supplemented by U. S. Geological Survey 7 1/2 minute topographic quadrangles (from 1948-1973, 1:24,000, 172 maps).

(f) Computerized land use map (cadastre or tax maps) - temporarily not available due to revision of tax maps.

(g) Surface flow gaging stations with computerized data concerning quantity and quality of the available water. (Available at present only at U.S.G.S.)

The Land Oriented Reference Data System parameters can be located by a seven digit number on the "State Rectangular Coordinate System" where the first two digits indicate the "Atlas Sheet," the third and fourth digits identify the "Block" and the fifth to seventh digits narrowing down the area of information to 0.12 km^2. Introducing additional digits for identification would substantially increase the cost of computer without any benefits except in urbanized areas where possibly additional details are needed. On the other hand, the urbanized areas account for less than 5% of the whole territory of the state and therefore further extension of digitizing was omitted. The State Rectangular Coordinate System data are given in "UTM Grid" in meters including latitude and longitude in degrees, minutes and seconds and also in "N. J. State Plane Coordinate System" in feet. The conversion of data for these systems is computerized.

Finally, the described Data Bank is supplemented by the publications and map collection of the N. J. Bureau of Geology & Topography. The Bureau was established in 1825 and since 1854 a continuous systematic mapping of the state has taken place. This mapping is supplemented by aerial photos in four-year intervals since 1930.

A sample from the Basic Data Bank, Atlas Sheet 25 - Blocks 23 and 24 are attached.

BLOCK #25-23

A. Bernardsville, Chatham

B. Passaic-Upper Passaic, Raritan-Lower Raritan

C. 2.

Map No.	Location	Period of Record
10	Passaic River near Millington	1903-1906, 1921

3.

243	Passaic River at Millington	1964-

Water Quality Standards: (explained in Atlas Sheet description)
FW2 except where classified FW3

D. Brunswick Formation (Trb), Triassic Conglomerates (Trc), Basalt Flows (Trbs), hornblende granite and gneiss (gh), pyroxene gneiss (px)

E. 1. Physiographic Province: New England (Reading Prong)
Subdivision: N. J. Highlands
Major Topographic Features: Mendham Mountain
Elevations (ft. above sea level): ridges 350, valleys 250
Relief (ft.): 100

Physiographic Province: Piedmont
Subdivision: Triassic Lowlands
Major Topographic Features: Red Sandstone Plain, Watchung Ridges, Passaic Valley
Elevations (ft. above sea level): ridges 450, valleys 200
Relief (ft.): 150

2. a. Normal Year: 49"
Dry Year: 41"
Wet Year: 57"

b. January: 29°F
July: 73°F

c. 236 days. Last killing frost: 4/25; first killing frost: 10/15

F. Div. of Parks and Forestry:
McEvoy (Miscellaneous Area)
Somerset County:
Lord Stirling Park
Morris County:
Passaic River Park
Bernards Water Company:
Private Watershed

G. U.S. Fish and Wildlife Service:
Great Swamp National Wildlife Service

I. Water Well Records

Location	Owner	Year Drilled	Screen Setting or Depth of Casing	Total Depth	g/m Yield	Formation
25-13-126	Bernards Water Co.	1962	64	1450	412	Trb
25-23-138	Allen A. Swenson			160	100	"
25-23-334	Ebasco Services			100	-	Q
25-23-358	"			100	-	"
25-23-364	U.S. Bur. of Sport Fisheries	1968	130	300	94	"
25-23-426	Samuel Owens			235	80	Trb-Trbs
25-23-635	Copper Spgs. Beach & Tennis Club	1960	99	200	151	Trb
25-23-675	Stirling Water Supply Co.			128	115	"
25-23-675	"			225	115	Trb-Trbs
25-23-675	"			75	115	Q
25-23-676	Passaic Twp.			500	45	Trb
25-23-825	Clover Hill Swim Club	1974	50	300	100	"
25-23-961	Watchung Hills Reg. H.S.	1960	30	300	70	Trbs
25-23-986	Anthony DeFillipo			460	90	"

J. Geodetic Control Survey monuments described
Index Maps 24, 25; adjacent Index Maps 29,30

BLOCK #25-24,25

A. Chatham, Roselle

B. Arthur Kill-Rahway; Passaic-Upper Passaic; Raritan-Lower Raritan

C. 1. Watchung - Recording precipitation gauge

2.

Map No.	Location	Period of Record
11	Passaic River near Catham	1903-1911, 1937-
76	Robinson's Branch Rahway River nr. Goodmans	1921-1924

Water Quality Standards: (explained in Atlas Sheet description)
FW2 except where FW3

D. Brunswick Formation (Trb), Diabase (Trdb)

E. 1. Physiographic Province: Piedmont
Subdivision: Triassic Lowlands
Major Topographic Features: Wisconsin Terminal Moraine, Red Sandstone Plain, Watchung Ridges, Passaic Valley
Elevations (ft. above sea level): ridges 550, valleys 200
Relief (ft.): 350

2. a. Normal Year: 49"
Dry Year: 43"
Wet Year: 56"

b. January: 30°F
July: 73°F

c. 240 days. Last killing frost: 4/25; first killing frost: 10/15

3. a. About 70% urban or suburban. Areas of Harding, Chatham, Chatham Boro, Passaic, Warren, Watchung, North Plainfield, Berkeley Heights, New Providence, Summit, Scotch Plains, Mountainside, Springfield, Plainfield, Fanwood, Westfield, and Millburn are included.
b. Limited to small farms N.W. of the Great Swamp.
c. About 40% oak forest. Primarily on Watchung Ridges and in Great Swamp.
d. Concentrated along C.R.R.N.J., Erie-Lackawanna, and U.S. 22. Bell Telephone Murray Hill Center.

e. Traprock (Watchung, Springfield)
f. Interstate 78, U.S.22, N.J.28, N.J.24, C.R.R.N.J., ErieLackawana, Rahway Valley.

F. Morris County:
Loantaka Brook Reservation

Union County:
Passaic River Park
Watchung Reservation
Commonwealth Water Company:
Private Watershed

G. U.S. Fish and Wildlife Service:
Great Swamp National Wildlife Refuge

H. Cory House, Westfield
Baptist Parsonage, Scotch Plains

I. Water Well Records

Location	Owner	Year Drilled	Screen Setting or Depth of Casing	Total Depth	g/m Yield	Formation
25-24-226	Commonwealth Water Co.			238	0	Q-Trb
25-24-262	Butterworth			450	0	Trbs
25-24-285	Commonwealth Water Co.			137	0	Q
25-24-286	"			137	0	"
25-24-326	Ciba Pharamaceutical Prod. Inc.	1959	-	838	517	Trb,Trbs
25-24-326	"			600	50	Trb
25-24-326	"			185	50	Q
25-24-326	"			580	260	Trb
25-24-326	"			600	125	"
25-24-326	"			81	108	Q
25-24-326	"			-	105	"
25-24-326	"			503	135	Trb
25-24-331	Commonwealth Water Co.			145	0	Q
25-24-331	Columbia Cleaners			225	150	Trb
25-24-332	Commonwealth Water Co.			100	0	Q
25-24-334	Ciba Pharmaceutical Co.			623	271	Trb
25-24-334	"			687	150	"
25-24-334	"			125	184	Q
25-24-341	Commonwealth Water Co.			145	0	"
25-24-352	Ciba Pharamaceutical Prod. Inc.	1958	199	719	401	Trb,Trbs
25-24-352	Natl. Grocery Co.	1955	195	348	83	Trbs
25-24-347	Willard E. Closs			512	220	Trb
25-24-384	Clearwater Club Corp.			196	99	Trbs
25-24-389	U.S.G.S.	1967	105	124	100	Qtm
25-24-453	Berkeley Chemical Co.	1956	67	200	80	Trb

25-24-461	Gibbon Associates			185	44	"
25-24-463	American Pharama-ceutical, Reheis	1965	41	303	270	"
25-24-533	Azoplate Corp.	1962	46	310	128	"
25-24-537	Fablok, Inc.	1962	49	200	164	Trbs
25-24-544	Automatic Injec-tion Well	1969	76	300	125	Trb
25-24-544	Reheis Co.			160	260	"
25-24-657	Union Co. Park Commission			144	28	Trbs
25-24-665	"			365	20	"
25-24-674	"			229	75	Trb
25-24-674	Grassman			229	75	Trbs
25-24-687	Plainfield-Union Water Co.	1957	38	500	135	"
25-24-838	Fanwood Stone Co.	1959	26	325	100	"
25-24-864	Watchung Die Casting Co.	1962	50	305	92	"
25-24-876	Stavis Engineering	1959	40	318	125	"
25-24-885	Two Guys from Harrison	1958	62	350	440	"
25-24-885	"	1959	41	325	393	"
25-24-926	Plainfield-Union Water Co.			665	351	Trb
25-24-926	"			650	300	"
25-24-927	Scotch Plains Twp.	1965	99	450	150	"
25-24-929	Custom Molders			514	62	"
25-24-929	"			320	100	"
25-24-934	Plainfield-Union Water Co.			708	150	"
25-24-934	Custom Molders	1964	117	320	100	"
25-24-939	Elizabethtown Water Co.			416	-	"
25-24-961	"	1964	109	500	197	"
25-24-965	Plainfield-Union Water Co.	1960	79	400	295	"
25-25-131	Commonwealth Water Co.			195	-	Trbs
25-25-139	Dasil Realty/Arch Restaurant	1957	185	430	100	Trb
25-25-159	Houdaille Const. Co.	1962	25	100	100	"
25-25-178	Commonwealth Water Co.			-	700	"
25-25-178	"			394	110	"
25-25-191	Celanese Corp.			226	0	Q-Trbs
25-25-193	Houdaille Const. co.			341	-	Trbs
25-25-455	Plainfield-Union Water Co.			572	221	Trb
25-25-457	"	1960	43	300	457	"
25-25-461	"			554	504	"

25-25-464	Sterling Plastics Co.	1963	59	456	275	"
25-25-465	"	1966	60	590	214	"
25-25-465	Turbine Equipment Co.	1956	54	250	72	"
25-25-466	Echo Lake Holding Co.			400	180	"
25-25-468	Best Way Prods. Co.	1968	115	475	125	"
25-25-468	Hago Products	1955	93	250	66	"
25-25-482	Plainfield-Union Water Co.	1960	43	300	457	"
25-25-492	"			325	495	"
25-25-493	Echo Lake Country Club	1968	100	500	100	"
25-25-711	Adcon Realty Corp.	1962	44	600	292	"
25-25-712	Plainfield-Union Water Co.	1955	108	506	401	"
25-25-712	"	1955	92	511	521	"
25-25-743	S. Engle			265	135	"
25-25-752	Plainfield-Union Water Co.	1959	27	525	495	"
25-25-753	Elizabethtown Water Co.	1964	40	246	100	"
25-25-753	Rialto Theater/ Westfield Realty Co.			250	200	"
25-25-754	Plainfield-Union Water Co.			523	500	"
25-25-755	"			502	350	"
25-25-755	Westfield Y.M.C.A.	1937	-	210	130	"
25-25-755	Plainfield-Union Water Co.	1953	79	572	221	"
25-25-756	H. Sturke			226	80	"
25-25-761	"			108	150	"
25-25-775	Elizabethtown Water Co.	1965	80	500	300	"

J. Geodetic Control Survey monuments described Index Map 25; adjacent Index Map 30

TIDAL WETLANDS

Since over 15% of the state is in the tidal wetlands area, special attention was given to data collection of the region and a detailed account of this program is appropriate. Besides the uniform Land Oriented Reference Data System, a special survey for wetland was initiated in 1970.

The tidal wetland delineation is of utmost importance to the State of New Jersey because the state claims ownership of all land below the Mean High Water Line unless the state sells the land in question. This claim is based on laws from the XVII Century and on the New Jersey Wetlands Act of 1970. In simplified terms, the state's claim to tidal wetland parcels is based on the following tests, Yunghans (1977):

a) Do "virgin" wetlands have tidal access and are they now flowed by mean high tide;

b) Did "improved" (reclaimed) tidal wetlands once have tidal access and were they formerly flowed by mean high tide?

Based on the above principles, 28% of the whole state or 5440 km^2 area is claimed to be affected by tide.

It is interesting to mention that the Dutch settlers of New Jersey had already reclaimed the wetlands "polders" in the early Colonial times and there are still "Dyke companies" in many areas of New Jersey. In 1888 the report of the New Jersey State Geologist recorded only 780 km^2 of tidal marshland.

Wetlands Mapping Program:

The Wetlands Mapping Program implemented provisions of the New Jersey Wetlands Act of 1970, the purpose of which is to protect wetlands by regulating the use of private property. The act authorizes the Department of Environmental Protection to inventory and map certain tidal wetlands within the state and to adopt orders regulating activities which alter or pollute coastal wetlands. Wetlands are defined in the act as "any bank, marsh, swamp, meadow, flat or lowland subject to tidal action along any inlet, estuary, or tributary waterway including those areas now or formerly connected to tidal waters whose surface is at or below an elevation of one foot above local extreme high water, and which is capable of growing some but not all of the following species (Brown, 1977);

In Saline Wetlands:

A - Spartina alterniflora (high vigor) (Salt marsh cordgrass)
B - Spartina alterniflora (low vigor) (Salt march cordgrass)
C - Spartina patens (Salt meadow grass)
D - Distichlis spicata (Spike grass)
E - Iva frutescens (Hightide bush)
F - Juncus geradi (Black grass)
H - Baccharis halmifolia (Sea Myrtle)
J - Predominantly bare ground

In Fresh/Brackish Wetlands:

1 - Typha spp. (Cattail)
2 - Zizania aquatica (Wild rice)
3 - Nuphar advena (Yellow water lily)
4 - Peltandra virginica (Arrow arum)
5 - Phragmites communis (Common reed)
6 - Leersia oryzoides (Cut grass)
7 - Pontedaria cordata (Pickerel weed)
8 - Polygonum punctatum (Water smartweed)
9 - Hibiscus palustris (Marsh mallow)
10 - Bare ground
11 - Echinochloa Walteri (Water millet)
12 - Spartine cynosuroides (Salt reed grass)
13 - Scripus americanus (American three square)
14 - Panicum virgatum (Switch grass)
15 - Scripus Olneyi (Olney's bulrush)
16 - Bidens laevis (Bur marigold)
17 - Carex spp. (Sedge)
18 - Acorus Calamus (Sweetflag)
19 - Impatiens biflora (Jewelweed, Touch-me-not)
20 - Polygonum arifolium (Tearthumb)
21 - Eleocharis spp. (Spike-rush)
22 - Juncus spp. (Rugh)
23 - Rosa spp. (Rose)

Description of the Methods:

A feasibility study was undertaken (under contract) to determine existing wetlands mapping methods, availability of data, and funding. The major findings were that wetlands should be defined only in terms of the vegetation species without incorporating a specific elevation criterion (if these species are present, the elevation test is automatically satisfied). Second, that false-color infrared photography should be used as the primary method to define plant species. Consequently, a combination of aerial photography and interpretation along with field verification was selected for delineation of wetlands.

A contract for wetlands delineation was awarded Earth Satellite Corporation.

Mapping of saline wetlands were obtained by aerial photos on Kodak Aerochrom Infrared 2443 film at an altitude of 1800 m fitted to existing triangulation of the New Jersey Geodetic Control Survey. The tidal wetland delineation is by mapping the plant species of the area demanding saline water. The survey is achieved by 7 species having high frequency in saline water. An additional 22 species were used which are typical for fresh-brackish wetlands. Each delineated area was defined as having an aerial extent of 2 or more hectares. Delineated categories representing associations were designated by the species present, but were limited to species which covered 25% or more of the unit delineated. The interpretations were spot checked by helicopter low-altitude flight. 1430 base maps at a scale of 1:12,000 were prepared for the whole tidal wetland area. These maps were also enlarged to 1:2,400 for easier evaluation.

Besides the vegetation, topographic characteristics and soil conditions were also applied as indicators of the tidal area. Finally, 240 tidal gaging stations supplemented the remote sensing technique of the aerial photo evaluation and topographic maps based on geodetic surveys from the Nineteenth Century were used too.

BRIEF ANALYSIS OF THE USERS

The request profiles of the users of the data bank are expected to result from user query categories as follows:

(1) Point information: information sought by a citizen or corporation such as prospective owner or builder who is interested in a point or limited area, where he needs all information which can influence his future construction or planned use of hs property

(2) Area information: information sought by a planner from the local, county, state or federal level who needs all information which can affect the planning decisions

(3) Vertical, group information: specified governmental or research agencies or corporations interested in special group information only, such as Bureau of Water Pollution Control

(4) Horizontal, point or areal information, prevent or avoid: looking for information concerning a point or an area, possibly only of a certain type, due to some legal or financial problem

Any one of these user categories may involve request matching or cross-correlation of information.

STORING DATA BY TAPE, FILM AND COMPUTER, INCLUDING ITS EVALUATION

Studies were conducted as to methods of storage and retrieval at lowest cost and highest efficiency. The gathered data were classified as follows:

(1) Areal or map-type information

(2) Descriptive-type data including references

(3) Point-type information or data pertaining to smaller standard size area, especially in land use, streamflow records, water quality gaging stations, etc.

The available methods could be summarized into:

(1) Computerized data systems

(2) Map-type information service based on maps and microfilms

(3) Descriptive MTST methods

(4) General information with little change in the future - in book form

(5) Supplementary information: Publications and map collection of the N. J. Bureau of Geology & Topography

It was determined that all or most of the information in the program would have been compiled in a descriptive or map-type form before the data could be put into a computer program. In seeking information on the data required and method of storage and recovery, discussions were held with experts in computer science dealing with various computer programs including data bank. As a result of these discussions with Columbia University, City University of New York, Stevens Institute of Technology and U.S. Geological Survey, and from preliminary estimates of what would be required for New Jersey, it was found that once maps were prepared for use with a microfiche reader/printer, recovery would be quicker (about 30 seconds) than by using computer plotting devices. Furthermore, the survey revealed that regions of less than 50,000 km^2 in size could not use efficiently a computerized system unless they are part of and tied into a larger system. On the other hand, any other method such as microfilms, tape recording, etc. cannot compete with a computerized one if they embrace larger areas or have a wealth of itemized point-type information.

Therefore, it was decided to have a data bank with a combined method using:

(1) Microfiche films and printer/reader for map-type information

(2) Magnetic tape/selectric typewriter's tapes for descriptive and reference material

(3) Computerized system (Fortran or similar) for land use, streamflow record, water quality control, etc.

(4) General information in book form; it contains descriptive material which will have little change in the future

(5) Map collection and publications of the N. J. Bureau of Geology & Topography

This combined method has the advantage of considerably cutting the cost by 94% in establishing the data bank (from an estimated $1,000,000 in 1972 to a real $60,000 in 1973/74) and the efficiency of information service for such size of area as New Jersey is better than any other non-combined system including the computerized one since it needs the least time for recovery. The disadvantage of the method is its apparent complexity. But, even with such diversity in training the necessary personnel and in purchasing the needed equipment, there could be no comparison in price including budget for continuous service and maintenance of equipment because of the still high cost of the computer at present. A further disadvantage of the combined system is a capacity limitation. Therefore, the whole data bank must be prepared in such a form that it can be converted easily into a fully computerized system. The itemized information should fit without any difficulties for computer feeding, storage and recovery in the future.

ASSESSMENT OF "LORDS"

The system proved to be extremely valuable. In preliminary investigations, planners, developers, builders, administrative officials and interested corporations or individuals gathering data are increasingly using the Data Bank. Generally, they need the collected data for an area of 80 km^2 because environmental impact statements demonstrating the feasibility and usefulness of a project without disturbing the environmental balance will not have a bigger area of interest.

The data put on tapes and Mircofiche films were easy to retrieve. This secured efficient handling of the gathered information. From the very beginning the system was prepared for computerization. To locate every bit of information, a seven-digit identification number was used which corresponds to a 74 hectares area. However, computer use for the Data Bank was limited due to financial reasons.

A serious attempt was made to computerize the tax and land use maps. To eliminate the inaccurancy in the tax maps, it seemed essential that these maps should be based exclusively on the geodetic survey. To update the geodetic control network for this purpose, an increase in density of monumentation by 300% seemed to be appropriate. Such a program was already started in 1975 and the tax maps will be included in the system after being refined by the geodetic survey. The Geodetic Control Survey started to use a computer technique in its calculations to speed up the operation. The land use information was secured by remote sensing technique and it should be revised in four-year intervals by aerial photos.

The surface water quantity and quality data of the state were computerized separately and they will be integrated into the Data Bank.

Revision of the available material was scheduled yearly. Because of personnel and financial limitations, the general revision is now planned in four-year intervals. Finally, it is appropriate to mention the extreme difficulties in data gathering. Various utilities or information holders - such as water supply, sewage authorities, electrical, gas and oil companies - are extremely reluctant to share their data with anybody. In many instances, this information is the only one which can be secured in a reasonably short period of time but still needs some additional updating due to inaccuracy.

In conclusion, it is evident that the Data Bank has not only been well established within the past three years but also substantially expanded. The users are charged nominal fees for the information to cover the expenses of the system. It needs further expansion, especially in the following areas: railroads, highways, underground cables, forests, wildlife, enlarged geodetic network, and taxation. The data already computerized should be centralized and tied into LORDS by standardizing the various methods of recording. On the other hand, Microfiche films and tapes will still be the bulk of the system for a longer period. The computerization of the whole Data Bank, however, is essential if we wish the system to become a regional information center for New Jersey in the National Information Network of the U. S.

REFERENCES

1. Halasi-Kun, G.J. (1971), "Aspects hydrologiques de la pollution et des resources en eau, dans les domaines urbains et industriels," Actes du Congress: Sciences et Techniques An 2000. Paris: Societee des Ingenieurs Civils de France.

2. Halasi-Kun, G.J. (1972), "Data Collecting on Water Resources and Computations of Maximum Flood for Smaller Watershed," International Symposium on Water Resources Planning, Vol. I (Mexico: Secretaria de Recursos Hidraulicos).

3. Halasi-Kun, G.J. (1973), "Improvement of Runoff Records in Smaller Watersheds Based on Permeability of the Geological Subsurface," Symposium on the Design of Water Resources Projects with Inadequate Data, Vol. I (Madrid: UNESCO-WMO-IAHS).

4. Halasi-Kun, G.J. (1974), "Ground Water Computations in New Jersey, U.S.A." Nordic Hydrology 5.

5. Halasi-Kun, G.J. (1975), "Computation of Extreme Flow and Ground Water Capacity with Inadequate Hydrologic Data in New Jersey," Proceedings of Columbia University Seminars on Pollution and Water Resources, Vol. V (Columbia University - State of New Jersey).

6. Halasi-Kun, G.J. (1975), "Water Resources Data Bank in New Jersey and Computations of Extreme Flows" in G.C. Vansteenkiste, Modeling and Simulation of Water Resources Systems (North Holland Publishing Company).

7. Vladimirov, A.M., and Chebotarev, A.I. (1973), "Computation of Probabilistic Values of Low Flow for Ungauged Rivers," Symposium on the Design of Water Resources Projects with Inadequate Data, Vol. II (Madrid: UNESCO-WMO-IAHS).

8. Widmer, K. (1964), The Geology and Geography of New Jersey (Princeton: Van Nostrand).

9. Enviro Control, Inc. (1972), The Development of a Procedure for Acquiring and Disseminating Information on Water Use, Vol. I-II (Washington, D.C.).

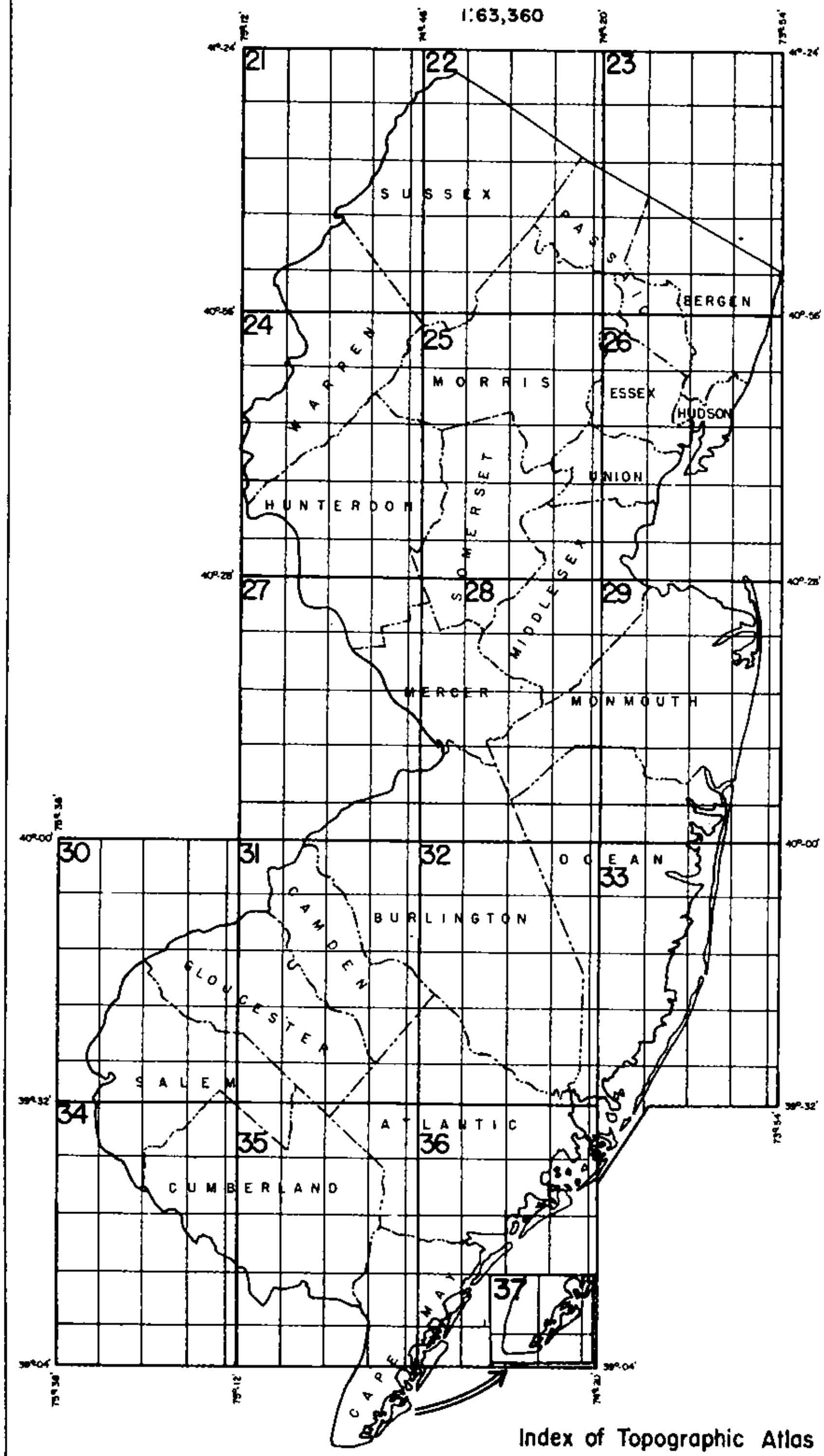
10. Widmer, K. and Halasi-Kun, G.J. (1974), Land Oriented Reference Data System, Bulletin 74, New Jersey Geological Survey.

11. Brown, W.W. (1977): "Wetlands Mapping in New Jersey and New York" in Proceedings of the American Society of Photogrammetry (Washington, D.C.).

12. Yunghans, R.S. (1977); "New Jersey's Operational Meadowlands (Tidelands) Mapping Program" in Hackensack Meadowlands-Today and Tomorrow (Fairleigh Dickinson University, Rutherford, N.J.).

13. Anderson, J.R., Hardy, E.E., Roach, J.T., and Witmer, R.E. (1976): A Land Use and Land Cover Classification System for Use wth Remote Sensor Data (Geol. Survey Professional Paper 964, Washington, D.C.).

TOPOGRAPHIC ATLAS OF NEW JERSEY
Scale: 1" = 1mi.
1:63,360



Index of Topographic Atlas Sheets

Fig. 1

Prepared By
The Bureau Of Geology & Topography

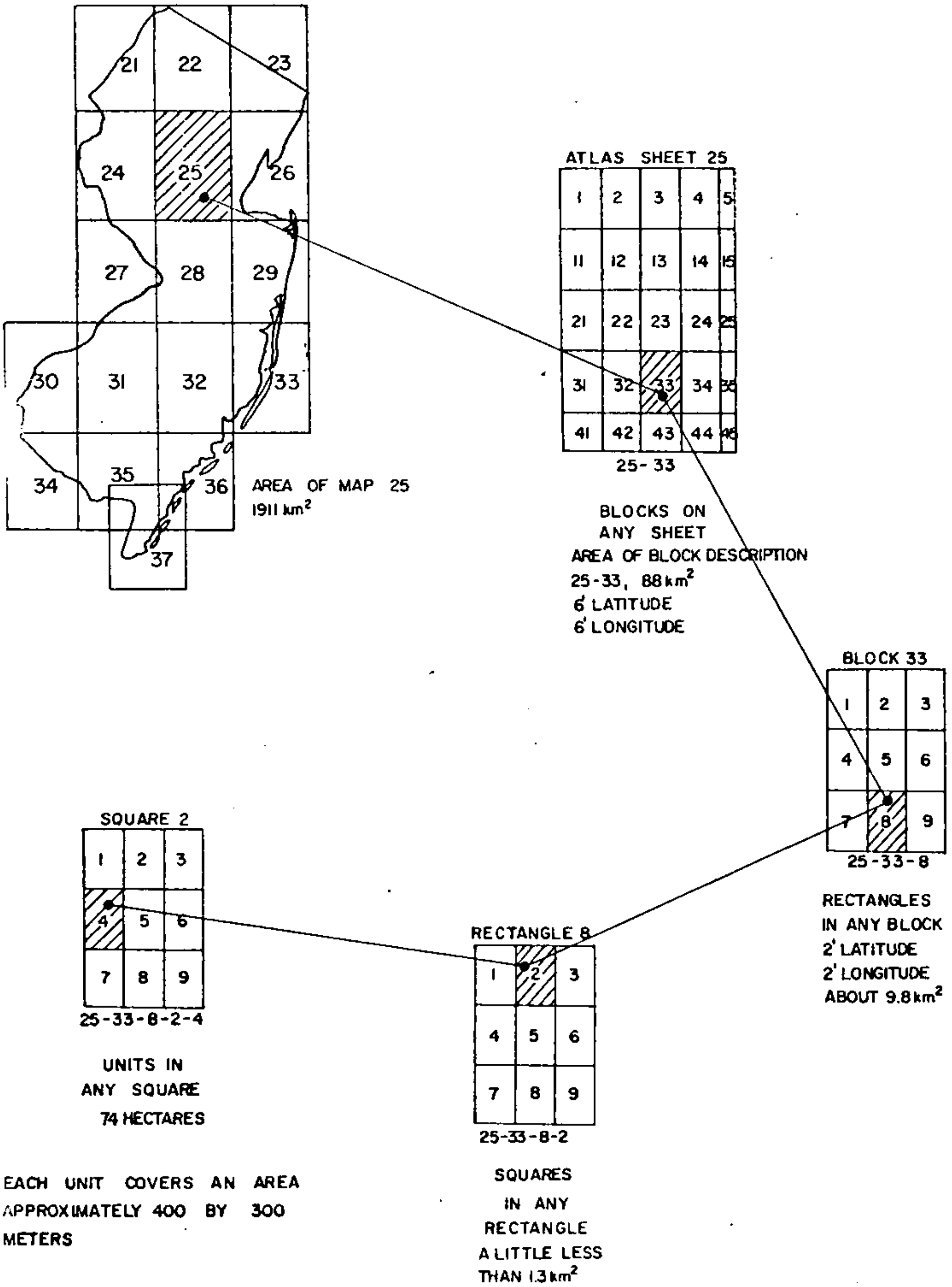
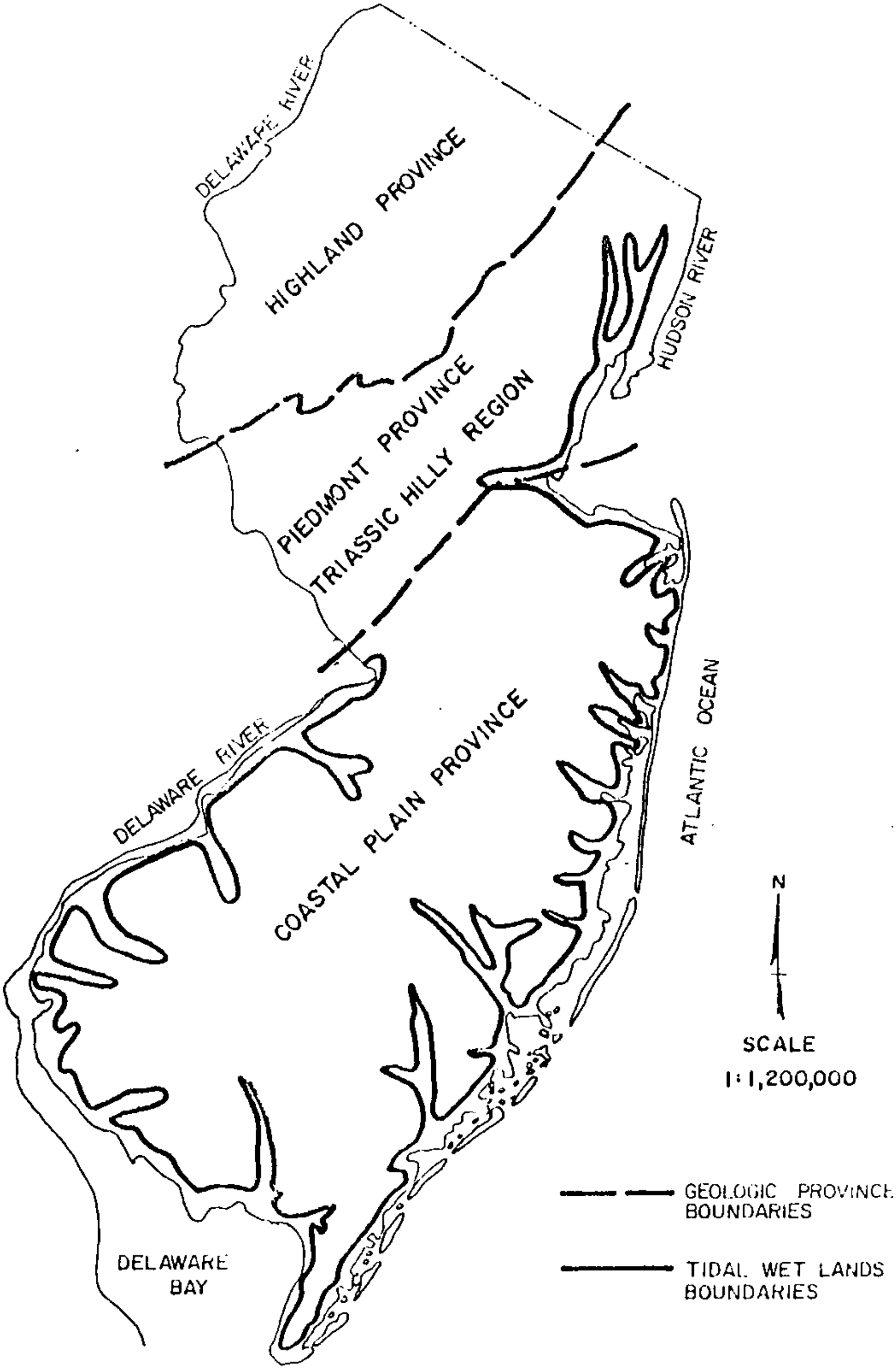


DIAGRAM SHOWING USE OF NEW JERSEY RECTANGULAR COORDINATE SYSTEM TO LOCATE A FACILITY AT 25-33-8-2-4

Fig. 2 SCHEMATIC DIAGRAM LOCATING INFORMATION



PHYSIOGRAPHIC PROVINCES OF NEW JERSEY WITH TIDAL WETLANDS

Fig. 3

SIMPLIFIED DIAGRAM OF PEAK RUNOFF EXPECTED ONCE IN 100 YEARS IN NEW JERSEY, U.S.A.

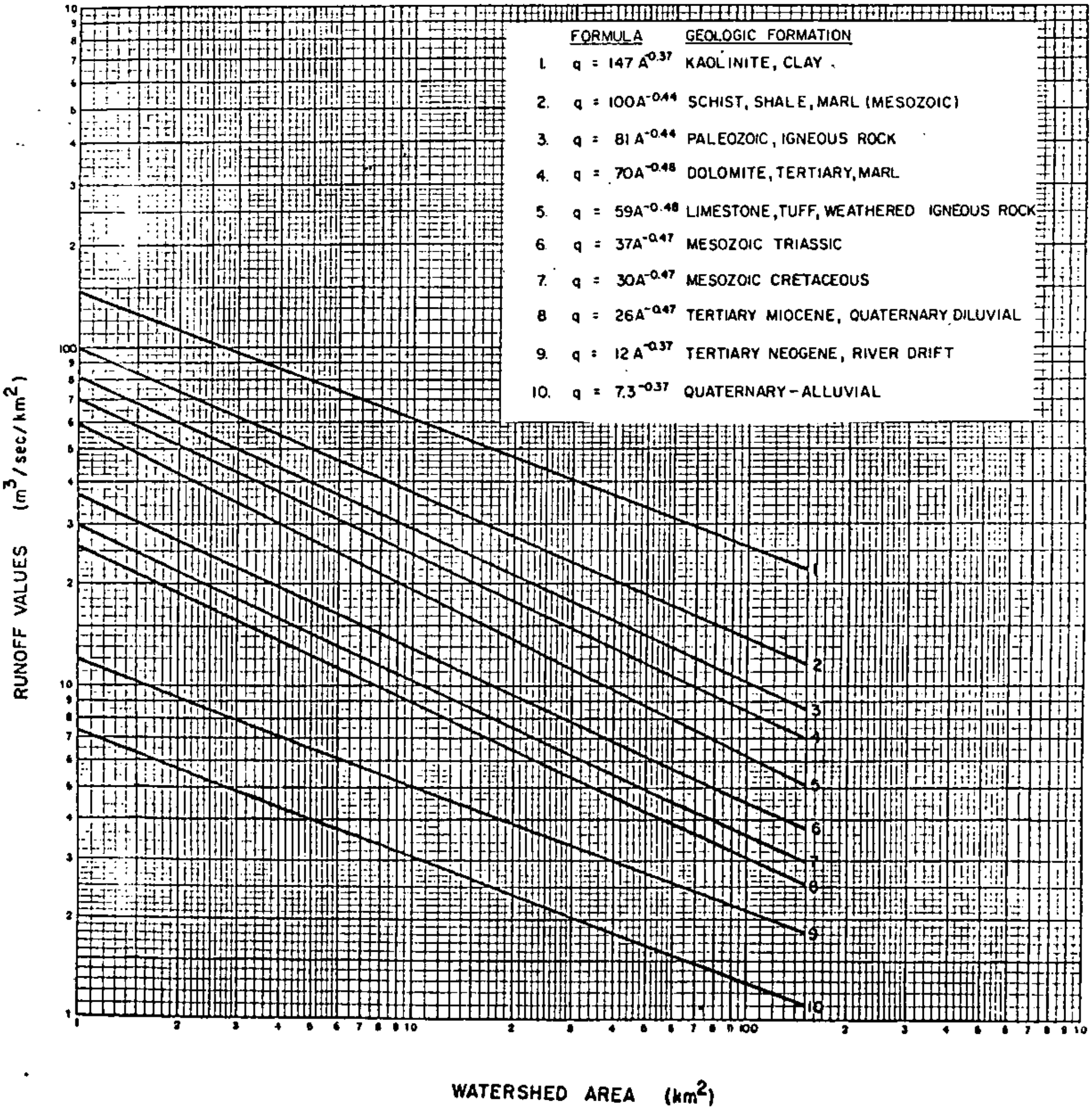
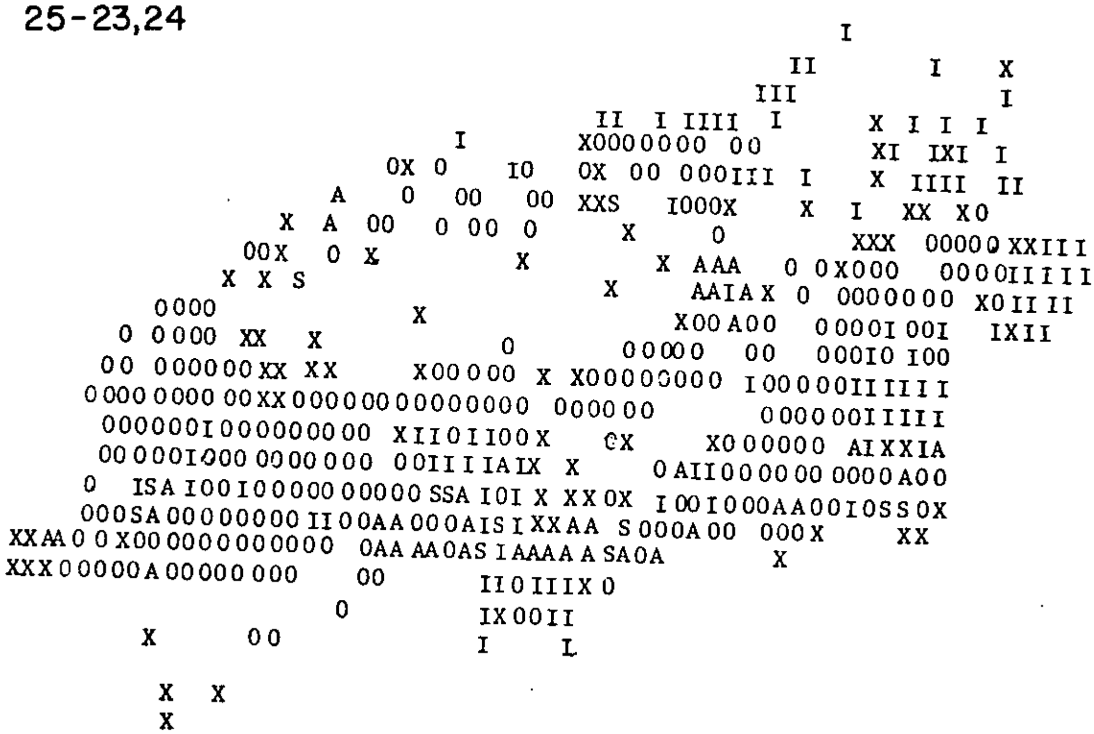
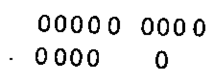


Fig. 4

COMPUTERIZED LAND USE

25-23,24





Quickmap Display of Predominant
Land Use in Passaic Township, 1972

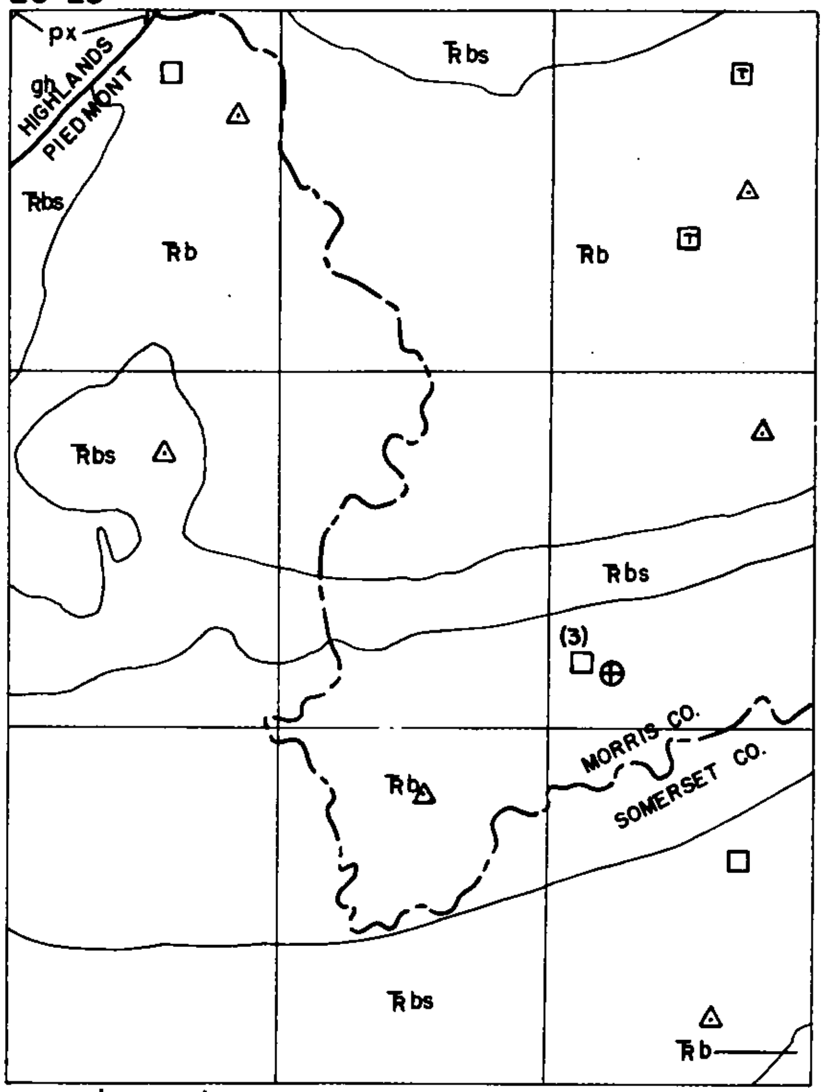
Key

01	Vacant	= X
02	Residential	= 0
04A	Commercial	= A
04B	Industrial	= S
15C	Public (non-school)	= I

Fig. 5 COMPUTERIZED LAND USE BASED ON TAX MAP

GEOLOGIC MAP

25-23



74° 34' 40° 38'

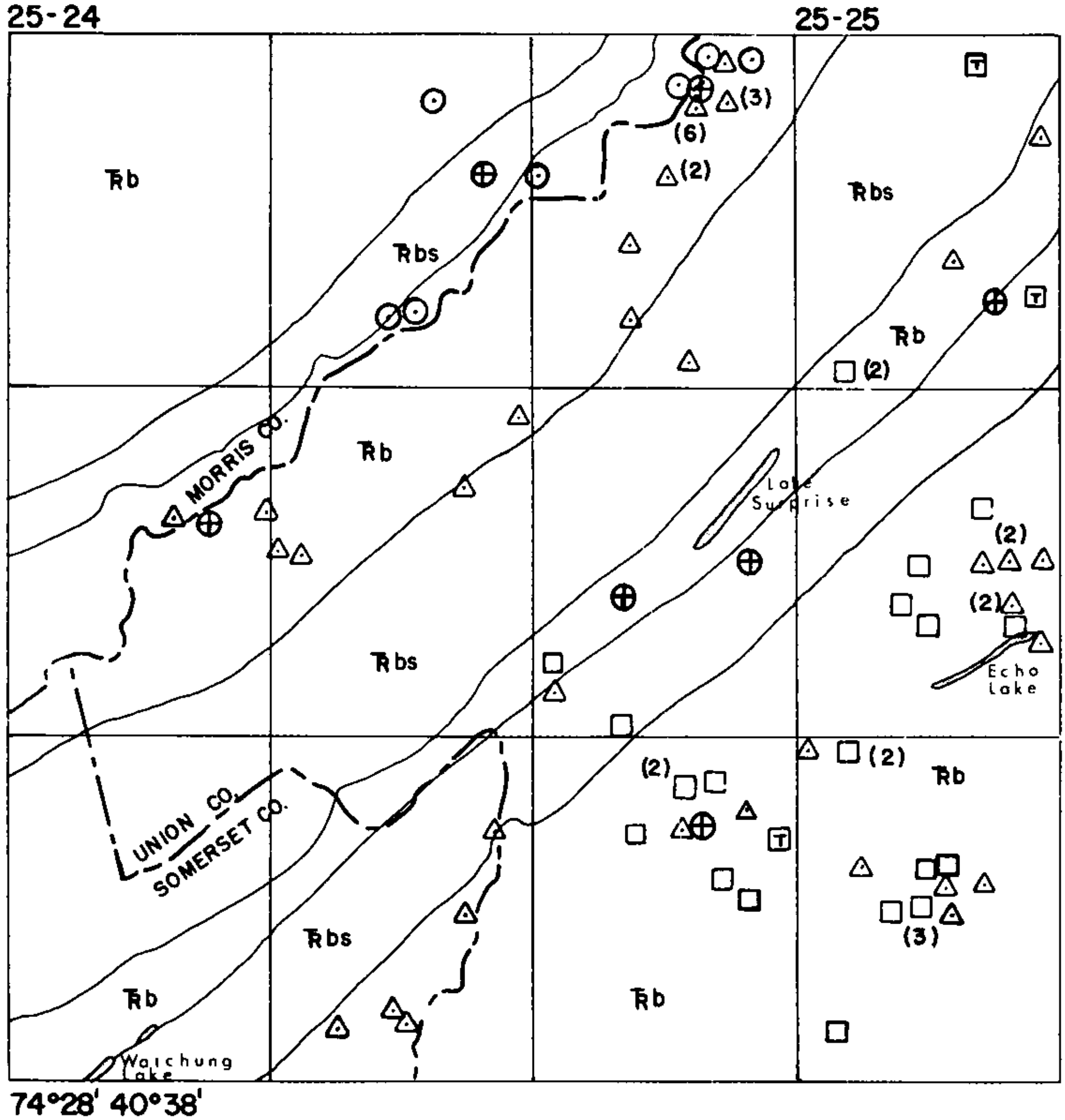
X = 2027755.81

Y = 655672.31

NJGS 11-76

Fig. 6

GEOLOGIC MAP



X = 2055511.62

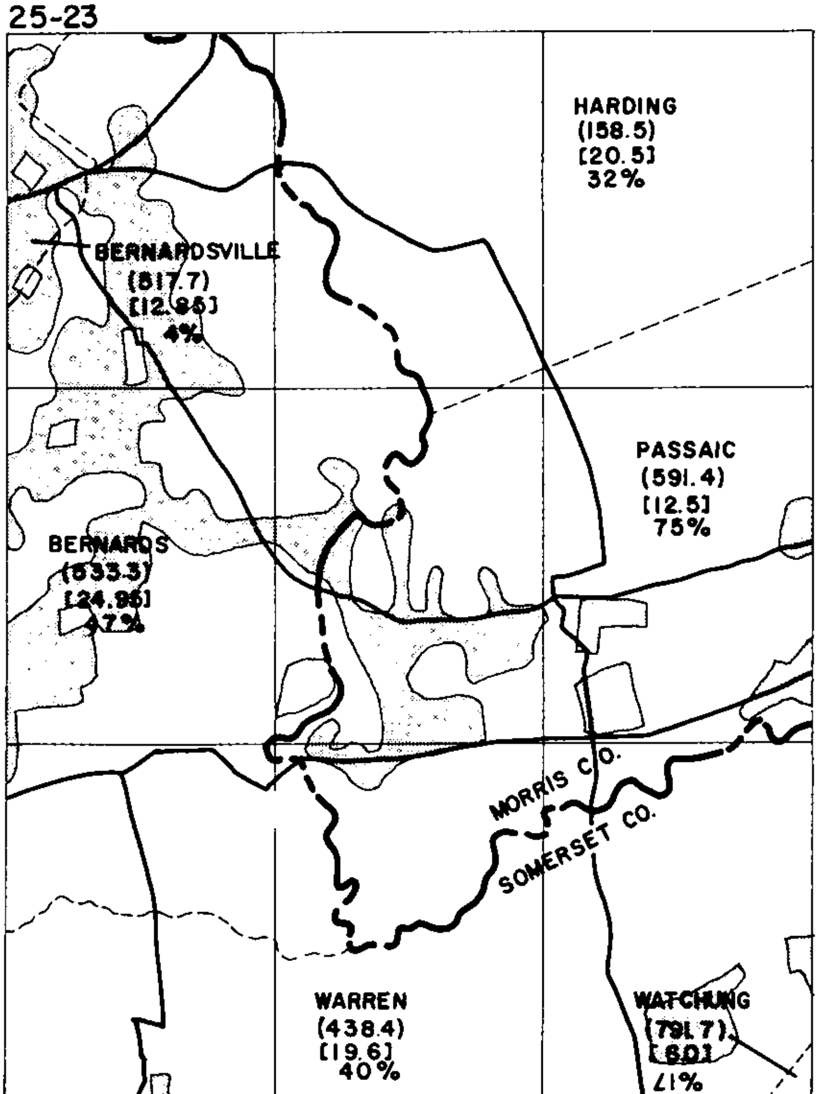
Y = 655719.63

NJGS 12-74

Fig. 7

POPULATION MAP

25-23



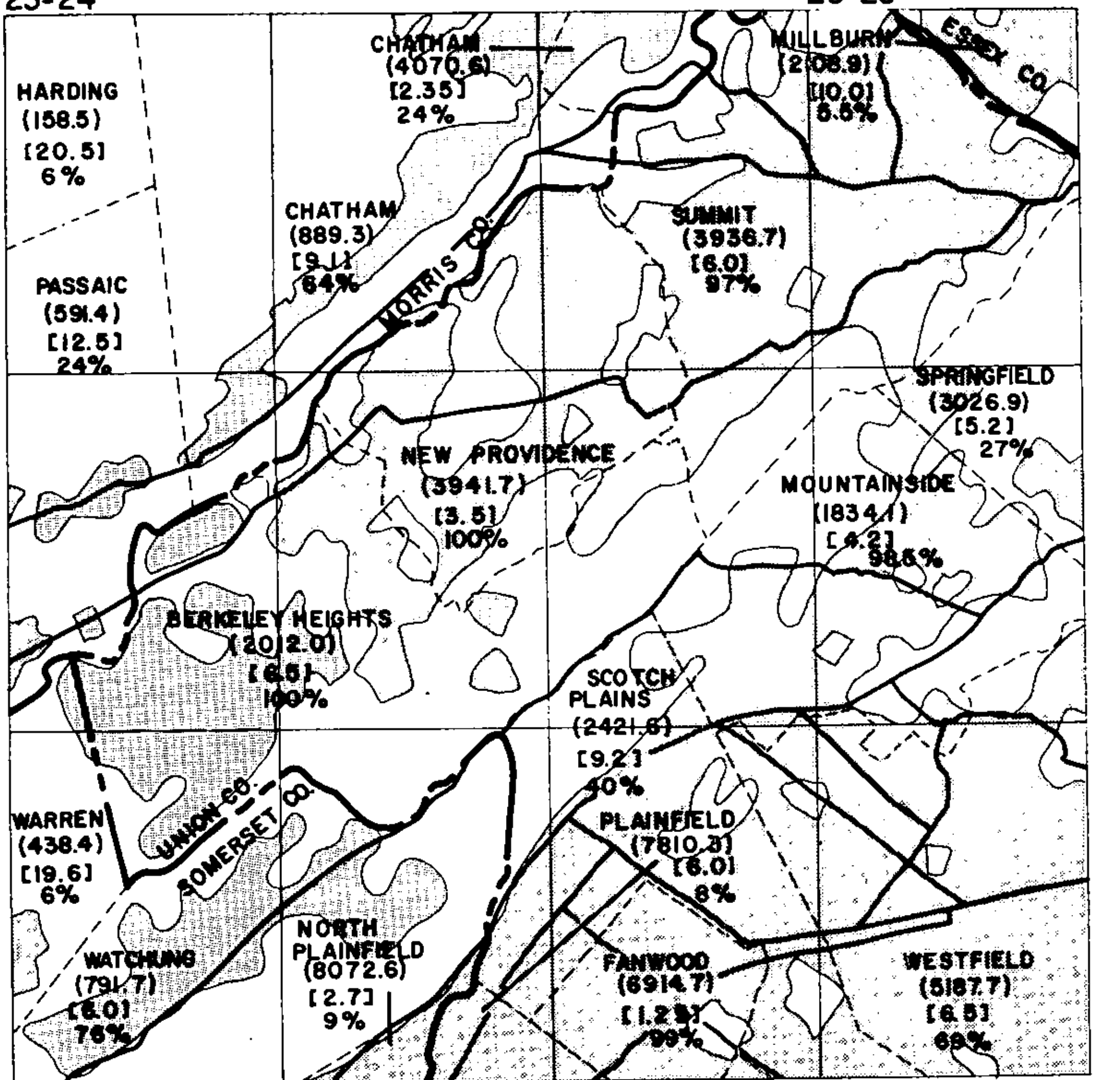
74° 34' 40°38'
X=2027755.81
Y=655672.31
NJGS 2-75

SHADED AREAS - URBANIZED

Fig. 8

POPULATION MAP

25-24 25-25



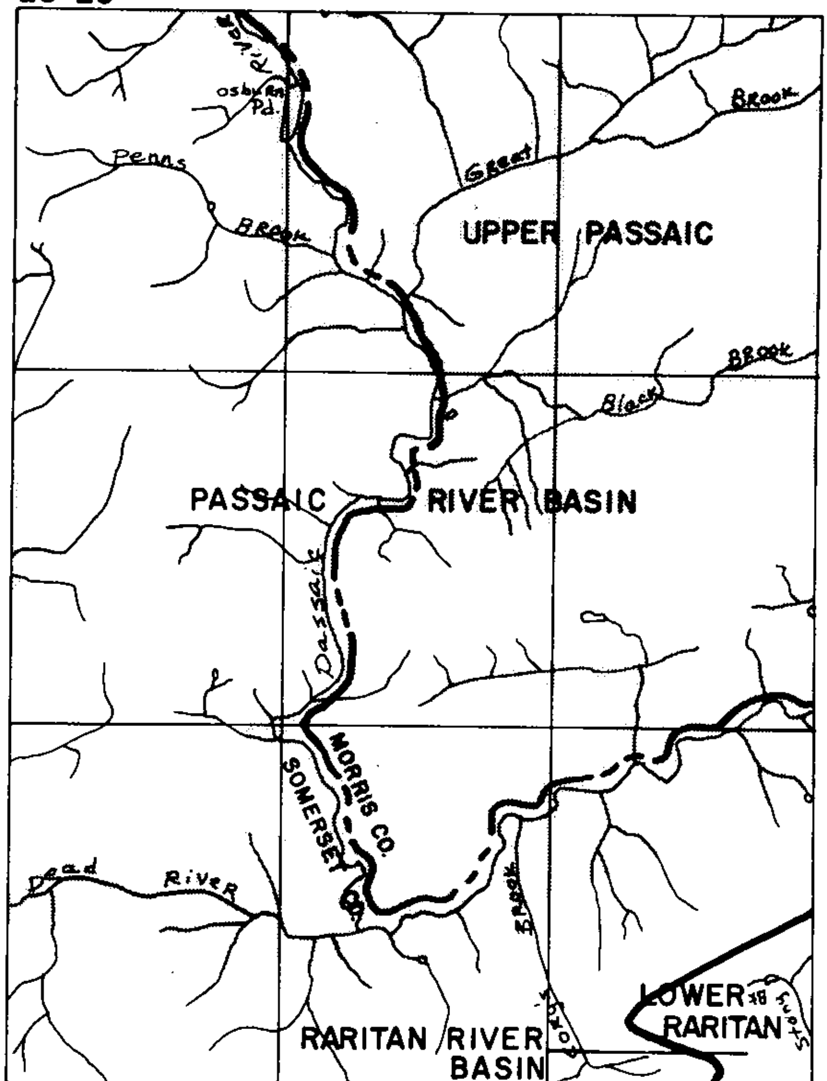
SHADED AREAS - URBANIZED

74°28' 40°38
X=2055511.62
Y=655719.63
NJGS 2-75

Fig. 9

DRAINAGE BASIN MAP

25-23



74°34' 40°38'

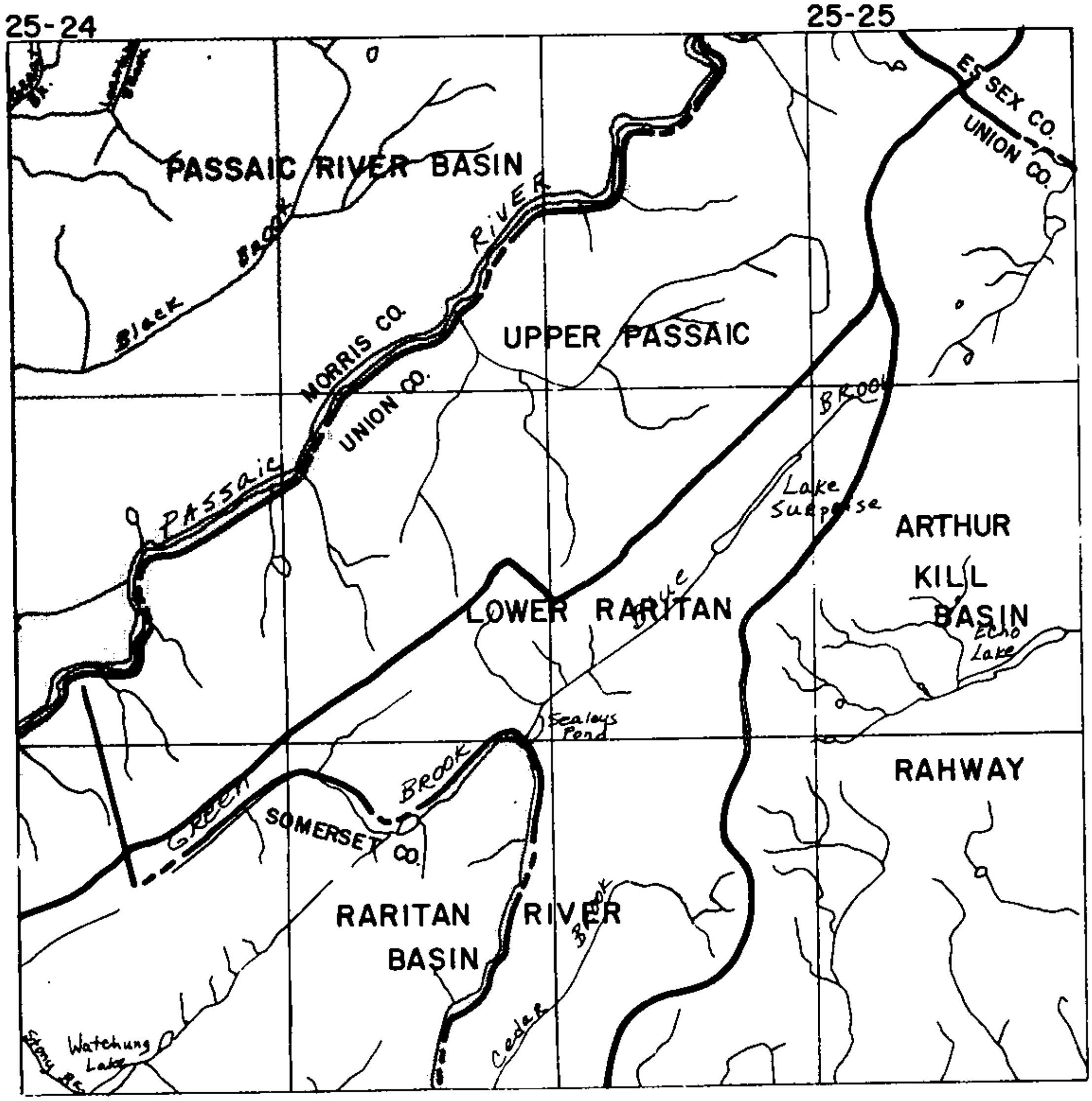
X = 2027755.81

Y = 655672.31

NJGS 11-73

Fig. 10

DRAINAGE BASIN MAP



74°28' 40°38'

X = 2055511.62

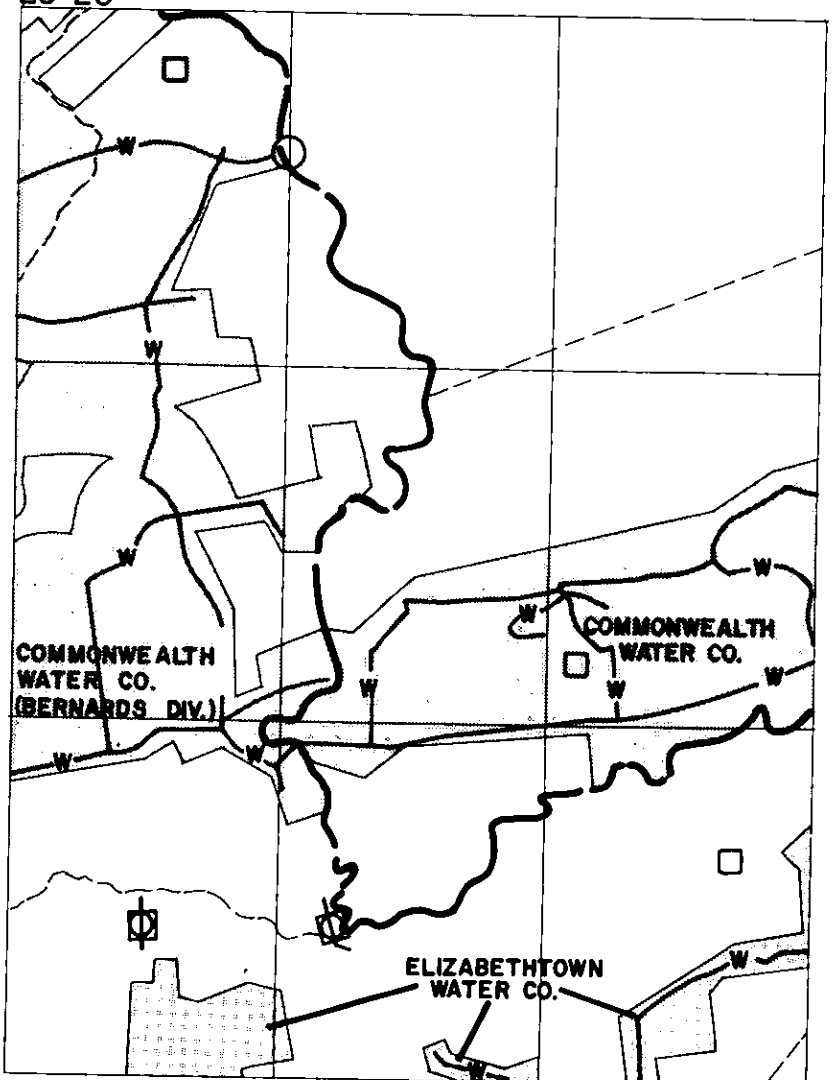
Y = 655719.63

NJGS 11-73

Fig. 11

WATER SUPPLY MAP

25-23



74°34' 40°38'

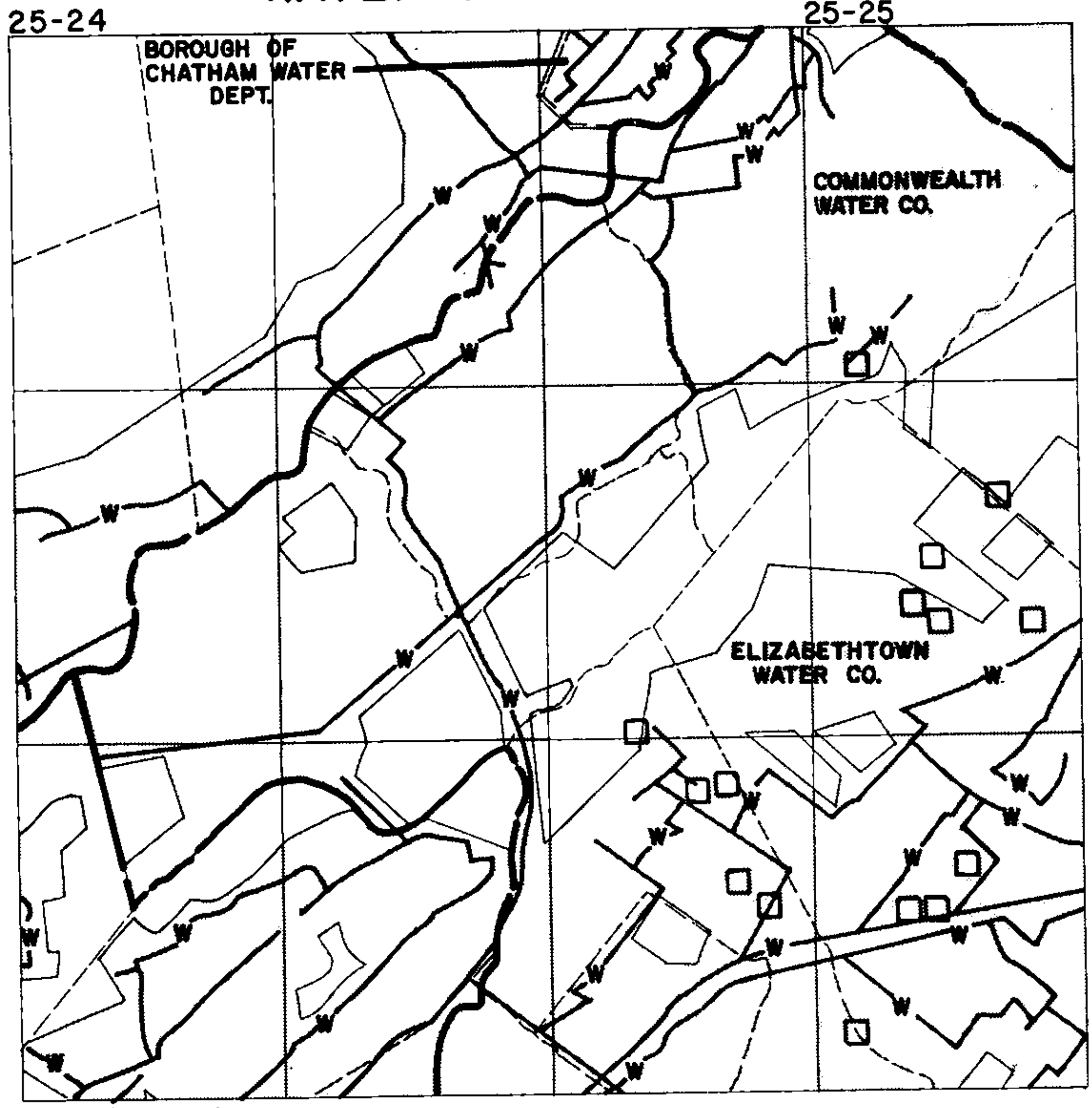
X = 2027755.81

Y = 655672.31

NJGS 11-76

Fig. 12

WATER SUPPLY MAP

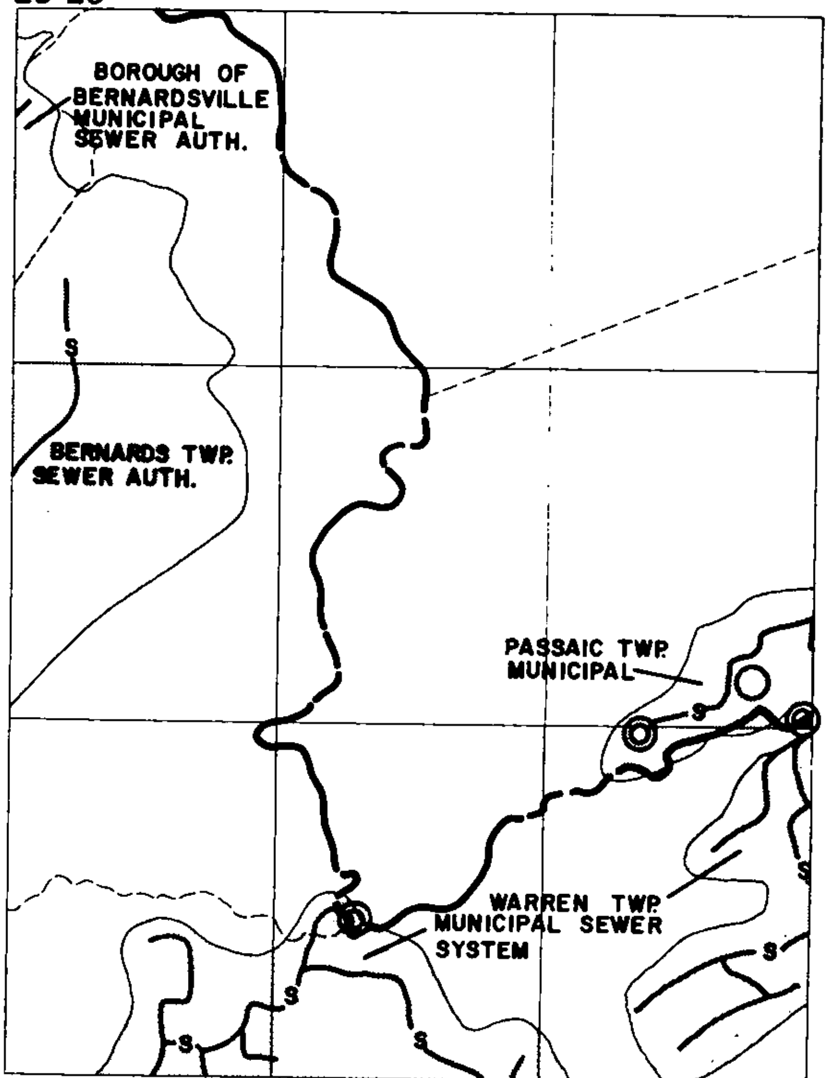


74°28' 40°38'
X = 2055511.62
Y = 655719.63
NJGS 11-76

Fig. 13

SEWAGE, LANDFILL MAP

25-23



74° 34' 40°38'

X = 2027755.81

Y = 655672.31

NJGS 01-76

Fig. 14

SEWAGE, LANDFILL MAP

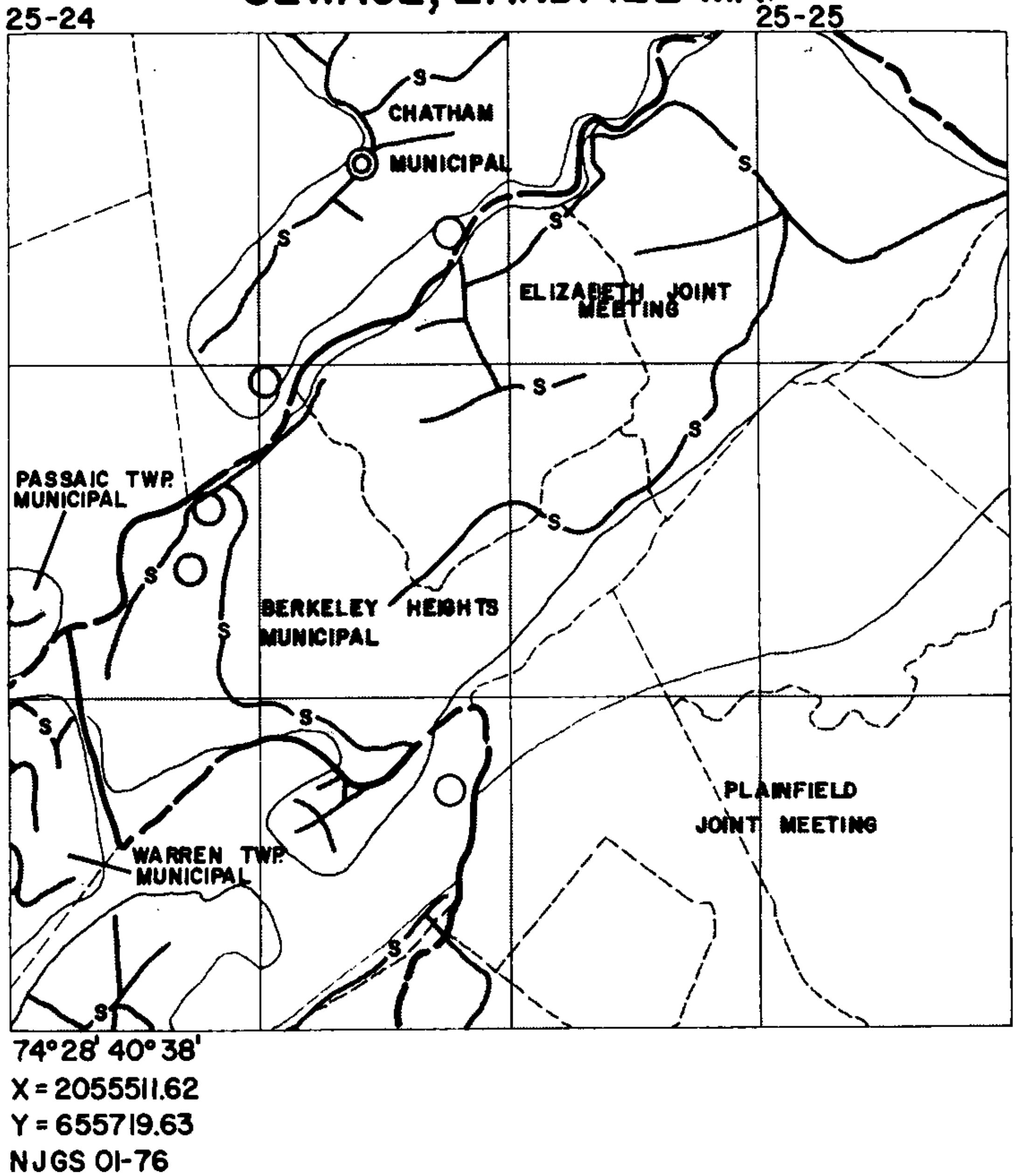
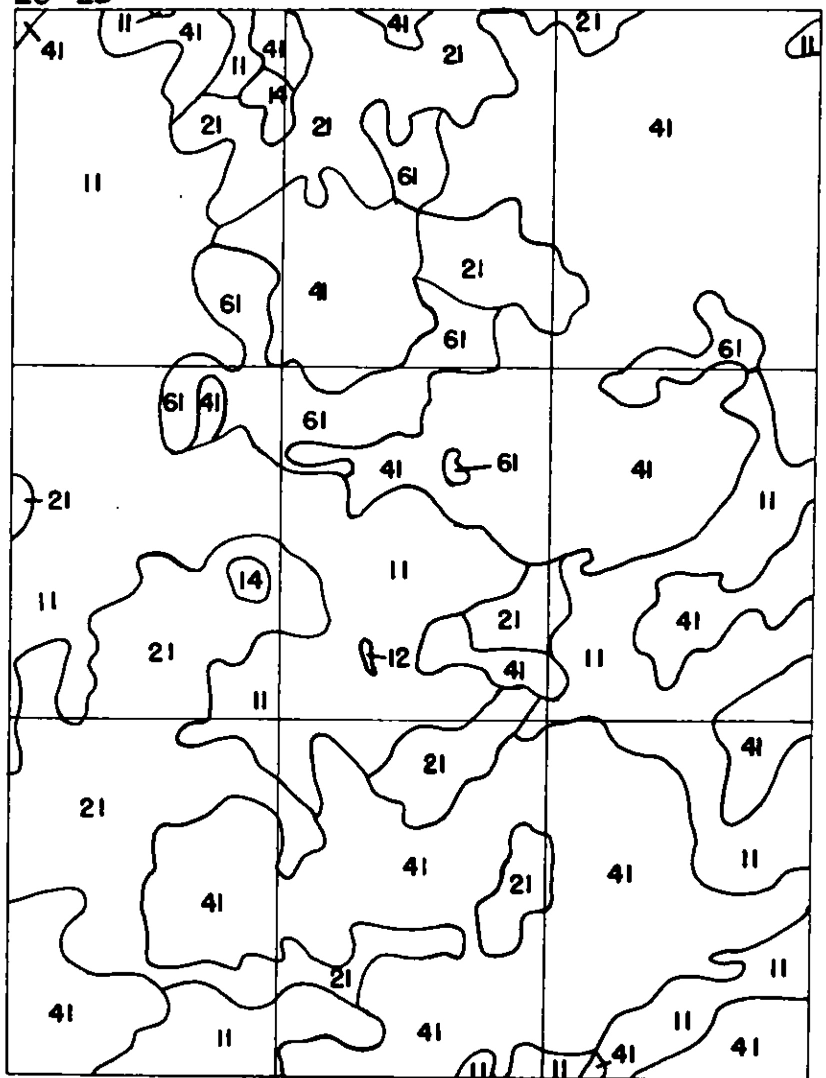


Fig. 15

LAND USE MAP

25-23



74°40' 40°38'

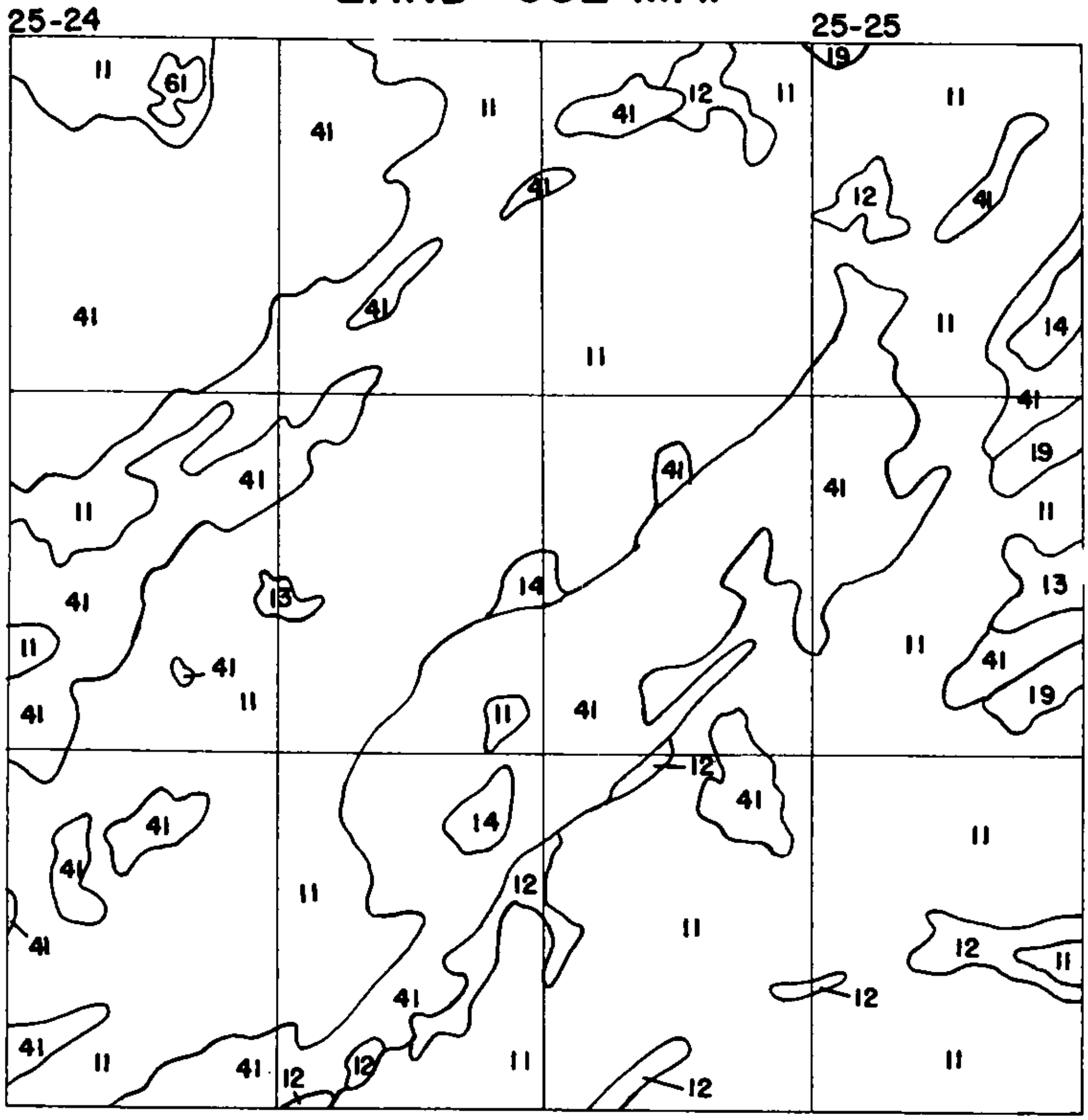
X = 2000000

Y = 655656.54

NJGS 12-75

Fig. 16

LAND USE MAP



74°28' 40°38'
X= 2055511.62
Y = 655719.63
NJGS 12-75

Fig. 17

SEGREGATION AND DEPOSITION OF PARTICLE SIZE-CLASSES BY HYDRODYNAMIC FORCES

by

DAVID PAUL HARPER, M.S. in Geology

Columbia University Seminar on Pollution and Water Resources,
Rutgers - The State University
New Brunswick, New Jersey, 08901*

*Present Address: New Jersey Bureau of Geology and Topography, Trenton, New Jersey, 08625

Abstract:

Factor analysis is a valuable but underutilized technique for elucidating the effects of environmental variables on sediment deposition.

In the present study R-mode factor analysis allowed the identification of eight statistically independent grain-size classes which are combined in varying proportions in estuarine sands from the Shrewsbury Entrance Area of Sandy Hook Bay, New Jersey. A limited number of discrete sediment types is present and reflects the existence of four hydrodynamically distinct states of flow. The range of grain-size compositions possible within each sediment type is the result of sizes and abundances of particles which can be deposited from traction, saltation, and suspension under the hydrodynamic conditions at a particular state of flow.

Introduction:

The processes governing grain-size compositions of water-laid sands have been studied continuously since the early years of the present century (Udden, 1914; Gilbert, 1914). Despite a voluminous literature, these processes remain only partially understood. Among the few points on which general agreement appears to have been reached are that waterlaid sands consist of distinct, simultaneously deposited grain-size population representing tractional, saltational, and suspensional components of the sediment load (Gilbert, 1914; Udden, 1914; Friedman, 1967; Visher, 1969; Moss, 1972; others) and that systematic variation of grain-size compositions with depositional conditions allows sediments to be grouped into a relatively small number of categories (Krumbein and Aberdeen, 1937; Passega, 1964; Friedman, 1967; Visher, 1969; Moss, 1972; Klovan, 1960; others).

A fuller understanding of the processes governing deposition of clastic sediments would accomplish more than clarification of such questions of present disagreement as: What characteristics are appropriate for distinguishing among sediment types? How many basic types are present among water-laid sands? and, To what extent can grain-size composition be used to infer depositional environment? Among other benefits, a greater understanding of sedimentary processes would increase the utility of sediment texture in assessing conditions influencing benthic organisms, predicting sedimentary response to natural and artificially induced changes, and determining whether sediments are in equilibrium with their present environment and can be presumed to be mobile or relict from past, more energetic conditions and thus relatively stable.

Three examples from among numerous currently tenable models of sediment deposition will serve to illustrate the variety among interpretations suggested by different situations:

1) Moss (1972) relates grain-size compositions of alluvial sediments to hydrodynamic conditions at the bed surface through a series of four distinct bed stages paralleling the sequence of primary sedimentary structures described by Simons and other (1961). At successive fine ripple, coarse ripple, dune and rheologic (upper flow regime) bed stages qualitatively important differences in the influence of viscosity at the bed surface result

in unique size ranges and proportions of saltational, tractional, and suspensional grains in the bed deposit.

2) Visher (1969) studying estuarine sediments, suggests that unique combinations of winnowing, mixing of suspended and bed-load populations, and bed shear are responsible for distinctive sediment types corresponding to deposition from unidirectional currents, swash and backwash, waves, tidal currents, fallout from suspension, turbidity currents, and wind. Combinations of depositional agents give rise to additional sediment types.

3) Swift and others (1971) found it necessary to consider historical development in the explanation of textural characteristics of surface samples of continental shelf sediments. Rather than being "relict" in the sense of having rested undisturbed since some previous geologic time, shelf sediments were found to be responsive to present-day waves and currents and slowly approaching a new compositional equilibrium.

While these models are not contradictory, each emphasizes unique aspects of the particular environment under study and by itself is poorly suited for the study of other environments.

In view of the wide and incompletely evaluated variety among environments it seems unwise to interpret grain-size compositions in terms of any preconceived model. A more fruitful approach is to identify differences among sediments in some empirical manner, group sediments into categories on the basis of these differences, and only then attempt to relate categories to present and historical environmental conditions.

From among the many empirical techniques for describing samples, factor analysis was chosen for this study of sediments from the Shrewsbury Entrance Area of Sandy Hook Bay, New Jersey (Fig. 1). Factor analysis is a class of multivariate statistical techniques designed to discern simple relationships within large and cumbersome collections of observational data. R-mode analysis is used to study relationships among variables. Q-mode analysis is used to study relationships among samples.

In the present study R-mode factor analysis is used to identify grain-size populations present within a group of sediment samples.

Factor Analysis of Grain-Size Data:

As excellent discussions of the techniques of factor analysis are available in Davis (1973, p. 473-533) and Joreskog and other (1976) only a brief description is given here.

Prior to the actual analysis, relationships among variables are summarized as a similarity coefficient matrix (Davis, 1973, p. 458). Such a matrix may be visualized as a cluster of unit vectors originating at a single point in multidimensional space. Each vector represents measurements of a single variable for the entire group of samples. The cosine of the angle between any two samples is equal to the similarity coefficient relating their behaviors. With the correlation coefficient (Davis, 1973, p. 73) as the similarity coefficient, similarly behaving variables will have a similarity coefficient near 1 and be represented by nearly coincident vectors.

Statistically independent variables will have a correlation coefficient near 0 and be represented by orthogonal vectors. Inversely related variables will have a correlation coefficient near -1 and be represented by opposed vectors.

Factors analysis in this visual analogy is the placement within this cluster of the minimum number of coordinate axes (factor axes) required to describe the significant aspects of the relationships among variables.

Each statistically independent linear relationship among variables will require an additional axis.

Numerous methods are available for placing factor axes. In most, each axis approximates the orientation of a vector or a group of closely oriented vectors and can be used to represent the corresponding variables in describing samples. The closeness with which a factor axis describes the behavior of a variable is given by the loading of the corresponding vector on the axis. For orthogonal axes, the loading is equal to the cosine of the angle between the factor axis and the vector. A closely approximated variable will have a loading near 1 or -1 and is said to be heavily loaded on a factor.

Samples are described according to the coordinate system of factor axes by factor scores. The score of a sample on a factor provides a measure of the influence of the variables approximated by the factor axis. A high score indicates a strong influence.

General objections to the use of factor analysis are related to the inability to make direct observational measurements of factors; the underdevelopment of criteria for evaluating the significance of results; and subjectivity in selecting variables, the similarity coefficient, the method of placing axes, and the number of axes to be placed (Matalas and Reiher, 1967).

Additional objections are specifically relevant to the nature of grain-size data. Biases in the placement of factor axes will result from correlations among variables, autocorrelation (interrelationships related to the use of constant-sum data), non-normal frequency distributions of variables, and non-linear intervariable relationships. All of these are to be expected in grain-size data.

Despite these criticisms, continuing and successful use demonstrates the value of factor analysis to the understanding and classification of clastic sediments. Using R-mode analysis Davis (1970) placed a single axis distinguishing between fine and coarse populations identified graphically by Spencer (1963). Dalrymple (1973) interpreted three factors as corresponding to traction, intrmittent suspension, and suspension populations. Allen and other (1971) identified four size classes on the basis of three factor axes. Size classes are identified as being transported primarily by either suspension, graded suspension, saltation, or surface creep. Mather (1972) identifies, but does not interpret, six size-related factor axes and suggests that as many as eight might be geologically meaningful.

The use of R-mode factor scores as variables potentially minimizes the ambiguity of sediment classifications. Grains within a size range identified by R-mode analysis are similarly distributed among samples and differ in geographic distribution from grains in other size classes. To the extent that geographic segregation of particle-size classes is the result of geographic distribution of sediment types, further analysis can be based on statistics which are relatively constant among samples of a type, but different between types.

In the present study, sieve analysis was used to obtain 14 grain-size measurements describing each sample. Variables in R-mode analyses were percentage of weight within each of 12 intervals of approximately 1/2 phi between 4.00 mm and 0.063 mm, percentage coarser than 4.00 mm and percentage finer than 0.063 mm.

Factor axes were placed within a correlation coefficient matrix of standardized data according to the Varimax criterion. The Varimax criterion places axes so that magnitudes of most loadings are near 1 or 0 (Davis, 1973, p. 511). Axes are thus either closely related to or statistically independent of specific variables.

Because of the numerous advantages of using orthogonal rather than oblique variables and because of the exploratory nature of this study, oblique factors were used only experimentally and will not be considered further.

Area and Method of Study:

The Shrewsbury Entrance Area of Sandy Hook Bay, New Jersey (Fig. 1), consists of sand shoals and artificially maintained navigation channels.

A broad range of sedimentary environments reflects broadly ranging combinations of exposure to waves and tidal currents. Bottom sediment varies from silt in the most sheltered areas to plane-bedded, upper flow regime sands and gravelly sands in the most exposed areas. Harper (1975) describes waves, currents, topographic changes and sediments through an annual cycle.

Factor analyses were based on sieve analyses of grab samples collected seasonally through a year. 146 samples were collectd in April, 1973; 49 in July, 1973; 66 in October, 1973; and 64 in January, 1974. Samples were mechanically dispersed after soaking in a sodium hexametaphosphate solution, rinsed through a 0.063 mm sieve to determine the silt and clay content, then conventionally sieved using wire mesh sieves spaced at approximate 1/2 phi intervals from 4.00 mm to 0.063 mm.

Results of Analysis:

Loadings on up to seven factors were reproducible from season to season and identified distinct size classes (Fig. 2a). Loadings on an eighth factor were complex, of low magnitude and somewhat erratic (Fig. 2b). Grain-size classes generally recognized as typical of clastic sediments were not as clearly separated by loadings on six or fewer factors. Accordingly seven axes, allowing description of 96 to 98% of the variance within the correlation coefficient matrix, were considered appropriate for the description of data from the Shrewsbury Entrance Area.

Factors I, III, IV and V describe the behavior of sand, Factor II of granules, VII of gravel, and VI of silt and clay (Udden-Wentworth Scale).

Factor IV identifies the size range from 0.71 to 0.079 mm, the upper and lower size limits typical of saltational populations of rippled alluvial and shallow marine sediments. Ripples have been reported in sediments coarser than 0.70 mm, but are rare (Moss, 1972). Examples from sediments coarser than 0.70 mm do not conform to experimentally determined hydraulic criteria for ripple formation established by Allen (1968). Ripples in sediments finer than 0.079 mm have been produced experimentally and are common in turbidites (Rees, 1966, Kuenen, 1966). Their rarity in alluvial deposits is attributed to the preferential deposition of coarser sand at current velocities capable of producing ripples (Kuenen and Humbert, 1969).

Inverse loadings on grain-sizes finer and coarser than the 0.35 to 0.25 mm size range (Fig. 2a) correspond to the mutually exclusive size ranges of saltational populations at the fine ripple and coarse ripple bed stages identified by Moss (1972). Contrasting distributions are attributed to differing behaviors of coarser and finer sand in the face of strong turbulence generated near the bed surface if grains deposited from the saltational population form irregularities larger than 0.25 mm on the bed surface. At both the fine ripple and coarse ripple bed stages, suspended sediment is isolated from the bed surface by hydrodynamic lift forces in a thin zone of viscous flow. At the fine ripple bed stage, the saltational population has a mean diameter finer than about 0.25 mm. In the absence of large irregularities on the bed surface, strong turbulence is absent immediately above the zone of viscous flow. The coarser portion of the suspended load settles to near the bed surface, becoming concentrated as a "graded suspension." At moments of low flow velocity in the viscous sublayer particles are able to settle through the viscous sublayer and are copiously deposited in interstices between saltational grains. At the coarse ripple bed stage, the saltational population has a mean diameter coarser than 0.25 mm. Bed surface irregularities are larger than 0.25 mm and intense turbulence is generated above the viscous sublayer. Suspended sediment, including sand finer than 0.25 mm, becomes dispersed and is unavailable for rapid deposition at moments of low flow velocity.

Factor V describes the 0.35 to 0.25 mm interval as statistically independent in distribution among samples of the mutually exclusive coarser and finer grains described by Factor IV. It is, in other words, impossible to predict the abundance of coarser or finer grains knowing only the proportion of a sample within the 0.35 to 0.25 mm interval.

This statistical independence possibly reflects an equal ability of grains of this size to enter fine ripple or coarse ripple bed state deposits and a comparable abundance in both. Alternatively, these grains may have a unique sedimentary behavior, responding to environmental processes unlike either finer or coarser sand.

Support for the latter possibility is found in the numerous descriptions of the sedimentary behavior and geographic distribution of particles of about this size. In three examples, Fuller (1962) ascribes a deficiency in this size material in shallow marine sediments to either high susceptibility to erosion (Hjulstrom, 1938; Sundborg; 1956) or to a two-stage frationation process in which sand of about 0.25 mm is first concentrated on beaches with the coarse portion of the near-shore sediment load, then preferentially removed by wind.

Moss (1972) describes a mechanism of sediment transport, "boundary riding," restricted to grains of about 0.25 mm. Grains are raised by fluid-dynamic lift to the top of the viscous sublayer, but are unable to pass into true suspension at generally prevailing levels of turbulence at the coarse ripple bed stage. Carried rapidly downcurrent at a height of two to three grain diameters above the bed surface, boundary riding grains cannot be equated with either saltational or suspensional grains.

Folk (1968), noting that the easiest mobility is at approximately this grain-size whether transport is by water, wind, or gravity fall through a funnel, suggests that sedimentary behavior may, in part, be the result of inherent grain or particle properties and unrelated to environmental processes.

Factor III is heavily loaded on size intervals coarser than is typical of saltation at the coarse ripple bed stage but finer than the 2.2 mm maximum grain-size carried by saltation at the dune bed stage. Accordingly it is interpreted as identifying particles which are transported by saltation under hydrodynamic conditions similar to those present on a stream bed during ripple formation, but not under conditions resembling those during ripple formation.

Despite a superficial similarity, dunes and ripples are not large and small examples of the same bed-form. Illustrating the differences between dunes and ripples, ripple size is related to grain-size, but unrelated to depth of flow; dune size is only weakly related to grain-size, but is related to depth of flow (Blatt and others, 1972 p. 132).

Sedimentary mechanisms at the dune and coarse ripple bed stages are described by Moss (1972). At the coarse ripple stage, hydrodynamic forces are the predominant sedimentary influence and the degree of sheltering from flow determines particle stability. Only grains within narrow size and shape limits can achieve stable positions and be added to a tightly packed deposit. At the dune bed stage saltation is intense and intergranular collisions are comparable in importance to fluid forces in influencing grain stability. As a result fall velocity is comparable to packing properties in grain deposition and dune deposits are loosely packed.

The gradual and coincident decrease in loadings on Factor III and increase in loadings on Factor IV is interpreted as reflecting a gradual change in particle behavior with decreasing size from 1.00 to 0.35 mm. Particles of about 1.00 mm are deposited primarily from saltation at the dune bed stage. For particles of about 0.35 mm, a strong inverse relationship indicates deposition at the coarse ripple, rather than the dune, bed stage.

Factor I is heavily loaded on the 0.175 to 0.063 mm size range and is interpreted as identifying particle sizes carried in uniform suspension.

On theoretical grounds, Bagnold (1966) noted that a significant proportion of grains finer than 0.25 mm would be carried in suspension at the onset of particle motion and that grains finer than about 0.10 mm would be carried in uniform suspension (uniformly suspended through the water column) at the lowest flow velocities capable of maintaining sediment transport.

Visher (1969) shows suspension populations of estuarine and year-shore marine sediments as varying somewhat, the upper size limit ranging to as coarse as 0.25 mm, but generally being between 0.18 and 0.079 mm.

In agreement with both authors, gradual and coincident increase in loadings on Factor I and decrease in loadings on Factor IV with decreasing grain-size from 0.25 to 0.079 mm is interpreted as reflecting an increasing tendency towards deposition from suspension.

Consistent with the bed-stage model, Factor I shows suspensional grains to be inversely related in abundance to sizes characteristic of saltational populations of coarse ripple bed stage sediments.

Factor II has high loading values on the very coarse sand to very fine gravel size range, recognized as distinctive by Udden (1914), Pettijohn (1949), Yatsu (1955) and many others. Early accounts of the paucity of this size material as the result of mechanical instability or low rate of production have been increasingly called into question (Sundborg, 1956; Russel, 1968; Shea, 1973). A more likely explanation appears to be transport to less than representatively sampled distal portions of sand and gravel deposits as a result of instability on beds of either sand or gravel (Russel, 1968). This explanation is consistent with the bed stage model, which describes limited deposition of tractional grains at the ripple and dune bed stage and selective removal of smaller tractional grains from rheologic stage gravels.

Factor VII identifies pebbles, transported downstream onto sandy beds only under upper flow regime conditions (Fahnestock and Haushild, 1962; Simons and others, 1965), corresponding to the rheologic bed stage. At the lower flow regime, corresponding to the rippled and dune bed stages, upstream scour will cause pebbles and cobbles to move upstream and become buried.

Discussion and Conclusions:

R-mode factor analysis provides an effective strategy for the study of grain-size data. In the present study fourteen essentially arbitrary variables were replaced by seven variables corresponding to environmentally distinct grain-size classes.

Loss of information was minimal. Only 2 to 4% of the information present in the initial data was not reflected in the final results.

R-mode analysis demonstrated that at least eight distinctly behaving grain-size classes, all previously described from marine, alluvial, or flume sediments, are present in the Shrewsbury Entrance Area.

Particle behavior is not, of course, uniquely determined by size. Reflecting the influence of shape, density, surrounding grains, characteristics of the transporting flow and other conditions on the mechanisms by which particles are transported and deposited, R-mode factors indicate gradational, rather than abrupt boundaries between size classes. Transitions span intervals of from 1/2 phi to 2 phi.

Despite a change in water temperature from near $0^{o}C$ in winter to near 20^{o} C in summer, size ranges of grain-size classes were constant between seasons. Rate of sediment transport (Leliavsky, 1955, p. 187) and bed-form (Blatt and others, 1972, p. 123) respond to changes in water temperature. An increase in the maximum size of suspended particles has been predicted (Moss, 1972), but is apparently not discernable on the basis of samples sieved at 1/2 phi intervals.

Previous R-mode factor analyses of estuarine sediments described in the literature have involved fewer than seven axes. At least four size classes appear to be generally identifiable. Allen and other (1971) extracted three factors in an analysis of sediments from the Gironde Estuary, France. Four populations were interpreted as corresponding to size classes deposited from suspension, graded suspension, saltation, and surface creep. Reinterpreted according to the more recently proposed bed-stage model, these sizes are comparable to those seen in the present study to be deposited primarily from suspension, saltation at the fine ripple bed stage, saltation at the coarse ripple bed stage, and saltation at the dune bed stage. Dalrymple (1973), describing samples from Cobequid Bay, Nova Scotia, obtained three similarly loaded factors, one heavily loaded on sizes finer than 0.125 mm, one heavily loaded on sizes from 0.125 to 0.50 mm but with strong inverse loadings on either side of the 0.35 to 0.25 mm interval, and the third heavily loaded on sizes coarser than 0.50 mm.

The results of these factor analyses are, of course, specific to the Shrewsbury Entrance Area. Description of samples from other areas in terms of factors described in this study is feasible, but should be attempted only with great caution. There are numerous conditions which could vary so as to influence the results of analyses.

The eight grain-size classes identified in the Shrewsbury Entrance Area have been previously identified in other environments, but are neither invariable nor exhaustive of all possibilities. Systematic variation among environments of grain-sizes characteristic of bed-forms will result from different conditions of particle availability. Additional grain-size classes and sediment types might be expected in subaqueous deposits of the upper flow regime and of each of the several types of sediment-gravity flow. None of these is represented in the present study by more than a few, if any, samples. None is apparent from factor analyses.

Effects of organisms on gravel and mud have been noted. Organisms have been noted to influence size and mineral composition of sand as well (Wells, 1970). Where these effects are more pronounced than in the Shrewsbury Entrance Area, significant modifications of grain-size compositions of sediment types are to be expected.

In conclusion, water-laid sands are composed of distinct grain-size populations selected from saltational, suspensional, and tractional components of the sediment load. While systematic variation of sediment type with environment allows sediments to be grouped into a relatively small number of categories, the conditions influencing the end-member compositions of these categories are liable to be complex. In any incompletely known environment, a useful approach to the study of sediments is to identify differences among samples, group samples into types according to these differences, and only then attempt to relate compositions to environmental conditions. Factor analysis provides an effective means of describing samples.

In the present study, R-mode factor axes placed by the Varimax method described samples in terms of size classes which were relatively constant in abundance within sediment type, but of strongly contrasting abundance between types.

ACKNOWLEDGMENTS

I thank R. C. Murray, J. E. Sanders, N. P. Psuty, and R. N. Hordon for their many helpful comments during the course of research. Financial support was provided by the Marine Sciences Center, Rutgers University. Computer time was provided by the Department of Geology, Rutgers University, New Brunswick.

REFERENCES CITED

Allen, G. P., Castaing, P., and Klingbiel. A., 1972, Distinction of elementary sand populations in the Gironde Estuary (France) by R-mode factor analysis of grain-size data: Sedimentology, V. 19, p. 21-25.

Allen, J. R. L., 1968, Current ripples: Amsterdam, North-Holland Pub. Co., 433 p.

Bagnold, R. A., 1966, An approach to the sediment transport problem from general physics: U. S. Geol. Survey Prof. Paper 422-I, p. I11-I137.

Dalrymple, R. W., 1974, Factor analysis of grain-size data from Cobequid Bay, Bay of Fundy, Nova Scotia: Geol. Soc. America, Abs. with Programs (Northeastern Sec.), v. 6. no. 1, p.17.

Davis, J. C., 1970, Information contained in sediment-size analyses: Mathematical Geology, v.2, p. 105-112.

Davis, J. C., 1973, Statistics and data analysis in Geology: New York, Wiley, 550 p.

Fahnestock, R. K., and Haushild, W. L., 1962, Flumo studies of the transport of pebbles and cobbles on a sand bed: Geol. Soc. America Bull., v. 75, p. 1431-1436

Folk, R. L., 1968, Bimodal supermature sandstones: Product of the desert floor: Internat. Geol. Cong., 23rd, Prague, v. 8, p. 9-32.

Friedman, G. M., 1967, Dunamic processes and statistical parameters compared for size-frequency distributions of beach and river sands: Jour. Sed. Petrology, v. 37, p. 327-354.

Fuller, A. O., 1962, Systematic fractionation of sand in the shallow marine and beach environment off the South African coast: Jour. Sed. Petrology, v. 32, p. 602-606.

Gilbert, G. K., 1914, The transport of debris by running water: U. S. Geol. Survey Prof. Paper 86, 263 p.

Harper, D. P., 1975, Sedimentary dynamics of a disturbed estuary entrance sand shoal: The Shrewsbury Entrance Area of Sandy Hook Bay, New Jersey, in Halasi-Kun, G. J., and Widmer, K., cds., Proceedings of Columbia University Seminar on Pollution and Water Resources, v. 8, p. 102-133.

Hjulstrom, F., 1938, Transportation of detritus by moving water: in Trask, P.D., cd., Recent marine sediments: Tulsa, Okla., Am. Assoc. Petroleum Geologists, p. 5-31.

Joreskog, K. G., Klovan, J. E., and Reyment, R. A., 1976, Geological factor analysis: Amsterdam, Elsevier, 178 p.

Klovan, J. E., 1966, The use of factor analysis in determining depositional environments from grain-size distributions: Jour. Sed. Petrology, v. 36, p. 115-125.

Krumbein, W. C., and Aberdeen, E., 1937, The sediments of Barataria Bay: Jour. Sed. Petrology, v. 7, p. 3-17.

Kuenen, P. H., 1966, Experimental turbidite lamination in a circular flume: Jour. Geology, v. 74, p. 455-462.

Kuenen, N. C., and Reiher, B. J., 1965, Some comments on the use of factor analysis: Water Resources Research, v. 3, p. 213-223.

Mather, P. M., 1972, Study of factors influencing variation in size characteristics of fluvioglacial sediments: Mathematical Geology, v. 4, p. 219-234.

Moss, A. J., 1972, Bed-load sediments: Sedimentology, v. 18, p. 159- 219.

Passega, R., 1964, Grain size representation by CM pattern as a geological tool: Jour. Sed. Petrology, v. 34, p. 830-847.

Pettijohn, F. J., 1949, Sedimentary rocks: New York, Harper, 525 p.

Rees, A. J., 1966, Some flume experiments with a fine silt: Sedimentology, v. 6, p. 209-240.

Russell, R. J., 1968, Where most grains of very coarse sand and fine gravel are deposited: Sedimentology, v. 11, p. 31-38.

Shea, J. U., 1973, Proposal for a particle-size grade scaled based on 10: Geology, v. 1, 3-8.

Simons, D. B., Richardson, E. V., and Nordin, C. F., Jr., 1965, Sedimentary structures generated by flow in alluvial channels, in Middleton, G. V., ed., Primary sedimentary structures and their hydrodynamic interpretation: Soc. Econ. Paleont. and Mineralogists Spec. Pub. 12, p. 34-52.

Spencer, D. W., 1963, The interpretation of grain size distribution curves of clastic sediments: Jour. Sed. Petrology, v. 33, p. 180-190.

Sundborg, A., 1956, The river Klaralven, a study of fluvial processes: Geografiska Annelor, v. 38, p. 125-316.

Swift, D. J. P., Stanley, D. J., and Curray, J. R., 1971, Relict sediments on continental shelves: a reconsideration: Jour. Geology, v. 39, p. 322-364.

Udden, J. A., 1914, Mechanical composition of clastic sediments: Geol. Soc. America Bull., v. 25, p. 655-744.

Visher, G. S., 1969, Grain size distributions and depositional processes: Jour. Sed. Petrology, v. 39, 1074-1106.

Wells, H. W., 1970, Sabellaria reef masses in Delaware Bay: Chesapeake Science, v. 11, p. 258-260.

Yatsu, E., 1955, On the longitudinal profile of a graded river: Am. Geophys. Union Trans., v. 36, p. 655-663.

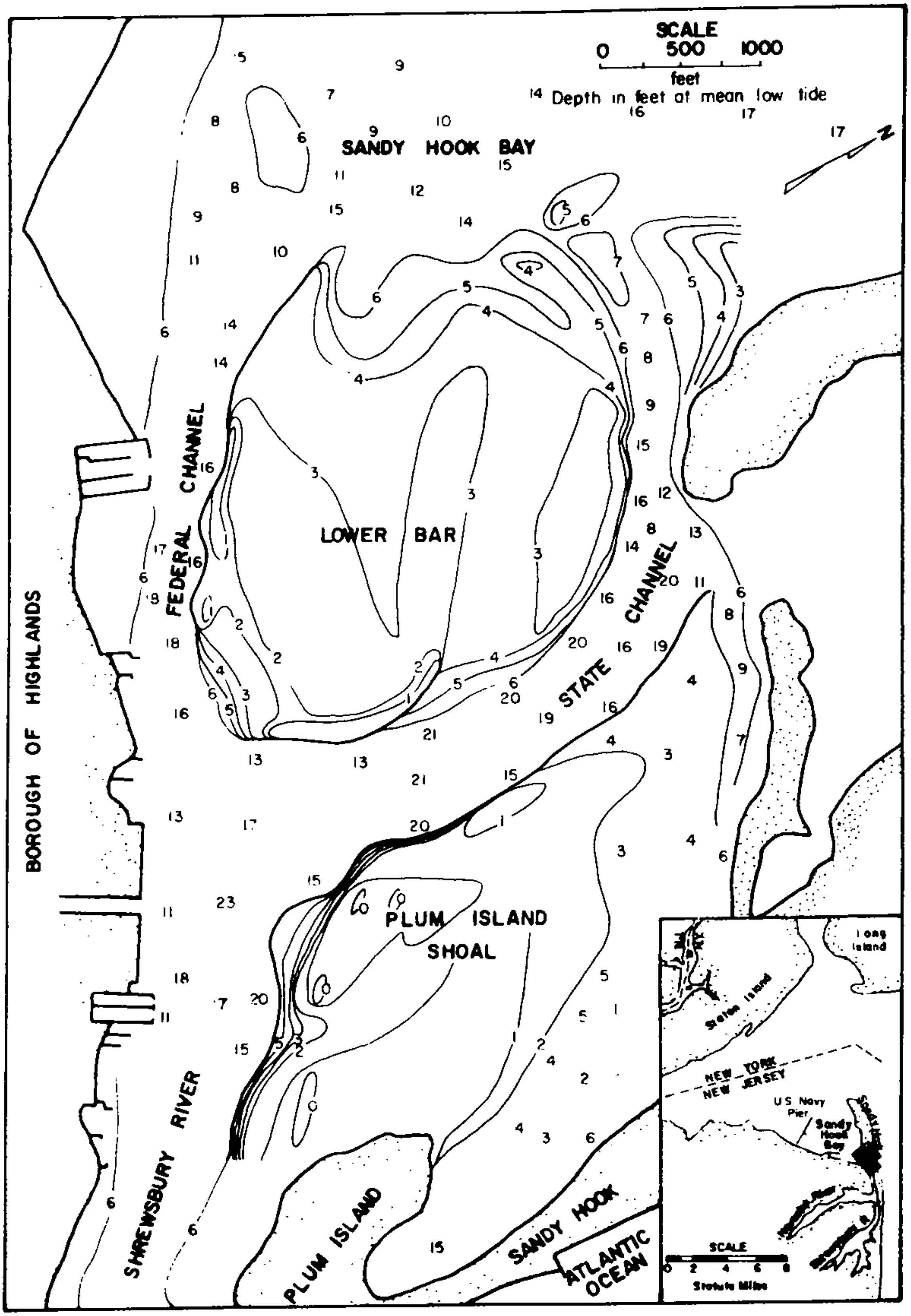


Figure 1. Location and features, Sandy Hook Bay, New Jersey.

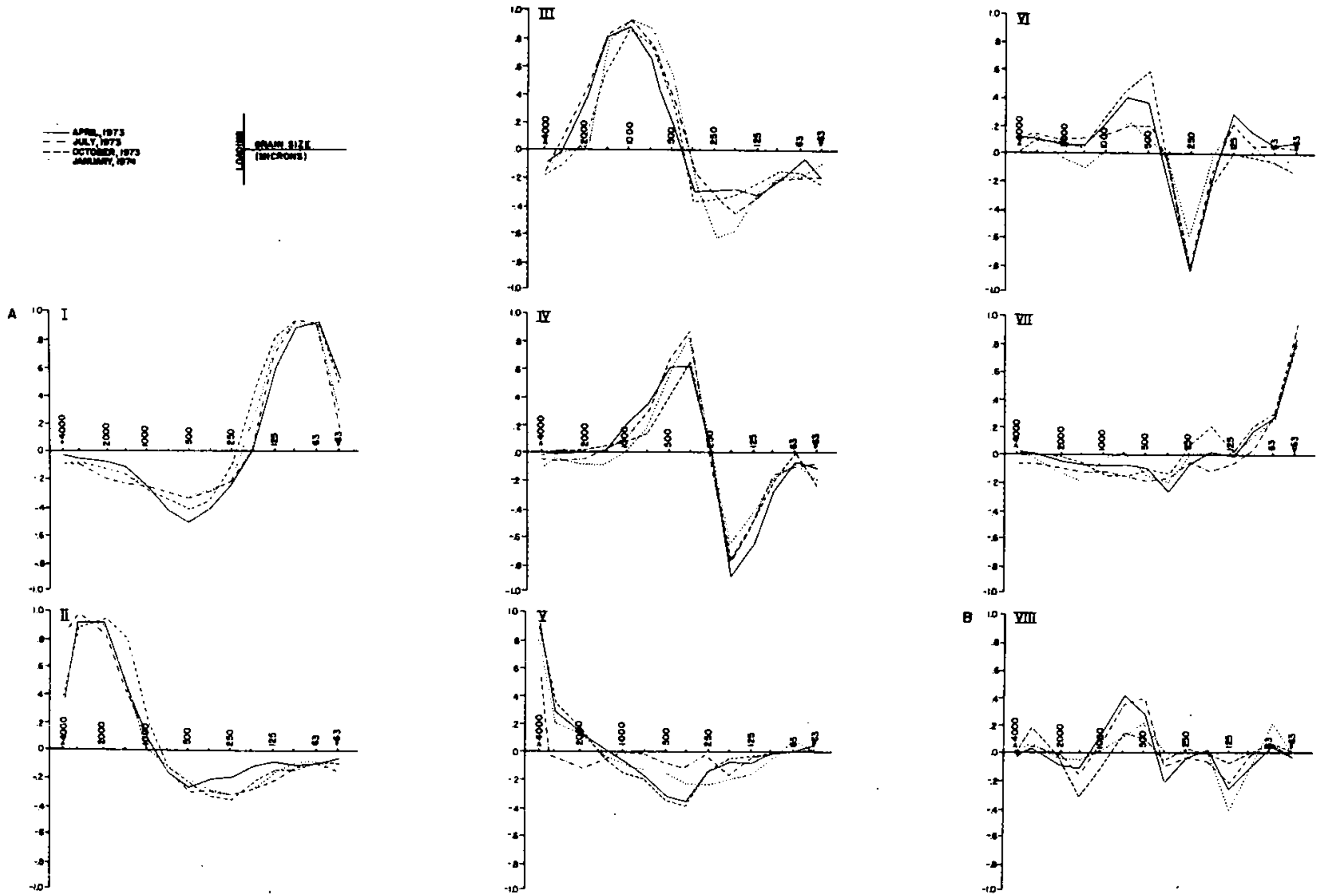


Figure 2. a. Loadings on seven factor axes. Ordering of axes varied somewhat between seasons. Order shown is for 325 samples analysed simultaneously. Sense of axes was reversed where it was felt that this would contribute to clarity. b. Loadings on Factor VIII of eight factors. Loadings on Factors I through VII were similar to loadings shown above.

DESIGN OPTIMIZATION OF A FLUE GAS DESULFURIZATION SLUDGE HANDLING SYSTEM

by

RICHARD W. GOODWIN, D. Sc.

Research-Cottrell, Inc.
Bound Brook, New Jersey 08805

ABSTRACT

This paper reviews the waste disposal problems created by the introduction of flue gas desulfurization technology. The quantities of wastes produced and the different disposal and transportation alternatives, including piping, conveying, barging, railing, or trucking, are discussed and evaluated in terms of cost efficiencies, as well as in the light of the physical characteristics of the thixotropic $CaSO_3$ product. By utilizing an equipment selection decision matrix and by emphasizing system reliability, a solution was worked out, optimized for the simultaneous handling of the scrubber slurry and fly ash of a 750 MW coal fired power plant. Both primary dewatering (thickening) and secondary dewatering were used in the production of a fly ash blended transportable slurry. Although the system possesses extensive reliability, the estimated overall costs for the operation of the thickening/blending process is only approximately $3.3/metric tons of west product.

BACKGROUND

Generation of sludge through SO_2 scrubbers utilizing lime/limestone systems and that of fly ash produced by electrostatic precipitators poses substantial problems for the power industry. These include the high waste production rates, the large area requirements for their disposal, and the mode by which the latter is achieved.

Figure 1 represents the disposal options for the wastes generated by a coal fired power plant. Of primary concern is the SO_2 sludge and the fly ash. Table I shows the quantity of wastes produced (metric tons per hour) and the area requirements for disposal (cubic meters per year) for a low sulfur (0.7%S) and high ash (10% ash) coal fired power plant of 500 MW capacity. The SO_2 sludge production rate of 9.1 metric tons per hour is arrived at on a solids basis. It assumes a 50% solids content, which corresponds to a highly thickened effluent. A lower solids concentration would, obviously, give rise to a higher production rate of SO_2 sludge and lead to larger area requirements. Conversely, increase in the percentage of solids would reduce the area requirements.

Figure 2 illustrates the effect of dewatering upon the area volumetric requirements of the sludge. Although for ash-sludge blend this exceeds that of the concentrated sludge, in some cases blending may be preferable, especially if fly ash byproduct recovery is not economically feasible. Nonetheless, the quantities and volumes involved reflect the magnitude of the problem of handling and disposing of SO_2 sludge and fly ash.

If one considers the most commonly used disposal mode - land burial - it affords two options: on-site and off-site. Taking into account the production rate and area requirements, on-site land disposal within the plant's battery limits may pose problems to the utility. For instance, were this method practiced it would utilize a considerable amount of the plant's productive space due to its large area requirements; the disposal operation itself could also interfere with the daily routines involved in power generation. Hence, off-site disposal of these wastes seems preferable. This, however, requires transporting the sludge and/or fly ash blend to the area of disposal.[1]

In general, the sludge may be pumped, conveyed or transported by vehicles. Pumping is expensive (\$0.011/m. ton/km), since energy costs reflect the need for high pumping heads in order to overcome the strong frictional resistance of the sludge, as well as the necessity for booster stations when pumping over long distances.[2] To these one must add the costs of pipe burial, heat tracing and monitoring. The pumping system may incur operational and maintenance problems due to its dependence upon mechanical equipment (pumps, motors, etc.). Finally, pumping the sludge restricts the discharge to a fixed point, a constraint which limits the disposal site to one location and reduces the flexibility of the operation. Should the fixed disposal site become unsuitable for continued use, sludge pumping would be unresponsive to such a future contingency.

Transporting the sludge by rail, barge or truck would seem to be preferable, since usually these options are less expensive. For example, for hauling by rail the costs may vary from \$0.017/m.ton/km, (for a distance of 80 km) to \$0.0622/m. ton/km (for 483 km); while for barging the cost is about \$0.0961/m. ton/km and for trucking it may approximate \$0.006/m. ton/km.[2] These values result both from the lower capital outlays required and from savings on energy expenditures. Furthermore, transporting the sludge by one of these optional modes may offer the following advantages: (1) utilizing empty coal vehicles to return the sludge to the disposal site (if site is at the de-coaled mine or strip and the plant is mine-mouth); (2) greater reliability inherent in the system, with stand-by provided by additional vehicles; (3) flexibility in relocating the disposal site when necessary. One should bear in mind, however, that these comments are generalizations which may not hold true for each specific site.

PROBLEMS ASSOCIATED WITH TRANSPORTING SO_2 SLUDGE

Transporting the wastes, sludge and/or fly ash, by surface vehicles, however, poses other problems. The sludge, on exiting the FGD system, is thixotropic: that is, it "sets-up" in the absence of dynamic loading; however, it reverts to a semi-viscous or fluid condition when exposed to pressure. On this account the material is not easily piled and moved, and leakage and spillage may also occur during transport. Furthermore, moving the SO_2 sludge, per se, does not represent a cost-effective approach. Figure 2 showed the relative volumetric requirements with respect to solids concentration and this indicates that transporting a less concentrated material would be more expensive than moving a denser sludge, since the lower the solids concentration, the greater the amount of water. In other words, without high solids concentration more water is transported than sludge. Furthermore, moving this load not only adds to the haulage costs but represents a loss to the plant of useable water. Figure 3 depicts actual water usage reduction following blending and dewatering. The example cited justifies the dewatering of the sludge, as a savings in water use of close to 50% is realized.

ALTERNATIVES AVAILABLE TO RESOLVE TRANSPORTATION PROBLEMS

The problems associated with the vehicular transportation of sludge may be resolved by several methods, including oxidation, drying, and blending. Oxidation converts the $CaSO_3 \cdot 1/2H_2O$ (which causes thixotropicity) to non-thixotropic $CaSO_4 \cdot 2H_2O$. Drying removes the excess water, thereby reducing the liquid content. It may also be used as a means of by-product recovery in conjunction with oxidation. Finally, as depicted schematically in Figure 4, blending of the sludge with the fly ash utilizes both wastes to yield a transportable material.

Pumping a fly ash/sludge blend having a viscosity between 50-1000 c.p. is very difficult. With a ratio of from $0.2/_1$ to $0.5/_1$ fly ash/sludge the material becomes non-transportable since it hardens rapidly, and this could cause unloading difficulties. In general, a transportable blend will occur in the range of a fly ash/sludge ratio of from $0.8/_1$ to less than $5/_1$. It is noteworthy that with a blend having a ratio greater than $5/_1$ fly ash/sludge the material becomes dusty, thus creating a fugitive dust problem during transportation.

As previously mentioned, SO_2 scrubber sludge exhibits properties which complicate transportation. These characteristics are the result of the material's crystalline structure and its slump. In Figure 5 are depicted scanning electron microscopic structures of sludge from an SO_2 absorber and from a flooded disc scrubber. The latter material may partially be considered to represent fly ash (Figure 5c). The micrographs (Figures 5a and 5b) reveal the "house of cards" structure which contributes to the material's thixotropic nature. Figures 5c and 5d illustrate an agglomerating effect; showing small, separate needle-like particles (especially in Figure 5d) and agglomerated particles resulting from adherence of the ash to the sulfite/sulfate crystals (Figure 5c).[3]

The numerical value of slump is considered to represent the internal cohesiveness and rigidity of the material and its capacity to maintain itself without support. Slump is determined by placing the sludge in a 30.5 cm cone and measuring the fall of the material from its contained height.[4] Figure 6 indicates the slumps of laboratory prepared sludge/fly ash blends. For the particular material tested (initial solids content 50%) it was not possible to achieve any cohesiveness even at a fly ash/sludge ratio of 2.2/1. Hence it was necessary to considerably dewater the sludge before blending. Experience has shown that to achieve a transportable blend, dewatering is equally as important as utilization of the available fly ash. Figure 7 illustrates the benefit of a two-stage dewatering process to optimize the ratio of avilable fly ash to sludge. In fact, for the system under consideration the thickened centrifuged sludge was selected as the starting material, since it produced a transportable blend with the available fly ash.

EQUIPMENT SELECTION AND SYSTEM RELIABILITY

A treatment system was developed in recognition of the benefits of both primary dewatering (thickening) and secondary dewatering for the production of a blended, transportable material. To achieve optimization of this system a decision matrix was used (Table II). The matrix depicts the parameters considered during equipment selection. For instance, although cyclones would have cost less and occupied less area, thickeners were utilized because they achieved greater solids concentrations under flow conditions and provided storage capacity during weekend shut-down. Centrifuges were chosen over vacuum filters because they enhanced the process by leading to a greater solids content, as well as better quality of return water. The blender was selected primarily for its production of smaller particle sizes and upon the criterion that the product should not stick to the blender itself.

While Figure 3, as mentioned, is a scheme of a blending/transportation system which incorporates the design parameters discussed above, Table III summarizes the major types of equipment utilized. Figure 8 represents an operational flow diagram of the system.

The system discussed emphasizes reliability. Equipment was chosen so as to comply with this goal: the thickeners will not be subject to abrasion and corrosion problems; the centrifuges will likewise not wear much because of the utilization of hard cutting tips; and the blender, as a consequence of its relatively simple mechanical design (muller rotating wheels), will suffer a small likelihood of abrasion.

The sludge piping is made of fiberglass reinforced plastic (FRP) which affords protection against abrasion and corrosion, while at the same time mitigating the frictional resistance. The sludge pumps are also rubber and FRP lined for the same reasons.

To ensure against the sludge plugging the lines, either the pipes are self-draining or flushing points are provided. Those lines which are self-draining are filled with clean water until they are required for service.

Operational control (both automatic and manual override) is provided to maintain optimal fly ash/sludge ratios and to ensure proper feeding and loading.

The system illustrates several significant operational features. It enables the plant to shut down sludge loading by utilizing the storage capacity of the thickener. The sludge blanket is allowed to rise to accommodate stored solids. The various operational flow loops allow recirculation and bypassing to ensure reliable service, while at the same time providing the plant with by-pass disposal options. Dust control is achieved by maintaining an adequate fly ash/sludge blend ratio and providing for external wetting facilities. Spilling during rail car loading is prevented by an operator platform directly overlooking the operation. The operator is provided with a control interlock to ensure filling the car with adequate free board. Finally, optimum fly ash/sludge blend is maintained by utilization of instrumentation process control (manual and automatic adjustments from fly ash feeding system to sludge dewatering and blending building).

Table IV shows generalized costs for the described system. The total figure of $3.3/m. ton represents the thickening-blending system in January 1977. Since the plant is not presently functioning, some of the annual cost components, such as operation and maintenance, were estimated.

SUMMARY

The system described for handling SO_2 sludge and fly ash utilizing appropriate and controlled blending of these components represents a design optimally related to the needs and requirements of a particular coal fired power plant. Optimization was achieved by applying a logical, sequential decision making methodology which emphasized the consideration of operational

reliability. Notwithstanding the contingency provisions, the system detailed in the paper exemplifies a cost-effective solution.

ACKNOWLEDGMENTS

CREDITS

Harvey Fox and Robert J. Gleason are thanked for their continued interest in and support of this project. This work was first presented at the University of Wisconsin Professional Development seminar on Power Plant Ash/SO_2 Sludge Management (February 3-4, 1977).

AUTHOR

Richard W. Goodwin is Manager of Product Planning and Solids Handling for Research-Cottrell, Inc., Bound Brook, New Jersey 08805.

REFERENCES

1. Braden, H. H., "Providing for the Transportability of Calcium Based FGD Sludges and Other Power Generating Station Liquid Wastes." Presented at: Conference on Disposal of Scrubbers Effluents and Sludges on Low Sulfur Coal Fired Boilers, Denver, Colo. (April 21, 1976).

2. Jones, J.W., "Disposal of By-Products from Non-Regenerable Flue Gas Desulfurization Systems." Presented at American Society Civ. Eng., Annual Nat'l. Envir. Eng. Conf., Kansas City, Mo. (Oct. 21-25, 1974).

3. McClellan, G. H., and Mills, M. E., "Solids from Wet Lime-stone Scrubbing of Power Plant Stack Gases." J.A.P.C.A., 23 (2), 122 (1973).

4. "Standard Method for Test of Slump of Portland Cement Concrete." Desig. C143-74. In: "1975 Annual Book of ASTM Standards." Amer. Soc. Test. Mater., Philadelphia, Pa. (1975).

5. Gleason, R. J., "Improved Flue Gas Desulfurization Processes with Oxidation." To be presented at: Second Pacific Chemical Engineering Congress on Stack Gas Scrubbing Technology, Denver, Colo. (Aug. 28-31, 1977).

TABLE I

WASTE PRODUCT AND AREA REQUIREMENTS FOR 500 MW STATION

Location	-	Wyoming
Fuel	-	.70% S nominal 10% Ash
Compliance	-	86×10^{-9} kg SO_2 Max./kJ Input

	WASTE PRODUCTION	AREA REQUIREMENTS
SO_2 Sludge	9.1 m. tons/hr. (Solids Basis)	131×10^3 m^3/year (50% Solids)
Flyash	23.6 m. tons/hr.	159×10^3 m^3/year

TABLE II

EQUIPMENT SELECTION - DECISION MATRIX

ITEM	CAKE/ U.F. CONC.	QUALITY RETURN WATER	AREA REQ'D	COST	STORAGE	POWER	MAINTENANCE	OPERATION
Primary Dewatering:								
Thickener	X	-	0	0	X	-	X	X
Cyclone	0	-	X	X	0	-	0	0
Secondary Dewatering:								
Vacuum Filter	0	0	-	X	-	X	0	0
Centrifuge	X	X	-	0	-	-	X	X

	PARTICLE SIZE	MIXTURE HOMOGENITY	MAINTENANCE	OPERATION	COST	POWER	AREA REQUIREMENTS
Blending:							
Pugmill	0	0	0	-	X	X	0
Twin Shell Tumbler	0	0	0	-	X	X	0
Pan Mix Muller	X	X	X	X	0	0	X

Legend: X= Advantage
0= Disadvantage
-= Equivalent

TABLE III

MAJOR EQUIPMENT LIST

ITEM	NO. UNITS/ BOILER	SIZE	CAPACITY	TYPE	COMMENTS
Thickener	1	42.7 m. Dia. 3.7 m. Side-wall	2.85 m^3/min.	Cont. Rake	Designed to store weekend output when centrifuges are shut-down.
Centrifuge	3 (2+1)	Height = 1.2 m Width = 28.4 m. Length = 2.6 m.	0.95 m^3/min.	Cont. Solid Bowl	Designed to produce high % solids (or 70% centrifuge cake).
Blender	1	Height = 2.3 m. Width = 4.9 m. Length= 2.6 m.	90,700 kg/hr.	Stat. Pan Multi-Mull	Produces uniform blend without fouling.

TABLE IV

COSTS

Generalized costs for sludge treatment system including equipment installed, operation, maintenance, payback

o	Operating Costs	$1.54/m. ton
o	Fixed Costs	$1.76/m. ton
o	Total Costs	$3.30/m. ton

Power Generating Station Waste Disposal Options

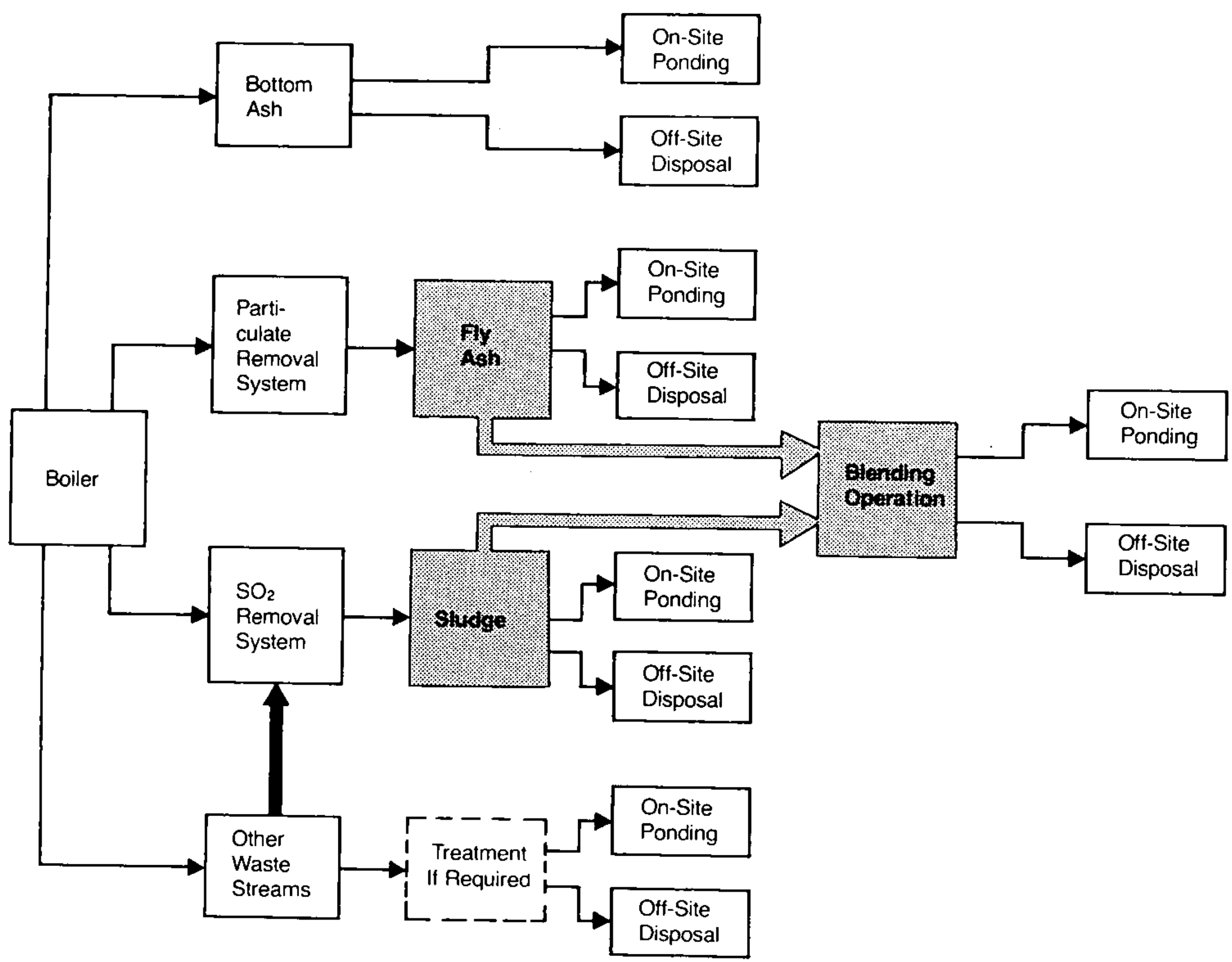


Figure 1

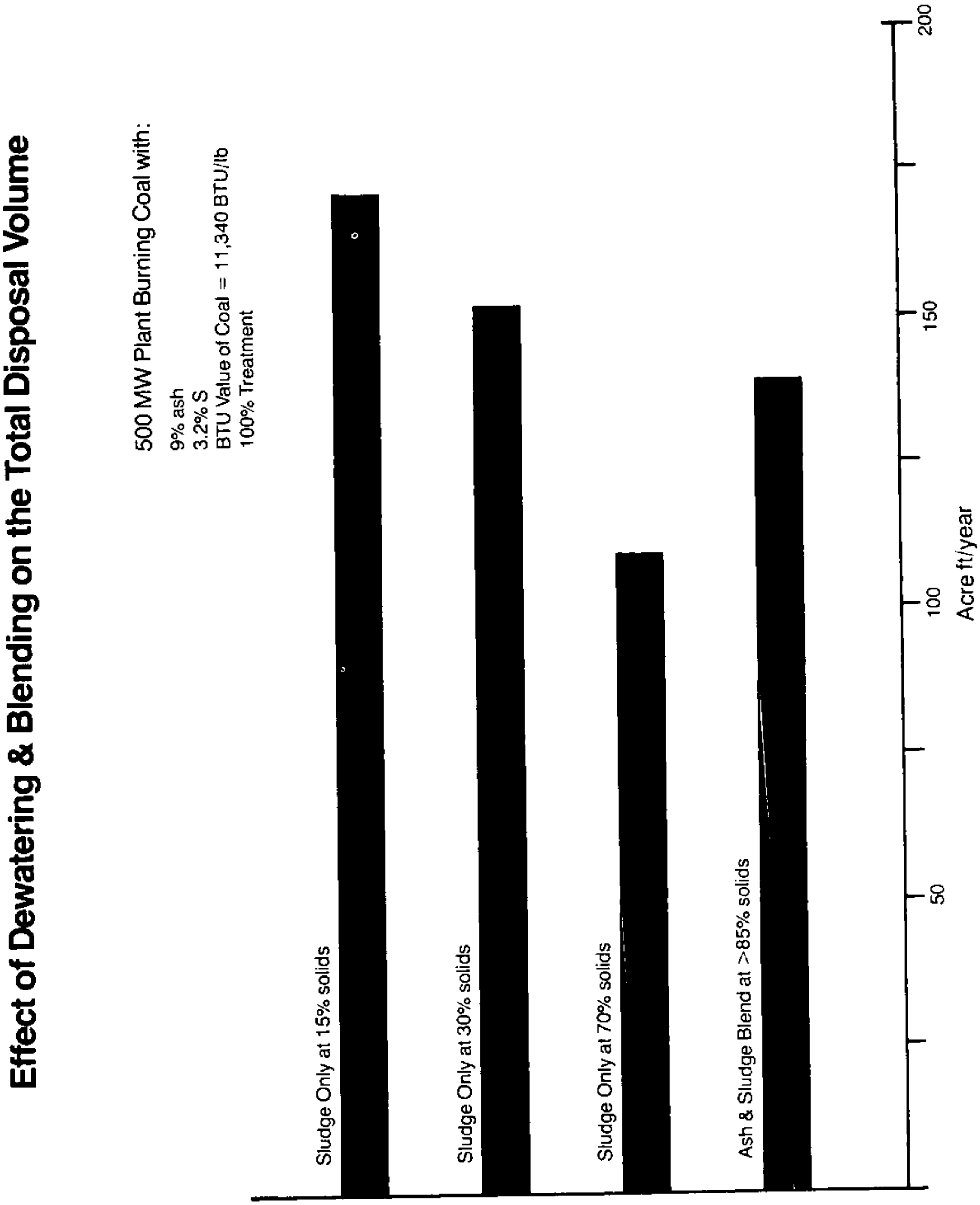
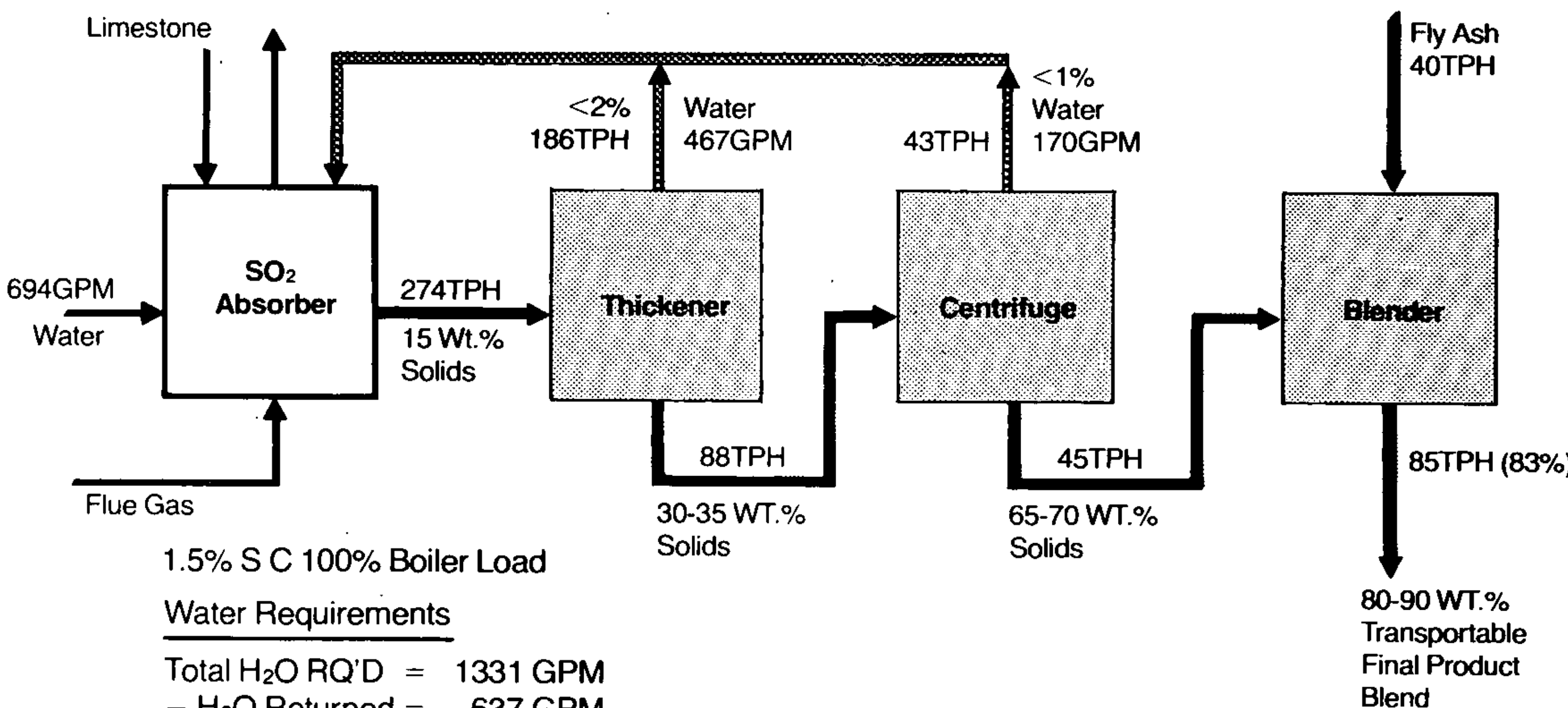

Effect of Dewatering & Blending on the Total Disposal Volume
500 MW Plant Burning Coal with:
9% ash
3.2% S
BTU Value of Coal = 11,340 BTU/lb
100% Treatment
Sludge Only at 15% solids
Sludge Only at 30% solids
Sludge Only at 70% solids
Ash & Sludge Blend at >85% solids
50
100
150
200
Acre ft/year

Figure 2

R-C Sludge/Fly Ash Blending Process

(Per Boiler - 750MW)



1.5% S C 100% Boiler Load

Water Requirements

Total H_2O RQ'D = 1331 GPM

− H_2O Returned = −637 GPM

H_2O Added = 694 GPM(47.9% Water Usage Reduction)

Figure 3

FLY ASH BLENDING STABILIZES SLUDGES

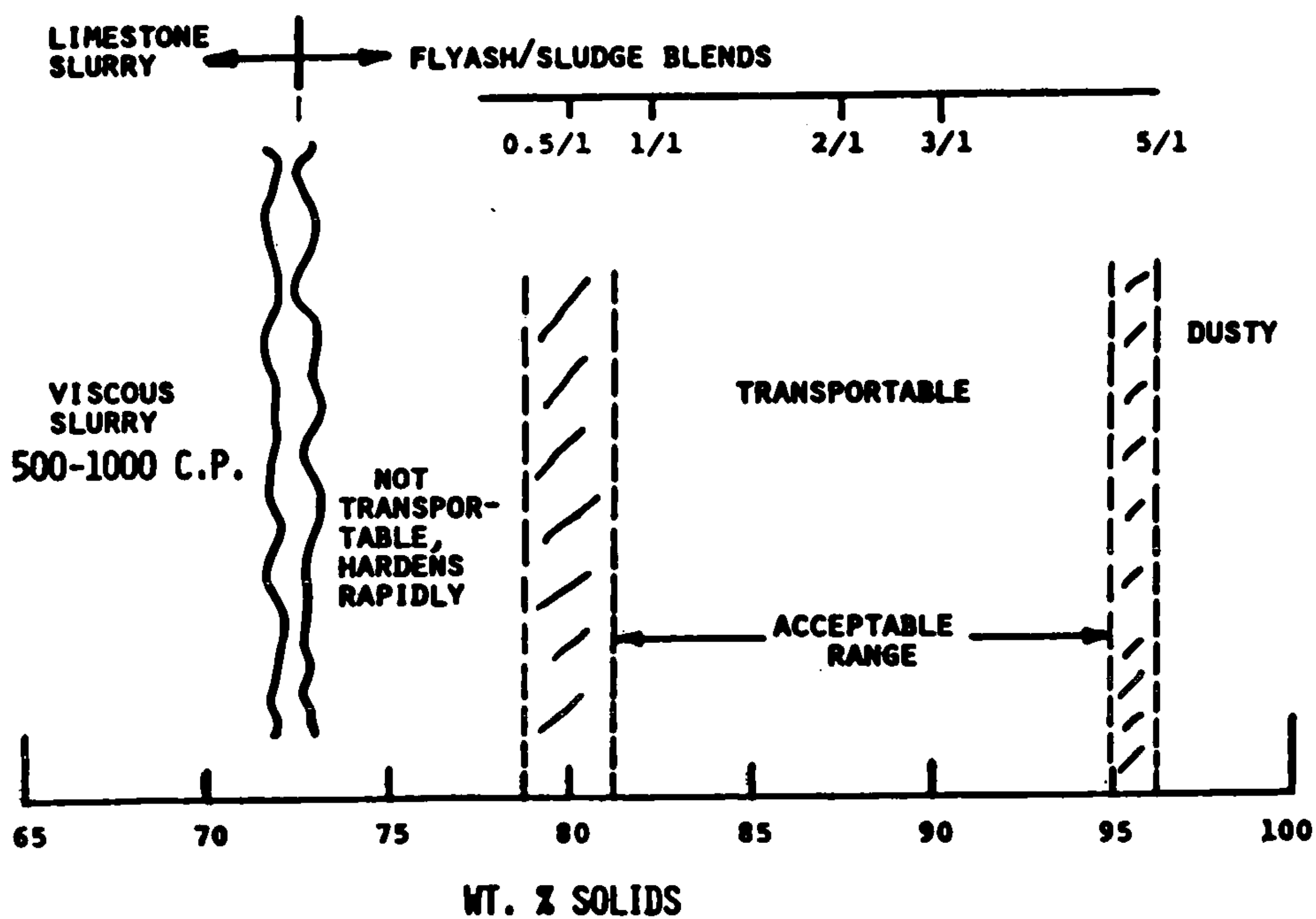


Figure 4

Micrograph Comparison

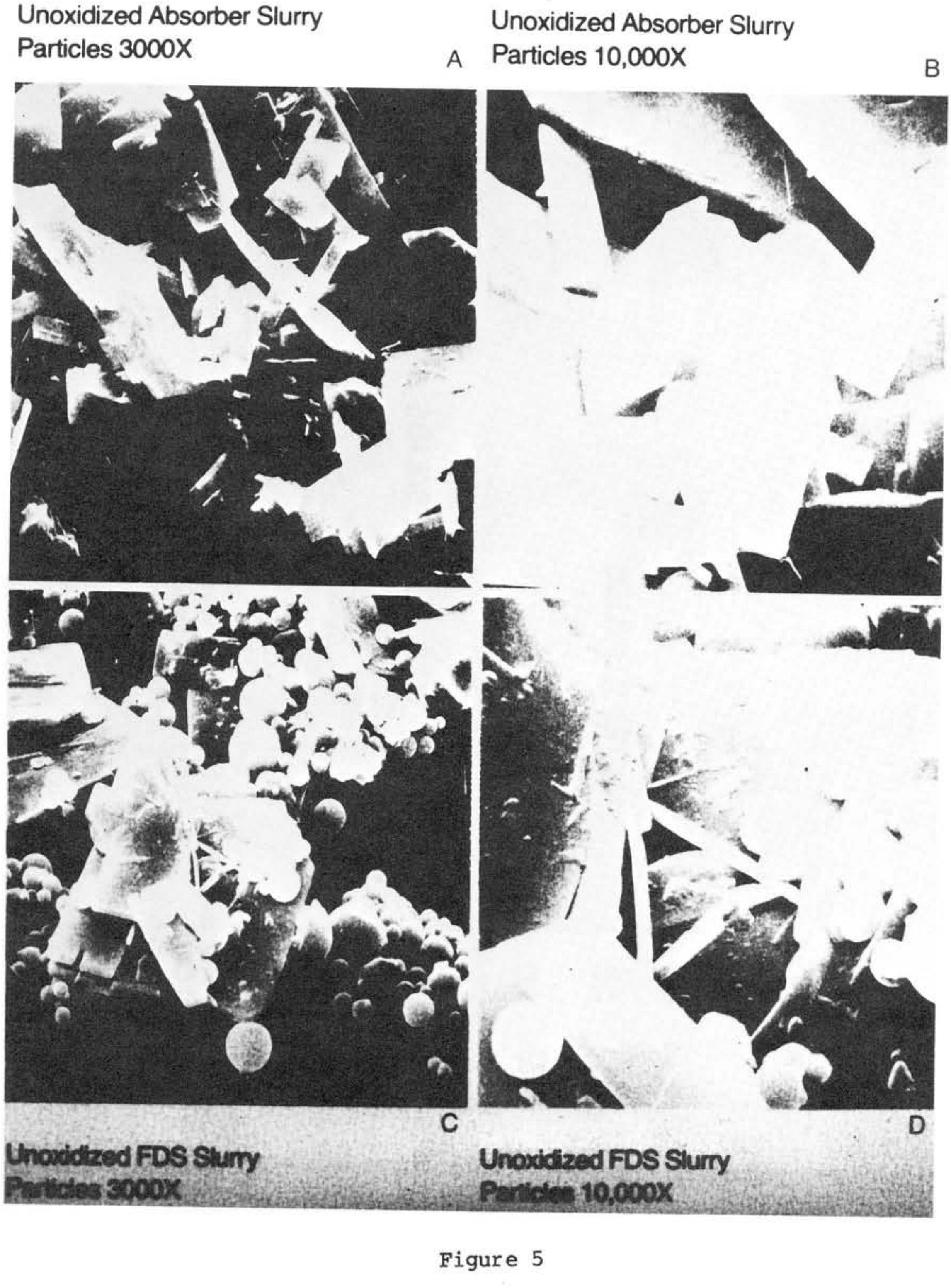


Figure 5

EFFECT OF SOLIDS CONTENT ON SLUMP

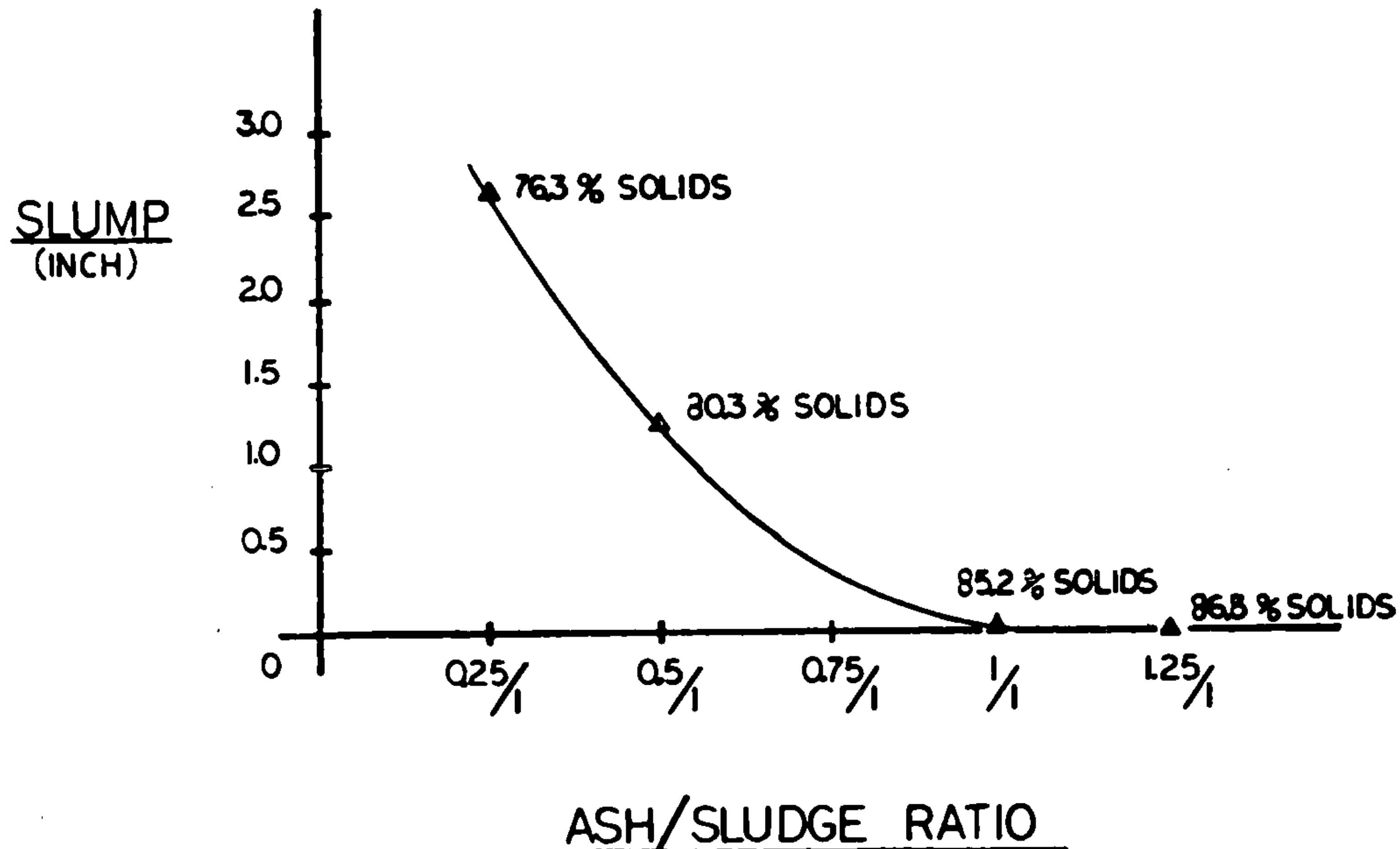


Figure 6

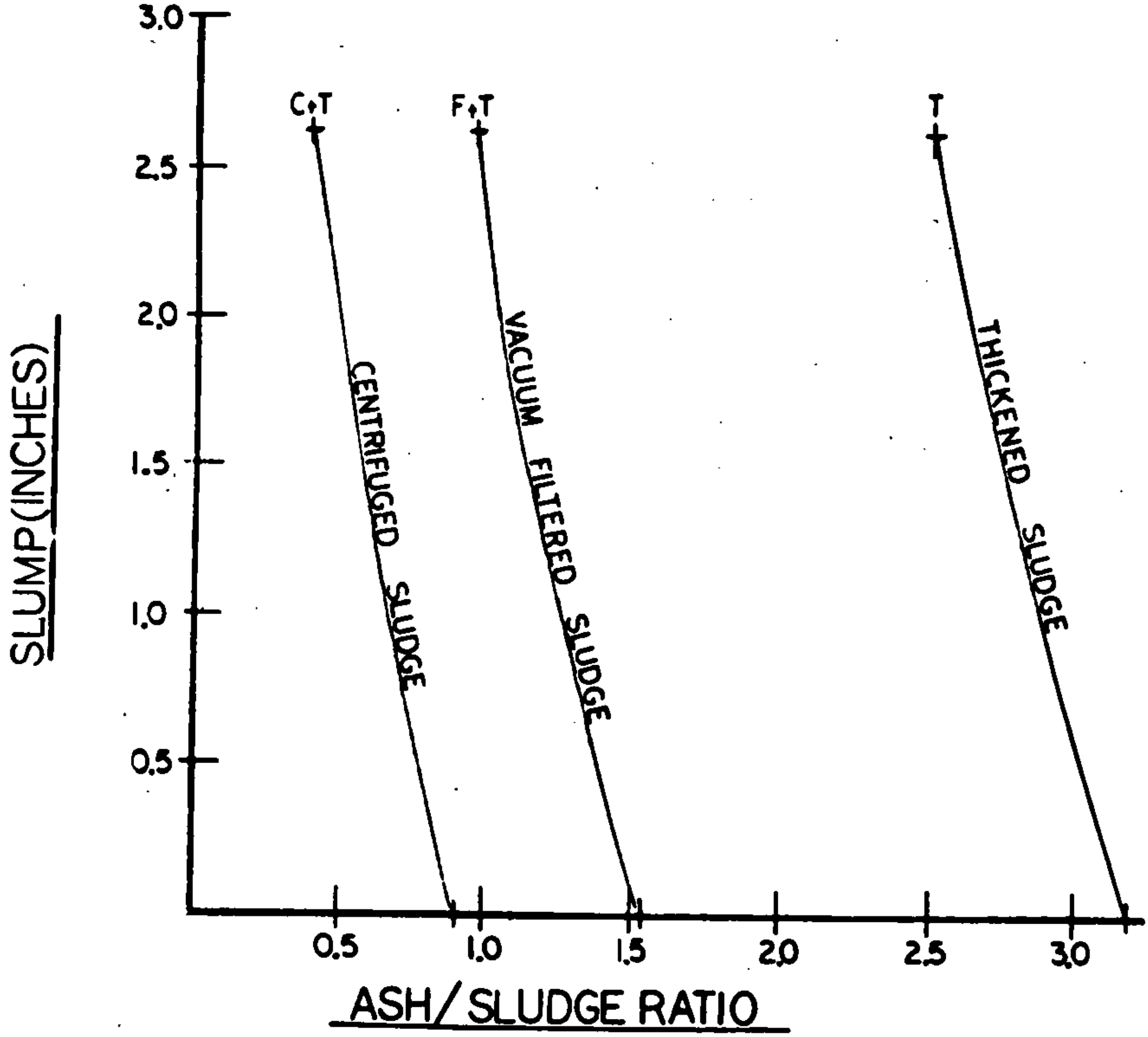
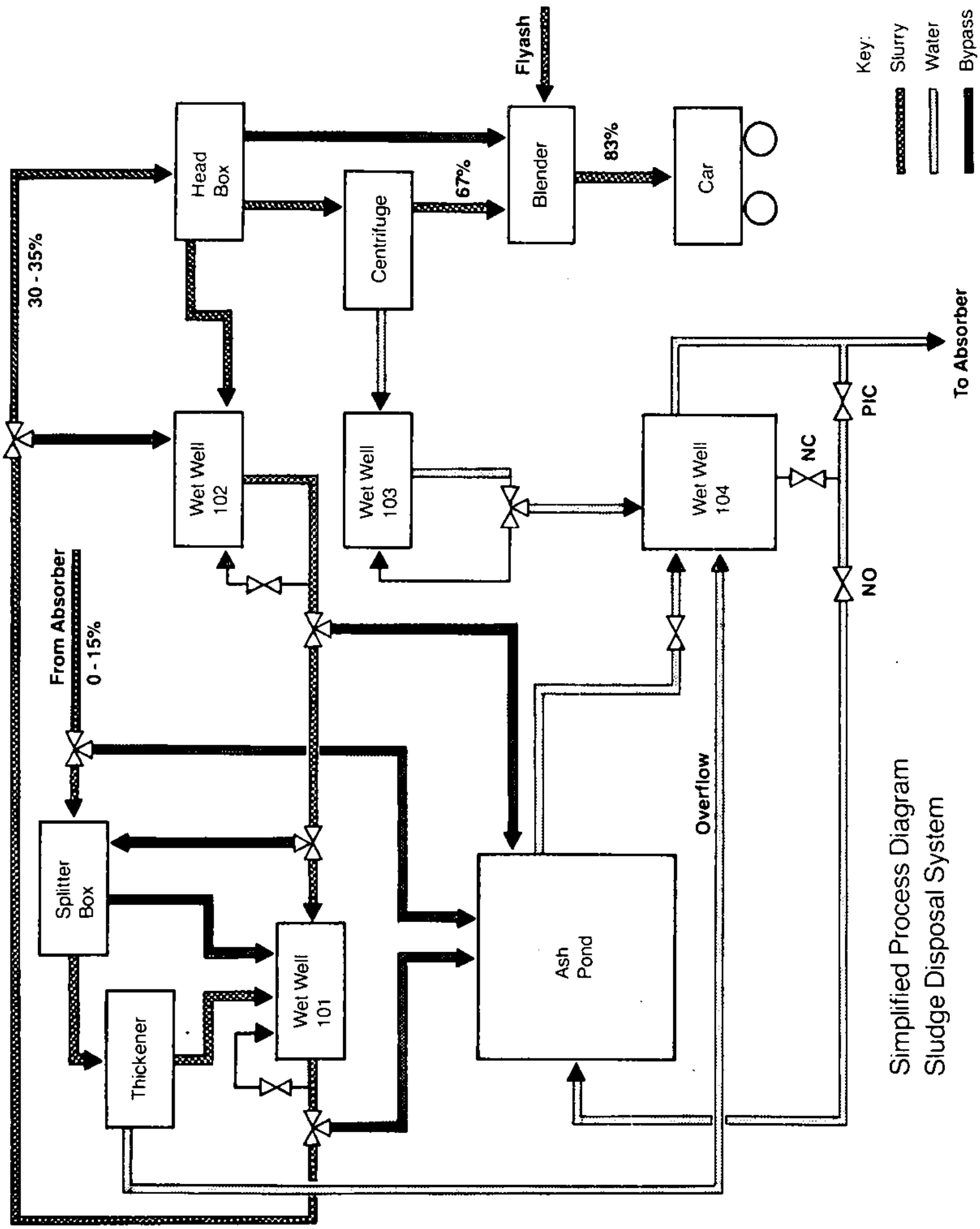


Figure 7. Effect of dewatering upon flyash blending requirements (in x 2.54 = cm)



Head Box
Centrifuge
Blender
Flyash
67%
83%
Car
30 - 35%
From Absorber
0 - 15%
Wet Well 102
Wet Well 103
Wet Well 104
NC
PIC
NO
To Absorber
Splitter Box
Thickener
Wet Well 101
Ash Pond
Overflow
Key:
Slurry
Water
Bypass
Simplified Process Diagram
Sludge Disposal System

Figure 8

SEDIMENT DYNAMICS AND TEXTURAL FACIES IN THE BRIGANTINE INLET AREA, NEW JERSEY

by

RICHARD F. KRAUSER, M.S., and NICHOLAS K. COCH, Ph.D.

Department of Earth and Environmental Sciences,
Queens College of CUNY, Flushing, New York 11367

Abstract

The Brigantine Inlet area of southern New Jersey includes flood and ebb tidal channels, an ebb delta, transverse bar, and ridge and swale topography. These features consist of distinctive sediments whose size distributions are characterized by differences in grain size parameters, and by differences in transport populations as determined by log-probability curve dissections. Morphology and sediment texture, together with historical shoreline changes, surficial sedimentary structures, and information about current patterns were used to infer sediment dynamics in the area. Brigantine Inlet is sediment starved, as it receives only a poor supply of relatively fine grained sediment mostly by downcoast (southwest) longshore drift. The sediment is then reworked by ebb and flood currents. Much of the sediment transported out of the inlet by the ebb current is deposited as an ebb delta. The ebb current is diverted to the south by interaction with the southwest flowing longshore current, making the delta asymmetric. The ebb delta and the shallow transverse bar at its seaward edge serve to shield the inlet area from the full destructive effects of northeast generated storm waves. Seaward of the delta, nearshore area sediments show a bimodal distribution, suggesting the mixing of a fine grained longshore transported fraction with a coarser grained wave transported one. The southern part of the study area includes ridge and swale topography, which is characteristic of the inner continental shelf. Sediment distribution here is strongly related to bathymetry, and little of this sediment is transported into the inlet area. South Spit, the southwestern margin of the inlet, is prograding into the inlet. Sediment textural analysis and surficial sedimentary structures are not inconsistent with the hypothesis that Brigantine is a downdrift-offset inlet, built up by a local reversal of longshore drift.

INTRODUCTION

With increased cultural pressure being placed upon coastal areas, and with a new awareness of the effects of environmental degradation, there is an expanding interest in determining the detailed response of these areas to natural coastal processes. By the use of such information, the effects of any cultural alteration can be better assessed.

This study was undertaken to describe the sediment distribution occurring within, and offshore from Brigantine Inlet - part of an extensive barrier beach-lagoon complex of coastal New Jersey. Sediment distribution characteristics are used to infer coastal sediment dynamics within a fair-weather cycle. This investigation was originally conceived as part of a larger study of Brigantine Inlet begun by the State of New Jersey and which included an intensive sampling program along with nearshore depth measurements and current measurements. Brigantine Inlet was selected for study because it is one of the few inlets of New Jersey still essentially unmodified and uncontrolled by man. Changes through time in this inlet have been documented by navigational charts dating from as early as 1769, and by aerial photographs from as early as the 1920s.

The results of this study, when compared to those from other Atlantic coastal inlets, show similarities and some important distinctions which may serve to characterize the coastal dynamics of New Jersey.

AREA OF STUDY

Location and General Description

The Atlantic coast of New Jersey is characterized by a series of well developed barrier islands which are separated from the mainland by an extensive lagoon complex, one to six miles wide. This lagoon complex extends from Barnegat Bay southward to Cape May, and is characterized by extensive tidal flats south of Great Bay (fig. 1). Inlets between the barrier islands, which allow an exchange of water between the lagoon and the open ocean, occur infrequently northeast of Great Bay, with only two inlets for 40 miles of barrier islands. South of Great Bay the number of inlets increases greatly, with seven inlets through 25 miles of these barriers.

Brigantine Inlet is located about eight miles north of Atlantic City and is entirely within the limits of the City of Brigantine and the Brigantine National Wildlife Refuge. The inlet separates two barrier islands, Brigantine Island to the southwest and Pullen Island to the northeast (fig. 2). Beach Haven-Little Egg Inlets lie three miles to the northeast and Absecon Inlet six miles to the southwest. To the west of Brigantine Inlet is an extensive lagoon which is partially filled with tidal flats and stabilized by *Spartina* grasses. Open water areas within the lagoon are Grassy Bay and Little Bay. Numerous tidal channels dissect the sediment flats of the lagoon, the largest and most important of these channels being Brigantine Channel and Great Thorofare. The confluence of Brigantine Channel and Great Thorofare has previously been referred to as North Spit (Lynch-Bloss, 1976). Two spits flank Brigantine Inlet, South Spit (op. cit.) at the northeast end of Brigantine Island, and Little Beach at the southwest end of Pullen Island. The relief of the study area is low, with maximum elevation rising to 15 feet on the dunes of Brigantine Island.

The largest nearby source of fresh water into the lagoon is the Mullica River which flows into Great Bay north of the study area. The total discharge of this river is slight when compared with the volume of water exchanged during the tidal cycle; a ratio of 1:138 in Great Bay (Charlesworth, 1968). This suggests that Brigantine Inlet is a vertically homogeneous inlet.

Geological Setting

During the Pleistocene epoch, successive glaciations caused contemporaneous lowerings of the sea level. At the maximum extent of the Wisconsin glaciation, sea level was lowered about 130 meters (427 ft) (Milliman and Emery, 1968) with the shoreline at this time occurring 55 miles (88.5 km) seaward from its present position. During glacial retreat, the exposed shelf was blanketed by fluvial sands and gravels from what must have been rivers greatly enlarged by meltwater from the glaciers. Because of mineralogical dissimilarities between these fluvial deposits and Cretaceous and Tertiary rocks of the New Jersey coastal plain (McMaster, 1954), the sediment may have been transported by the ancestral Hudson River (Frank and Friedman, 1973).

As the sea level rose during the Holocene transgression, portions of these fluvial deposits were reworked into beach deposits. Barrier islands and lagoons developed just seaward of the shoreline during periods of temporary stillstands. Some barrier islands appear to have migrated westward over lagoonal deposits as sea level continued to rise (Donahue, Allen and Heezen, 1966). There is evidence that some barrier complexes were "jumped" over so quickly by the advancing sea that they were preserved (Kumar, 1973). It has been suggested that these barriers have become reoriented upon approaching equilibrium with the modern hydraulic regime, and that they form the present ridge and swale topography of the continental shelf (Swift, 1969). Kraft (1971) presents evidence that some submarine linear ridges occurring at an angle with the present coast can be traced landward to features which may be barriers developed at higher sea levels than at present and isolated during sea level lowering.

Bathymetry

Fathometer data for the year 1969 were collected by the New Jersey Geological Survey. Depths, corrected for height of mean tide, were measured to a one-tenth foot precision. The writer contoured the data at a one foot contour interval. The resulting contour map provides good coverage for most of the study area (fig. 3).

Maximum submarine relief occurs within Brigantine Channel. Two linear troughs, parallel to the channel, occur along its north and south margins. The south trough attains a maximum depth within the study area of 21 feet, and terminates near the seaward end of the channel. The north trough appears as two separate scour depressions (fig. 3). The maximum depth of 39 feet within the study area occurs here just south of North Spit.

The 10 foot contour defines a shallow, lobate and asymmetric delta extending seaward from the inlet mouth (fig. 3). This delta is offset to the south. It is within this delta that the ebb channel, as a delta trough, terminates about two miles from the inlet mouth. One foot contouring has shown the existence of a clearly defined low ridge between the northeast side of the ebb channel and the seaward margin of the delta. This ridge is indicated by the five foot contour which shows it as a series of discontinuous mounds. The ridge is attached to the shore at Little Beach and trends to the southeast, curving to the south at the delta margin. The discontinuity of the uppermost surface of this ridge suggests that it is breached in at least three places by shallow transverse channels.

Another area of very shallow water is also defined by the five foot contour at South Spit (fig. 3). This wide shallow extension of South Spit shows two lobate forms near the southern margin of the delta. The 10 foot contour shows a broad shallow platform extending seaward from the shore to the northeast of Little Beach. This has been described as part of the ebb delta of Beach Haven-Little Egg Inlets, about three miles to the northeast (Charlesworth, 1968). It is offset to the south in a manner similar to the delta of Brigantine Inlet.

To the north and east of the delta, depths increase fairly uniformly at a rate of about 15 feet/mile. About one mile offshore, the slope increases to about 30 feet/mile. Within the southern part of the study area, ridges and swales are evident (fig. 3). They trend generally east northeast. These features are apparently nearshore extensions of the "ridge and swale topography" (Swift, 1969) found along the east coast continental shelf. Ridges stand about four to five feet above, and swales about four to 10 feet below the average bottom depth. This type of topography in the southern and southeastern portions of the study area forms a distinct morphologic province.

Previous Work

Several aspects of the coastal dynamics of the Brigantine Inlet area have been previously studied. Charlesworth (1968) analyzed about 160 bottom samples in relation to the effects of past coastal waves and currents. The effects of tidal currents were studied on areas of present erosion and deposition within the inlet (Lynch-Bloss, 1976) and on the cause of the downdrift-offset character of the inlet (Lynch-Bloss and Kumar, 1976). The historical changes in the coastal configuration of Beach Haven-Little Egg and Brigantine Inlets have been described and mapped by Plusquellec (1966). Rittschof (1976) has related shoreline changes and inlet migration of Brigantine Inlet to the effects of large storms.

A survey by McMaster (1954) of the textural and mineralogical variation of beach sands along the New Jersey coast provides information about potential source areas for the sands. The source of beach sand from the continental shelf seaward of the study area has been discussed by Frank and Friedman (1973) and Stubblefield et. al. (1975). These two papers also describe nearshore and inner continental shelf sediments off the central New Jersey coast.

The body of literature proposing actual mechanisms and models of inlet sedimentation is large, having grown most rapidly in recent years. For this study, some of the most useful have been those of Todd (1968), Price (1963), Duane (1964), Hayes (1969), Hayes et. al. (1973), Allen (1971), Ludwick (1970), Oertel (1972, 1975), Visher and Howard (1974), and Lynch-Bloss and Kumar (1976). Simons et. al. (1966) have described sedimentary structures and have related them to flow regimes. Techniques of statistical analysis of sediment populations and the use of these analyses as tools for describing sediment hydraulics have been discussed by Folk and Ward (1957), Folk (1965), Pessaga (1964) and Visher (1969). The Rapid Sediment Analyzer and methods for its calibration have been detailed by Schlee (1966), Sandford and Swift (1971) and Nelsen (1974).

Analyses of the nearshore ridge and swale topography and its mode of origin have been discussed by Donahue, Allen and Heezen (1966), Kumar (1973), Swift (1969), Kraft (1971) and Stubblefield et. al. (1975).

CHANGES IN COASTAL CONFIGURATION

A comparison of Brigantine Inlet shorelines of 1952 and 1972 (fig. 2) shows considerable change in the coastal configuration. These changes can be seen relative to the lagoonal tidal marshes and channels which have remained essentially unchanged in 20 years. The most dramatic change is in the growth of South Spit and Little Beach into the inlet. South Spit has prograded to the northeast about 1000 feet, and terminates at a point that was in the center of th channel in 1952. South Spit has been built by the addition of sand ridges which progressively extended the spit. The position of the shoreline of Brigantine Island to the southwest has remained unchanged.

A large shoal extended to the southeast from Little Beach in 1952. By 1972 this shoal had disappeared and a narrow spit had prograded about 3000 feet to the southwest. This spit at Little Beach has grown across what had been part of the outlet of Great Thorofare. The outlet of Great Thorofare is now confined to a narrow opening between the spit at Little Beach and North Spit. During this time the shoreline of Little Beach moved landward (northwest) about 500 feet. There was no movement of the shoreline at the north end of the study area.

The effect of the shoreline retreat at Little Beach and the seaward growth of South Spit was to create a seaward offset of South Spit. According to Rittschof (1976) this offset began in 1954. He also reports that periodically after 1954 both spits underwent extensive erosion and rebuilding. In 1961 South Spit began prograding, and in the four years previous to 1969 (the year of sampling for this study), both spits prograded. This pattern operates only within a cyclical fair weather system (Lynch-Bloss and Kumar, 1976). The time span of this study lies within this fair weather system which began in 1961 and continues to the present. Comparison of historical navigational charts and aerial photographs has led Rittschof (1976) to the conclusion that, while Brigantine Inlet may progressively move northeastward during periods of fair weather, the ultimate movement is to the southwest - in the direction of net littoral transport. This occurs during periods of severe storms which destroy the ebb delta and transverse bar on the ebb delta (fig. 3), and leave South Spit open to subsequent direct attack by high energy, short period waves coming from the northeast.

PROCESSES

Tides

Tides along the coast of New Jersey are semi-diurnal, having little diurnal inequality. The average height from 1911-1964 was 4.1 feet, with a normal range of 3.2 feet for neap tides to 5.0 feet for spring tides. Storms can produce a range of tides 5.4 feet above mean high tide to 3.5 feet below mean low tide (Wicker, 1965). Tides of high and low water at Brigantine Inlet are 38 and 27 minutes later, respectively, than at Atlantic City's Steel Pier to the southwest (Charlesworth, 1968). This indicates an upcoast movement of the tidal effect.

Winds

Northwesterly and westerly winds predominate from October to April, and south to southeast winds predominate from May to September. Northeast winds have a higher average velocity (19-20 mph), and most storms come from the northeast. Winds by themselves appear to be the least important process operating within the study area. They do, however, affect dune formation and the movement of some sand from these dunes into the lagoon. Onshore (southeasterly) and offshore (westerly) winds probably also reinforce or counter the effects of ebb and flood tides on the water prism. Onshore winds, which predominate during July and August, may also be of some influence in retarding the ebb flow.

Waves

Waves affecting the south coast of New Jersey can have both constructional and destructional effects. Waves generated by storms far offshore can have wavelengths of 30-500 times wave height (wave height one to two feet) in the Brigantine area (Charlesworth, 1968). The resulting swells usually transport material onshore. Short period storm waves are primarily destructional. They are steep and 11-12 feet high at maximum (Brigantine). Storm waves have wavelengths of seven to 20 times their wave height (U.S. Army Corps of Engineers, 1959). The average wave period is 7.3 seconds. During all months of 1955-1959, most wave approaches (61%) came from the southeast (Hall, 1962).

Storms

Hurricanes and "northeasters" are the storms which most commonly affect the coast of New Jersey. Hurricanes come from the south during late summer and early autumn. Northeasters occur during autumn and winter, and have the effect of increasing longshore sediment transport (Charlesworth, 1968). The major effects of storms along the New Jersey coast are the disruption of the sediment distribution cycle and the opening and closing of inlets (Charlesworth, 1968), or their migration (Rittschof, 1976).

Currents

Currents affecting the study area may be broadly categorized into two types: tidal and wind-induced (King, 1959). Wind-induced currents are resolved into orbital wave currents (refracted normal to shore) and longshore currents. Rip currents are uncommon.

Tidal currents are the dominant process affecting sediment distribution in Brigantine Inlet. Surface tidal current maps have been made by Charlesworth (1968) and Lynch-Bloss (1976). Current strength rapidly reaches maximum velocity shortly after slack tide. Within Brigantine Inlet maximum surface ebb speeds recorded for 1970 are 3.77 ft/second. An average ebb speed of 2.17 ft/second, compared with an average flood speed of 1.74 ft/second, appears to reflect an increased channelization of flow of the ebb current, as opposed to the sheet flow of flood tide. Because of the falling tide, the ebb current is forced through a smaller cross-sectional area. Current meter readings taken at two foot depth intervals at a number of stations across Brigantine Inlet have suggested that while surface measurements indicate a higher average velocity for ebb currents, the sediment transporting bottom currents show a higher velocity at flood (Lynch-Bloss, 1976). This would seem to indicate a net long term movement of sediment into the inlet, although this sediment is not observable as a well developed flood delta, but rather as extensive tidal flats. Ebb tidal flow, issuing as an ebb jet (Price, 1963) seaward of the inlet, curves southward because of interaction with a southwesterly flowing longshore current.

The north trough has been correlated with the delta ebb channel (Lynch-Bloss, 1976). However Coriolis motion indicates that flood waters would enter the inlet on the right side, making the north trough a flood channel and the south trough an ebb channel. This allows the correlation of the south trough with the delta ebb channel, which reaches a maximum depth of

15 feet. A map of the multiple ebb and flood channels in the entrance to Chesapeake Bay shows flood channels occurring to the right (north) of ebb channels (Ludwick, 1970). The current profile used by Lynch-Bloss (1976) is derived from data which measure current velocity and only whether they were taken at ebb or flood tide, and not current direction. Because of this and because of the absence of depth information at the inlet itself, there is a likelihood that the north trough is the flood channel, where a high speed current has been reported at flood tide (Lynch-Bloss, 1976).

Longshore currents are the most important wave-induced currents affecting sediment movement in the study area. The area between the Manasquan River and Barnegat Inlet is a nodal zone of no longshore current movement. North of this area, longshore current flow is to the north, whereas in the area to the south (which includes Brigantine Inlet), flow is to the south and southwest (Lucke, 1934; McMaster, 1954). Fair weather swells approaching from the southeast produce northward current flows. Storm related swells from the northeast produce southward flows (Charlesworth, 1968). Long Island serves to protect the northern coast of New Jersey from the effects of these storm-derived swells, and so longshore currents flow to the north. The south coast of New Jersey, however, receives their direct impact and this produces a dominant southerly flow. Current measurements made just seaward of Brigantine Inlet indicate a surface longshore southerly flow (Charlesworth, 1968).

Fair weather orbital currents operate in the nearshore region at depths generally less than 12 feet, and can move material inshore (shallow waves) or offshore (steep waves) depending on their steepness (Charlesworth, 1968). Rip currents off the New Jersey coast near the study area are not a common phenomenon (Charlesworth, 1968). When they are developed, these currents serve as a mechanism for the transport of surf waters out to the nearshore area, carrying only particulate matter winnowed out of the sand on the beach face by breaker action (Inman and Brush, 1973).

SAMPLING AND ANALYTICAL PROCEDURES

Sediment samples and fathometer data were collected by the New Jersey Bureau of Geology and Topography during July and August, 1969. A total of 302 offshore samples were analyzed. Samples were obtained by use of a clamshell sampler lowered from a small boat. Positioning was done by triangulation between fixed shore stations. Although instantaneous sampling over the entire study area would have been the ideal, the large number of samples made this impractical. The writers recognize that measurable changes can occur in a tidal inlet system during two months, however, no considerable storm activity ocurred. It is assumed that the broad pattern of sediment distribution remained generally stable within such a fair weather period.

RSA Calibration

Because of the visual uniformity of the samples, and the presumed narrow range of size parameter values, special attention was paid to reducing analytical error. A Modified Woods Hole Rapid Sediment Analyser (RSA) was used to determine size parameter values (Schlee, 1966; Nelsen, 1974). When the cumulative weight percent curve of a sample is traced onto the RSA roll chart, it records the cumulative weight percent against time. For the translation of time (in seconds) into size classes, the fall times of these sizes must be known. The factors governing the fall time of a particle in water is complex, and can vary from RSA to RSA. A technique described by Sandford and Swift (1971) essentially bypasses these variables. The mean grain sizes of a set of samples was measured by use of the RSA, and agin by use of a measured set of new 1/2 phi sieves. The fall time values of Schlee (1966) were used for the initial RSA run. Two mean grain size values were obtained for a sample and were plotted against each other on a graph. The resultant series of points, one point for each sample, fell close to a straight line. The equation for the line of regression through the points was then used to adjust the fall time values used for the initial RSA run, so that derived grain size parameter would conform with sieved values. These adjusted fall time values were then used to determine the weight percentages of each 1/2 phi size class for each sample. Parameters were calculated to 0.01 unit place. By this technique, RSA determined grain size parameters are calibrated against a well known standard technique (sieving).

GRAIN SIZE PARAMETERS

Mean Grain Size

Mean grain size distribution was mapped with a 0.10 phi contour interval (fig. 4). The terminology of Folk (1965) was used for verbal description of size and other sedimentary parameters derived from moment measures. Although these verbal descriptions refer to graphically derived parameters, values are close enough to moment measures to be meaningful for verbal usage. The majority of samples are very fine to fine sand (3.40 to 2.00 phi). While small areas of size variations, especially those resulting from one sample, must be looked at with some caution, some broad patterns of size distribution are apparent. These distinct mean grain size patterns are shown in figure 4 and are labeled areas A, B, and C.

Area A consist of mean grain sizes 1.56 to 2.80 phi which occur within Brigantine Inlet, Brigantine Channel and seaward from the inlet to a distance of about 0.8 mile from the inlet mouth. the 2.80 contour is the finest mean grain size contour which defines a concentric pattern of distribution around the inlet mouth. A close correlation is evident between the seaward limit of this area, as defined by the 2.80 phi contour, and the seaward limit of the ebb delta, as defined by the 10 foot contour (fig. 3). This concentric pattern of distribution is offset to the south, and a pronounced southward directed "spur" is nearly coincident with the axis of the seaward extension of the ebb channel as partially outlined by the 10 foot contour (fig. 3). A narrow area of 1.42 to 2.50 phi size sand occurs just seaward of Little Beach.

Area B generally consists of fine sand with a mean grain size of 2.80 to 3.40 phi. Mean grain size shows a general decrease with increased depth, and with increased distance from the inlet mouth. Within the northwest part of area B the relationship of mean grain size to depth is not as clear. The southern part of area B consists of an east northeast trending linear zone of very fine sand with a mean grain size of 3.00 to 3.40 phi.

Area C contains a wider range of mean grain sizes (0.63 to 2.95 phi) than do areas A and B. Mean grain size contours generally follow a general east northeast trend which is very similar to the trend of the depth contours (fig. 3). Nearshore, both mean grain size and depth contours are parallel to shore. No simple correlation between depth and mean grain size is apparent in area C.

The 2.80 phi contour, the finest mean grain size contour which is concentric around the inlet, also correlates with the break in slope of the delta, suggesting that the ebb current is primarily responsible for buildup of the delta.

Within Brigantine Channel, mean grain size contours follow a linear trend similar to that of the bathymetric contours. Data from intensive sampling have shown no direct correlation between mean grain size and depth. It may be expected that coarsest sediment sizes occur within deep scour troughs, such as the one adjacent to North Spit, because of the strong currents needed to form such troughs. However sediments within the trough are not noticeably different in size from those in the rest of the channel. This indicates that the very bottom of the channel is at present not undergoing active erosion, and may in fact be a site of deposition. The depths of these scour troughs may be the result of unusual conditions, such as a spring tide or storm surge coupled with an onshore wind. This would allow the pile up of a very large tidal prism within the lagoon. Subsequent rapid drainage of the lagoon during ebb tide could produce an unusually deep scour. Such a scour depression would be below the influence of more moderate ebb conditions existing during the time of sampling, and allow finer surficial sediments to build up to a point of equilibrium with present hydraulic conditions.

The mean grain size distribution within area A strongly suggests high energy current activity within Brigantine Inlet and Brigantine Channel relative to offshore areas. The restriction of coarser sand to the inlet and delta further suggests deposition of the sediment by currents within and issuing from the inlet. The progressive decrease of mean grain size of sediment increasingly distant from the inlet shows the decrease in velocity of the ebb current. Offset of the delta is caused by the deflection of the ebb flow issuing from Brigantine Inlet by the southward flowing longshore current. Sediments in the delta trough (fig. 3) are somewhat coarser than on the delta itself. The presence of a strong ebb current seaward of an inlet is characteristic of many inlets and has been termed an <u>ebb jet</u> (Price, 1963). A study measuring surface currents seaward of Brigantine Inlet has found that the ebb jet extends about 5000 feet southward from the inlet (Charlesworth, 1968). This distance correlates with the approximate position of the 2.80 phi contour within the ebb channel extension, the presumed limit of tidal influence.

The mean grain size distribution within area B shows a general decrease in size with distance from the inlet. Coarser sediment found in the northern part of the study area apparently indicates their proximity to the downdrift deflected ebb delta of Beach Haven-Little Egg Inlets immediately to the northeast.

Area C contains the coarsest sediment in the study area, along with the greatest variation in mean grain size. This indicates a relatively complex area in terms of the competency of the transporting medium. The general trend of the mean grain size contours, similar to those for depths, indicate a relationship between the two. Although there is no direct correlation between mean grain size and depth, there is a tendency for coarsest sediments to occur in the trough area. In an investigation conducted just seaward of the study area, Stubblefield et al. (1975) found coarsest sizes occuring in swales of the ridge and swale topography of the inner continental shelf, and described sediment transport as moving in a landward direction, transverse to the trend of the ridges and swales.

An area of material finer than 3.00 phi occurs as an east northeastern trending zone in the southern part of area B, which effectively separates the coarser sediments of areas A and B from those of area C. This indicates the isolation of the inlet transport system from that of the ridge and swale transport system. The relative coarseness of the material in area C may indicate a relatively high competency of the currents in this area or, more probably, that coarser material is available from a source seaward of the study area. The fine sediments separating area A and C indicate that, regardless of the relative competency of the transporting process operating within the area of ridge and swale topography, the bulk of these sediments, as well as the ridges themselves, are not actively moving into the inlet area.

Standard Deviation

Three areas which can be characterized by distinct patterns of standard deviation occur within the study area, and are labeled areas D, E and F (fig. 5). Standard deviation was mapped using a 0.10 phi contour interval.

Area D consists predominantly of very well to well sorted sediment (0.32 to 0.52 phi). These sediments are found within Brigantine Channel and Inlet, and in an area extending from the inlet to about 0.8 mile to the east. They become progressively closer toward shore to the south.

Area E occurs within the northeast part of the study area and contains samples with a standard deviation range of 0.50 to 0.90 phi. Most samples are moderately well (0.50 to 0.60 phi) to moderately (0.60 to 0.70 phi) sorted. Unlike the sorting of area D samples, the standard deviation of samples of area E do not show a decrease with decreasing depth and nearness to shore. In fact, some of the most poorly sorted samples of this area (greater than 0.80 phi) are found just offshore from Little Beach.

Area F consists of sediment which is well to poorly sorted (0.38 to 0.99 phi). The distribution pattern is characterized by closed contours which show a linear northeast southwest trend. A similar trend has been shown for both bathymetry and mean grain size (figs. 3 and 4). Although the most poorly sorted samples are generally found in swales, generally there is no direct correlation between depth and standard deviation.

The ebb delta of Brigantine Inlet is characterized by a linear transverse bar occuring at its northeast and east margins. This bar, which has been previously described in detail, occurs at a depth of four to six feet. Previous workers at Brigantine Inlet have postulated that this bar serves to protect Brigantine Inlet and the downcoast beach area from the direct attack by steep short period waves generated by northeast storms. Waves generated in the south, which dominate sediment movement during summer months, are generally low, long period waves with little energy (Charlesworth, 1968;

Lynch-Bloss and Kumar, 1976). This idea is valuable in explaining much of the standard deviation distribution in the study area. The sediments of area D are better sorted than those of area E because much of the high wave energy generated in the northeast is dissipated over the shallow depths of the transverse bar. An aerial photograph (taken in March, 1972) of Brigantine Inlet shows waves breaking at the seaward edge of the transverse bar and indicates its potential effectiveness in reducing the energy of those waves. The area of maximum sorting of sediment within the study area occurs within the "shadow" created by the transverse bar. Generally, only low energy southerly waves or much reduced northeasterly waves influence the sediment of area D (Lynch-Bloss and Kumar, 1976). Repeated reworking by ebb and flood tidal currents, even though it is an inefficient sorting process, contributes to the higher sorting of area D.

Within the channel and inlet, the very well sorted sediment (less than 0.30 to 0.40 phi) occurs within a narrow zone that approximately correlates with the mid-channel bar separating the ebb and flood tidal channels. Ludwick (1970) has postulated that in many tidal inlets, relatively closed sediment circulation cells form between the two mutually evasive ebb and flood currents. The null point between the two cells allows the deposition of sediment as a bar. This sediment is not static and continues to move back into the cells. The continual reworking of sediment on the mid-channel bar may account for the high degree of sorting observed. Very well sorted samples seaward of the inlet are restricted to nearshore areas and to the southern half of the ebb delta. Standard deviation in area D appears partially related to water depth. Seaward of the inlet, standard deviation increases with increasing depth.

Within area F, contours of standard deviation show an areal pattern similar to those of mean grain size and bathymetry. This suggests a relationship between morphology, grain size and sorting. Coarser, more poorly sorted sediments have a tendency to occur in swales; with finer, well sorted material on the ridges. This is only a generalized observation; no strong correlation is seen between standard deviation and depth. These trends, however, are similar to those reported by Stubblefield et. al. (1975). They describe fine moderately sorted sand occuring on the crests and flanks of ridges, with swales containing an admixture of coarse, poorly sorted sand and very fine, well sorted sand.

Charlesworth (1968) found a correlation between standard deviation and mean grain size for Brigantine Inlet, with coarse samples being the more poorly sorted. This study shows relatively independent behavior for the two parameters. Comparison of figures 4 and 5 shows that sorting does not appear to be dependent on mean grain size, and seems more to reflect the absence of relatively high energy waves from offshore and the absence of coarse material transported by them.

SKEWNESS

Skewness distribution was contoured with a 0.20 interval. For ease in comparison with Folk's classification, contours occur at odd-numbered values (e.g., 0.10, 0.30, 0.50, etc.).

Three broad fields of skewness distribution can be recognized, and have been labeled areas G, H, and I (fig. 6). Area G includes Brigantine Channel and Inlet, and an area extending about one mile east of the inlet and about three miles south from it. This area of positive skewness (generally 0.10 to 0.68) correlates well with area D (fig. 5), which consists of well sorted sediments. Area H, containing negatively skewed sediments (-0.10 to -0.85), includes an area northeast and seaward from the positively skewed sediments of area G. Area H is nearly coincidental with the area of moderately well to moderately sorted sediments of area E (fig. 5). Area I consists of negatively and positively skewed sediments (-0.85 to 0.71). Closed contours in this area trend to the northeast, showing a general relationship to bathymetry, mean grain size, and standard deviation (figs. 3, 4 and 5).

The negatively skewed samples of area H show a high percentage of bimodal samples. Computer plotted histograms show that the bimodal samples consist of a primary mode, which is characteristically 2.75 phi, and a secondary, much smaller mode of about 0.75 to 1.25 phi. It is the addition of the small coarser population which is responsible for the negative skewness of these samples. Apparently, almost all samples of area H have an addition of a coarser fraction, even though it may not show distinctly on histograms. Further evidence for this will be presented in the discussion of log-probability curves.

The dominant influence in the nearshore region of area H is longshore drift. Southwestward flowing longshore currents transport sediment downcoast from Beach Haven-Little Egg Inlets (Charlesworth, 1968). When this current interacts with the ebb current issuing from Brigantine Inlet, part of it is diverted seaward. This is similar to the "dynamic diversion" of Todd (1968). Part of it also enters Brigantine Inlet, carrying sediment into the inlet sedimentation system. The finer mode of 2.75 phi, which is transported by longshore drift, reflects the lack of available coarse sediment. Mean grain size on the beach decreases south of Beach Haven-Little Egg Inlets (McMaster, 1954) which indicates that coarse sediments are trapped in the inlet system making them unavailable for further downcoast transport (Charlesworth, 1968). The coarse tail of the curve, representing the addition of a small coarse fraction, is probably the result of offshore waves which carry some coarser material inshore from the continental shelf during storms and rework this sediment during times of quiet conditions.

Area I is characterized by areas of both negatively and positively skewed sediments which are related to the ridge and swale topography. These areas do not correlate directly with bathymetry, mean grain size or standard deviation, but show the same trends. It is probable that despite fairly intensive sampling of the area, the sediment dynamics which are reflected by the skewness distribution operate on too small a scale to be clearly discriminated by the sample density.

Area G is dominated by positively skewed sediments. Positive skewness appears atypical for areas dominated by dipolar flow. Dipolar flow characteristically transports all material finer than a certain critical threshold size and leaves behind the coarser fraction to form a generally coarse skewed population (Friedman, 1967). Negative skewness has been described for sediments of the inlets of the Cape Hatteras barrier chain (Duane, 1964), and the esturary of the Rhone River of France (Allen, 1971). However, Brigantine

Inlet is a sediment starved inlet, unlike most of the inlets and estuaries described in the literature. Relatively little sediment is added to the inlet system by the longshore drift at Little Beach. The result is that tidal ebb and flood currents serve to rework the existing sediments in the inlet, channel, and areas seaward of the inlet mouth. To these are probably added a fine component winnowed out from offshore sediments and carried into the inlet area by waves refracted by and breaking across the ebb delta. Since the tidal currents do not leave any coarse fraction as a lag deposit because of the fine nature of the sediments, the area within the "shadow" of the ebb delta is positively skewed.

Log-Probability Curves

A statistically normal curve will plot as a straight line on probability paper. However, sediment grain size distribution curves characteristically yield a curve with three straight line segments connected by two shallow truncation points. This suggests that the samples are a mixture of three log normally distributed populations. The presence of these populations has been ascribed to their differing modes of grain transport (Visher, 1969). The coarsest part of the total distribution is the population representing grains transported by traction (population C - of Visher, 1969), the finest part is transported by suspension (population B), and the middle part is transported by saltation (population A). Near coastal regions, the saltation population often contains two components (subpopulations A and A'), which in tidal areas are caused by ebb and flood currents.

Log-probability curves can characterize a sediment sample as to the hydrodynamic forces acting upon it. A study of the Altamaha estuary, Georgia, has shown how a source population (river) with a characteristic curve becomes modified as the sediment is progressively affected by coastal processes (Visher and Howard, 1974). Curve shapes can be used to partially infer sedimentation mechanisms, although the specific percentages of the populations in each grain transport mode have no genetic significance (Visher, 1969). Curve dissections were constructed for different sediment distributions in the study area, and characteristic curves were found for many sedimentary environments.

Log-probability curves were plotted using weight percentages at 1/2 phi intervals. This was often an insufficient interval to provide more than two points through which to draw a population line. To test the accuracy of a line drawn through only two points, three samples were selected which had differing curve slopes and were from presumably different hydrodynamic environments. The curves were remeasured at 1/4 phi intervals. When these dissected curves, plotted at 1/2 phi and 1/4 phi intervals, were compared, it was found that 1/2 phi intervals accurately portrayed the position of the inflection point and the general shape of the curve (fig. 7).

The points on the curves (figs. 7, 8, 9, and 10) are located at 0.75 phi, 1.25 phi, etc. because these sizes are the midpoints of the 1/2 phi size classes required by the computer program used for moment measures.

Brigantine Channel sediments characteristically show the absence of traction (C) and suspension (B) populations, and the presence only of a saltation population (A) (fig. 8). there is often a shallow truncation point within the saltation population, which is characteristic of channel sands and represents the differing competency of flood and ebb currents (Visher, 1969). Although ebb surface currents are strongest at Brigantine Inlet, bottom currents are strongest at flood (Lynch-Bloss, 1976). It is therefore probable that the coarser saltation component is the one deposited by flood currents. Samples from the ebb delta and its channel show a distribution similar to those from Brigantine Channel, with only a two component saltation population. The characteristic shape of these curves, showing an upward directed inflection point, indicates that the coarser component is better sorted than the finer component. This results in the positive skewness observed in the sediments of this area (area G, fig. 6).

In the area to the northeast of the ebb delta (skewness area H, fig. 6) samples characteristically have a saltation population with one or two components (A), and a traction population (C) which is less well sorted than the saltation population and averages about 10% of the total sample weight (fig. 9). This represents the small coarse "tail" of area H sediments and is responsible for their negative skewness. Fine grained sediments from just north of the ridge and swale topography (area B, fig. 4) show a similar distribution, but the traction population amounts to only about 2% of the total weight.

Samples from the mouth of Brigantine Inlet show a grain size distribution similar to those for the Channel, and consist only of a saltation population. Curves from samples located in the ridge and swale topography, corresponding to skewness area I (fig. 6), show dramatic changes in curve characteristics within relatively small areas. This no doubt indirectly reflects local topography. Characteristic curves have not been directly correlated to bathymetry, but it appears that curve shapes, as well as the percentages of sizes carried by the different transport modes, may depend on the sample's position on the crest or flank of a ridge, or within a swale. The strongly bimodal character of some of the study samples, generally located in the swales, can be seen by curves with multiple inflection points (fig. 10) and also shows the small-scale complexity of transport processes in this area. Stubblefield et. al. (1975) in their study of the ridge and swale topography about 30 miles seaward of Brigantine Inlet have described a mechanism of sediment transport. During intense storms fine and medium sand is carried upslope onto the ridge crests in suspension. Subsequently, during milder weather the fine sand is winnowed out and transported to downslope where it is added to the coarse sand in the troughs. The coarse sand remains in the troughs as a lag deposit.

CM Patterns

CM patterns have been found to be a useful technique in discriminating different modes of sediment transport. This technique involves plotting the grain size of the first coarsest percentile (C) against the grain size of the fiftieth or median percentile (M). This point is then compared with characteristics developed from numerous samples representing differing modes of transport (Passega, 1964).

Those study area samples having a C value larger than 1.35 phi show transport by bedload movement (Passega, 1964). This bedload transport is accomplished by a combination of graded suspension and rolling. Samples having a grain size for C smaller than 1.35 phi show transport by graded suspension alone.

Selected samples from the study area were analysed using CM parameters to determine if regions of bedload transport could be distinguished from those of graded suspension transport. Allen (1971) used such an analysis to separate those areas affected predominantly by tidal flows (bedload transport) from areas affected predominantly by wave action (graded suspension transport). The samples selected here were those from parts of the study area which differ in bathymetric expression and other sedimentary parameters. The CM values of these samples were plotted to determine if values for these different areas, representing differing sediment dynamic conditions, fell into distinct fields (figs. 11 and 12). Figure 11 shows no clear separation between samples taken from the inlet and ebb delta, the nearshore area off South Spit, and the ridge and swale topography. Similarly, no separation could be made between samples from the delta, the offshore area northeast of the inlet, and the nearshore area off Little Beach (fig. 12). These areas were selected as representing the presumed greatest range of sedimentary environments.

These results show that CM plots are not useful in distinguishing between sedimentary environments in the study area. The reason for this apprently lies in the atypically fine-grained nature of the sediment. It has already been described how Beach Haven-Little Egg Inlets trap the coarsest fraction of the sediment transported down the coast by longshore current. This creates sediment in which the C value is not determined by the competency of the mode of transport, but by the source material. This accounts for the observation that many of the samples appear to have been moved by graded suspension even though many may have actually been moved by bedload transport.

SUMMARY AND DISCUSSION

Mean grain size distribution and submarine morphology show Brigantine Inlet to be tidal dominated. Mean grain size values are 1.56 to 2.80 phi and decrease in size in a generally concentric pattern seaward from the inlet mouth and indicate deposition by ebb currents. The extent of the concentric pattern correlates with the seaward morphologic limit of the broad platform seaward of the inlet mouth, and shows it to be an ebb delta. The delta is offset to the south, as is the channel which extends across it. This channel is probably continuous with the southern trough in Brigantine Channel and is assumed to be an ebb channel, because mean grain size within the channel is coarser than within the flanking delta.

The ebb delta is offset to the south as a result of the deflection of the ebb tidal jet by a southward flowing longshore current near Little Beach. This "dynamic diversion" deflects the ebb jet to the south and deflects the longshore current around the seaward margin of the ebb delta. The loss of competency of the ebb jet as it passes into relatively more open water after leaving the more restrictive inlet is primarily responsible for the formation of the delta. It is the interaction of the longshore and ebb tidal currents that further allows the development of the transverse bar, which occurs on the northeastern and eastern margin of the delta.

The nearby source area for the inlet sediments is Little Beach; the sediments are transported by the longshore current which flows southwestward from Beach Haven-Little Egg Inlets. Probability curves of sediments to the northeast and east of the delta show them to consist mainly of a dominant fine, relatively well sorted component, and a minor coarser, poorer sorted one. It is the addition of the coarser component to the relatively symmetrically distributed finer fraction that accounts for the negative (coarse) skewed and moderately sorted nature of these sediments. The finer component is undoubtedly transported from upcoast areas by longshore drift, while the coarser fraction may be wave transported sediments from the inner continental shelf.

The sediments just seaward of Little Beach show a mean grain size of about 2.0 to 2.5 phi, only moderate to poor sorting, and negative skewness. These sediments are atypical for other sediments so close to the inlet mouth and are evidence supporting the idea that sediments are transported into the inlet area by longshore drift. All other sediments around the delta are noticeably finer than the inlet sediments, and because only a negligible amount of sediments are presumed to enter the inlet from the lagoon, which is fed only by a few low energy rivers from the land, this upcoast source appears as the only reasonable one.

The Beach Haven-Little Egg Inlet system has been studied intensively by Charlesworth (1968), who concludes that the coarsest fraction of the sediments carried into the inlets is effectively trapped and removed from further downcoast transport. Beach grain size and mineralogical studies by McMaster (1954) have also shown this. The results show that Brigantine Inlet is a starved inlet and receives only a reduced finer sediment supply. This accounts for the unexpectedly fine nature of the inlet sediments.

Northeast generated storms are a major factor in sediment transport during the winter months. The transverse bar on the margin of the ebb delta serves to protect the inlet and a downcoast shadow zone from the full destructional effects of these waves. It is these waves which bring into the inlet some of the finest fraction of the offshore sediments and account for the positive skewness of the inlet sediments, atypical for other inlet and estuary systems. The extent of the area of positive skewness approximately coincides with the 15 foot contour and lies within the shadow zone of the ebb delta and transverse bar.

Atypical also for tidal dominated inlets is the low standard deviation of the Brigantine Inlet, Channel, and delta sediments (less than 0.30 to 0.50 phi), which indicates a high degree of sorting. Three factors account for this high degree of sorting. The low influx of new sediment into the starved inlet system allows existing sediment to be reworked back and forth by tidal ebb and flood currents. Tidal currents alone are otherwise inefficient sorting agents, when given a continuous influx of new sediment (Allen, 1971). Another factor is that the transverse bar protects the inlet area frm northeast storm waves which would carry new, relatively poorly sorted material into the inlet. The third factor involves the idea that as a part of the southwestward moving longshore current is diverted seaward of the ebb delta, it eventually passes south of the influence of the ebb jet and moves inshore. Part of this current recurves and moves up the coast along South Spit and moves into the inlet during almost all of the tidal cycle

(Lynch-Bloss and Kumar, 1976). The effect of this current system is to create a partially closed sediment circulation system, allowing further reworking of sediments. A further effect is to carry sediment for the northeastward and seaward progradation of South Spit. The lobate forms which occur adjacent to South Spit (fig. 3) may be the point where this recurved current meets the shore.

The coarsest sediments in the study area are found near Brigantine Inlet and in the area of ridge and swale topography. These two areas are effectively separated from each other by a northeast trending zone of fine sand (mean grain size 3.00 to 3.40 phi). This implies that the area of ridge and swale topography is essentially isolated from the inlet system and contributes little sediment to it. The distributions of mean grain size, standard deviation and skewness are more variable here than elsewhere in the study area, and show trends which parallel the trends of the topography. However, good correlation between these parameters and depth cannot be made.

Within the ridge and swale area, sedimentary parameter values vary considerably over small distances. Some sediments are fine grained (mean of 2.5 to 3.0 phi) and consist of a single saltation population with positive skewness and a low standard deviation. Some samples show a mean grain size of 0.6 to 1.0 phi (coarse sand) which consists of a bimodal population, part of which shows traction grain transport and part of which shows saltation transport. This yields a high standard deviation.

In a study of the ridge and swale topography eastward of the study area, Stubblefield et. al. (1975) described upslope transport of sand to the ridge crests during storms, and downslope winnowing of finer material during more moderate conditions. Coarse sand exposed in the troughs is mixed with fine sand winnowed from the ridges. In this study area, the coarsest material appears confined to the swale areas and is mixed with a fine component, showing that these observations are not inconsistent with the proposed idea of upslope transport.

The similarity of trends between the ridge and swale topography and the sedimentary parameters show submarine morphology and recent sedimentation are interrelated. This area is perhaps most severly affected by fall hurricanes originating from the south and southeast, and is also modified by northeast storms and long period waves generated in the south. The relative importance of these different factors cannot be assessed with the available data. Southward generated storms might be expected to cause migration of ridge and swale sediments and structures up towards the inlet, but this is not apparent. It is possible that the ridges and swales are essentially stable features and that relatively little of the surface veneer of sediment is continuously in transport. The southward flowing ebb current and the longshore current, as it moves inshore from the seaward margin of the ebb delta, no doubt prevents or diverts the movement of this sediment to the north.

SOUTH SPIT AREAL STUDY

Once the submarine sediment distribution patterns of the Brigantine Inlet area were determined, a detailed reconnaissance of South Spit was undertaken to examine the sedimentary processes responsible for its formation. These processes are related to the offshore sedimentation dynamics described in the previous part of this study.

Geomorphology

South Spit (fig. 3) is a flat sandy platform which is largely innundated during high tide. Dunes occur in the backbeach area bordering the lagoonal marsh (fig. 13). At its northernmost margin, the slope of the nearshore bottom area is very shallow. Slopes along the beach increase to the south of the study area. Remnants of numerous beach and dune lines, shown on aerial photographs of 1969 and 1972, document the nature of the growth of the spit (fig. 13). This shows that the spit has prograded both northward into the inlet, and eastward into the ocean. The pattern of truncation of old beach ridges and the addition of new ones shows growth very similar to that described by Oertel (1975), illustrating the progressive narrowing of many Georgia inlets in response to a reduced water flow through the inlets. This reduced water flow relates to a reduction of the tidal prism because of lagoon infilling.

On the lagoon side of South Spit and Brigantine Island, irregular outlines of washover fans can be seen (fig. 13). Many of the older washover fans are covered by grass. The existence of a great many washover fans on Little Beach suggests that Little Beach has been more severly affected by storms than South Spit, apparently because it is unprotected by the ebb delta. It is clear that landward transport of sediment does occur during storms.

Field Work and Sampling

Field work was conducted in October, 1972, while the beach was still subject to moderate summertime wave and wind conditions. At least one sample wa-03ollected for each of the observed facies and types of surface sedimentary structures (ripples) observed (fig. 14a). This was done to determine if any changes in texture of the sediment could be related to these features and to the offshore sediments. In an attempt to maintain uniformity of sedimentological units, only the uppermost few millimeters of sediment were sampled (Hayes, 1969). Sedimentary structures observed on the surface of South Spit were also studied in cross-section, by the use of trench cuts and box cores. This was done to determine if hydraulic conditions over the spit had remained stable. Also, any change in the vertical sequence of sedimentary structures might represent lateral change in facies position caused by the rapid increase or decrease in the rate of spit growth during the time period immediately preceding the sampling.

Facies

Surface sediments were divided in three facies units based upon color, type of sedimentary structure, presence of algal mats, and degree of compaction. These facies are closely associated with surface morphology (fig. 14a, table 1). The sand facies (plates 1, 2) occurs on topographic highs and along the shore face; the sandy "mud" facies (plates 3, 4) occurs inland slightly lower than the sand facies; and the "mud" facies (plate 1) occurs at the lowest elevations. Clean white sand can be seen encroaching over the "mud" facies in plate 1, and over the sandy mud facies in plate 5.

TABLE 1. South Spit Sediment Facies

Facies	Color	Sedimentary Structures	Algal Mats	Compaction	Other Features
Sand	Clean white	small-scale ripples; laminae on steep slopes	none	hard to moderately hard	
Sandy "mud"	light gray-green	small-scale ripples	none	moderately soft	
"Mud"	dark gray-green	none	extensive	soft (high water content)	mats peel up in places

"Mud" is defined here as sand and organic material (less than 4.0 phi).

The "mud" facies consists of sand, with a small fine fraction (less than 4.0 phi) of dark organic material. The term "mud" refers to the general appearance and consistency of the sediment, and is not a true description of a size classification. The organic material is derived from partially decomposed algae. In poorly drained parts of the spit, algal mats accumulate. Nutrients necessary to support this algal growth are apparently supplied from the lagoon. The uptake of these land derived nutrients by marsh grass would serve to effectively concentrate them and make them available when the plants decayed. The presence of these organic particles and mats implies a low sedimentation rate.

Sediment Textures

Mean grain size (fig. 14b) shows a generally uniform distribution, with finer sizes concentrated towards the center of the spit and coarser sizes near Brigantine Channel. The narrow range of mean grain sizes (2.13 to 2.40 phi) is similar to that of samples in the adjacent offshore area. The distribution is the result of tidal drainage patterns across the spit surface. One of the coarsest sizes (2.14 phi at station 2) is found near a major drainage channel where current velocities would be suspected to be relatively rapid. Another coarse size (2.13 phi at station 3) occurs in the clean white sand overlying a sandy "mud."

The best sorting occurs near shore on the channel and inlet sides of the spit (fig. 14c). The range of standard deviation values is small (standard deviation of 0.37 to 0.48 phi), with all samples being well sorted and similar to the offshore sediments. Standard deviation values and mean grain sizes show that the source sand for spit buildup is derived from areas immediately offshore.

Most skewness values show a nearly symmetrical size distribution (-0.07 to 0.10) (fig. 14d). The distribution of negatively skewed (-0.17) and positively skewed (0.18 to 0.32) samples do not follow a regional pattern. The presence of symmetrically and negatively skewed values is noticeably different from the dominant positively skewed nearby offshore sediments. Negative values probably reflect the winnowing action of tidal drainage (sample 2) or backwash winnowing on the relatively steep beach slope (sample 12). In one area (sample 5) algal mats are evidence for a slow rate of sediment accumulation. It is the wash and backwash of tidal currents over a long time period that may account for the many symmetrically skewed samples. Positively skewed samples do not have a regional distribution, but may represent localized areas of most active sediment accumulation. The sediment source for the spit is the positively skewed sediments just offshore from the spit. These sediments are transported onto the spit platform and are reworked by subsequent tidal flooding and drainage operating over most of the spit surface. The finer fraction is probably preferentially winnowed out, creating the symmetrically and negatively skewed sediments observed. The degree of winnowing is dependent on the velocity of the tidal current, which in turn is dependent on local slope and general topography.

The study area was revisited for one day, during late November, 1972, during a time of cold temperatures and high offshore winds. Windblown sand could be seen sheeting across the spit platform, practically obscuring the surface ripples. This windblown sand no doubt affects the distribution of sand on the platform, but its contribution is probably small.

Sedimentary Structures

A small ridge and runnel system occurs near the northern tip of the spit. The traces of old ridges and runnels can be seen on the 1972 aerial photograph of Brigantine Inlet.

Ridges and runnels are formed on flat platforms by long period waves (King, 1959), and may represent a major mechanism of spit platform accretion, as occurs at Fire Island, New York (Wolff, 1972).

Water formed ripple marks are almost universally present on the surface of the spit platform. Those few areas without ripples are those with the greatest accumulation of algal mats (plate 1), remnants of sand sheets stabilized by beach grass, and back dunes. Bedforms range from lower flow regime, low energy, straight crested ripples to upper flow regime planar and antidune laminae (terminology from Simons et. al., 1966). All bedforms have a small amplitude, 2 cms. or less, which is the result of the shallow water depth over the platform during high tide.

Ripples, representing lower flow regime conditions, are by far the most common surface sedimentary structures. They are restricted to areas of shallow slope at the interior and the northern end of the platform. Ripples are usually asymmetrical in cross section, indicating formation by a undirectional current flow which flows from the spit platform margins. Ripples with straight to slightly undulating crest lines are the most common (plate 4) and indicate low energy conditions. Flat topped ripples (plate 4) are developed at flood tide and are sheared off by the retreating waters at ebb. Within drainage channels, linguloid ripples can be seen, and represent higher energy flow conditions than the straight crested types (plate 3). Linguloid ripples were observed to form during ebbing of water from the channels.

Along the seaward slope of South Spit, upper flow regime structures were observed. They are apparently directly related to the increased slope of the beach and the resulting increased velocity of wave backwash. Planar flow structures can be seen in cross section by the segregation of dark minerals into distinct laminae (plate 2). Within this area, small standing waves were observed during the backwash of waves. The segregation of dark minerals also forms broad bands across the surface of the beach where the standing waves were observed (plate 5).

Trench cuts and box cores showed no noticeable vertical change in the type of sedimentary structures (plates 2, 6). This indicates that for the time period immediately preceding the time of the study, the sedimentological environment had remained stable.

Discussion

The facies observed on South Spit are the result of the accumulation of biogenic organic material, which is related to the completeness of tidal drainage. This is in turn directly related to topography. The general mechanism of the buildup of the spit platform surface can be seen by examples of marginal clean white sand encroaching upon the more interior organic sand ("mud") facies. Some areas of poor drainage have a continuous accumulation of algal mats, which implies a low sedimentation rate. The poorly drained topographic lows are the result of as yet incomplete sediment infilling as the spit has prograded.

Textural analysis reveals that the sediment population is similar to the areas immediately offshore, in terms of mean grain size and standard deviation. The distribution of skewness values does not have a clear regional significance. However, symmetrically and negatively skewed values appear related to localized hydraulic conditions on the spit itself. Sedimentary structures on the spit surface also indicate low energy conditions during and immediately preceding field work.

Data for South Spit is consistent with the sediment dynamics detailed for the offshore area. The spit platform is built by a series of bars gradually welded to the spit margin to form ridges and runnels. This pattern can be seen on aerial photographs and in the field, and is probably accomplished by refraction of the long period waves. The spit appears to be prograding eastward and northward. Sand accumulation on the landward side is accomplished by the gradual infilling of troughs between the beach and bar ridges, and by storm related washover.

CONCLUSIONS

Morphologically, Brigantine Inlet has the general character of an ebb-tidal inlet. The sediment source for the inlet, channel, and delta is from material carried into the system by part of a southwest flowing longshore current seaward of Little Beach. The interaction of this longshore current with the ebb jet issuing from Brigantine Inlet allows the deposition of a transverse bar at the northeast margin of the ebb delta. Longshore and ebb tidal current interaction diverts part of the longshore current around the seaward margin of the ebb delta and diverts the ebb channel, and the delta sediments deposited by them, to the south.

Because much of the coarse fraction transported southwest by longshore drift is trapped in the large Beach Haven-Little Egg Inlets system immediately to the northeast, Brigantine Inlet receives only a small supply of relatively fine sediment. The ebb delta and transverse bar serve to protect the inlet-delta area from the full effects of northeast generated storms. The relatively quiet water conditions landward of the delta and transverse bar, together with a low rate of sediment influx into the area, create atypically well sorted sediments. Positive skewness of this sediment is attributed to fine sediments from the offshore zone which are carried by waves carried over the transverse bar. The area northeast of the delta consists of bimodal sediments, part of which can be attributed to downcoast longshore transport and part of which (coarser) come from wave transported offshore sediments. Sediments of the ridge and swale topography are more typical of inner shelf sediments than are those from the inlet-delta area, and their textural parameters are related to bathymetry. Little sediment from the area of ridge and swale topography is transported into the inlet area.

Both South Spit and Little Beach have prograded into the inlet within the last 20 years. Based upon textural analysis of bottom sediments, there has not been a contemporaneous scouring and deepening of the inlet. This implies a reduced water prism in the lagoon area, or the opening of a nearby inlet. Surface morphology, sedimentary structures, and sediment distribution of South Spit show that it is continuing to prograde to the north and northeast under low energy conditions. The progradation is accomplished by the welding of ridges to the shore by refracted waves. Infilling of depressions between successive ridges is gradually accomplished by encroachment of a sand sheet migrating from the seaward spit margin. Sediments of South Spit are very uniform and are similar to adjacent offshore sediments.

The sediment distribution of the study area is consistent with the hypothesis that South Spit is part of a downdrift-offset inlet formed by a local reversal of a portion of the longshore current which carries sediment northeast along the shore of South Spit. Textural analysis shows that this sediment must mostly come from recycled inlet material rather than from sediment seaward of the ebb delta or from the south.

This study, which describes an essentially natural inlet system, is potentially useful in determining the sediment response to any man-made alteration in Brigantine Inlet, or to similar, more controlled inlets to the south. The sediment dynamics of this sediment starved, vertically homogeneous inlet can also be contrasted to more typically estuarine systems, with abundant sediment, which have been the subjects of most active research in the past.

ACKNOWLEDGMENTS

The writers wish to thank George Halisi-Kun of the New Jersey Bureau of Geology and Topography, Manfred Wolff of Hofstra University, and Danial Habib of Queens Collge for their critical review of the manuscript. Dr. Halasi-Kun and the staff of the Bureau have also been instrumental in making the offshore samples and associated data available to us. Anthony Cok of Adelphi University made the Rapid Sediment Analyser available, and was helpful with suggestions regarding its calibration and proper use. Thanks are also extended to Donald Swift of NOAA who made the work of Dr. Cok known to us.

REFERENCES CITED

Allen, G. P., 1971, Relationship between grain size parameter distribution and current parameters in the Gironde Estuary (France): Jour. Sed. Petrology, V. 41, p 74-88.

Charlesworth, L. J., 1968, Bay, inlet and nearshore marine sedimentation: Beach Haven-Little Egg Inlet region, New Jersey: Ph.D. dissert., Univ. Michigan, 614 p.

Donahue, J., R. Allen, and B. Heezen, 1966, Sediment size determining profile on the continental shelf of New Jersey: Sedimentology, v. 7, p 155-159.

Duane, D. B., 1964, Significance of skewness in recent sediments, western Pamlico Sound, North Carolina: Jour. Sed. Petrology, v. 34, p. 864-874.

Folk, R. L., 1965, Petrology of sedimentary rocks: Univ. of Texas Press, Austin, 159 p.

Folk, R. L., and W. C. Ward, 1957, Brazos River bar, a study in the significance of grain-size parameters: Jour. Sed. Petrology, v. 27, p. 3-27.

Frank, W. M., and G. M. Friedman, 1973, Continental-shelf sediments off New Jersey: Jour. Sed. Petrology, v. 43, p. 224-237.

Friedman, G. M., 1967, Dynamic processes and statistical parameters compared for size frequency distribution of beach and river sands: Jour. Sed. Petrology, v. 37, p 327-354.

Hall, J. A., 1962, Surf climate at three selected U.S. Coastal locales--Atlantic City, New Jersey; Hillsboro Inlet, Florida; Yagunia Beach, Oregon: The Annual Bulletin of the Beach Erosion Board, U.S. Army Corps of Engineers, Washington, D.C., v. 16, p. 24-35.

Hayes, M. O., 1969, Erosion zone, northern Plum Island, in Hayes, M. O., ed., Coastal Environments: Northeast Massachusetts and New Hampshire: Field trip guide, eastern section Soc. Econ. Paleontologists and Mineralogists, p. 36-42.

Hayes, M. O., E. H. Owen, D. K. Hubbard, and R. W. Abele, 1973, The investigation of form and process in the coastal zone: in Coates, D. R., ed., Coastal Geomorphology, Proceedings of Third Ann. Geomorphology Symposium Series, State University Press, Binghamton, New York, 404 p.

Inman, D. L., and B. M. Brush, 1973, The coastal challenge: Science, v. 181, p. 20-32.

King, C.A.M., 1959, Beaches and coasts: London, Edward Arnold, 570 p.

Kraft, J. C., 1971, Sediment facies patterns and geologic history of a Holocene marine transgression: Geol. Soc. America Bull., v. 82, p. 2131-2158.

Kumar, N., 1973, Modern and ancient barrier sediments: New interpolation based on stratal sequence in inlet-filling sands and on recognition of nearshore storm deposits: Annals of New York Academy of Science, v. 222, art. 5, p 245-340.

Lucke, J. B., 1934, A study of Barnegat Inlet, New Jersey, and related shore phenomena: Shore and Beach, v. 2, p 45-94.

Ludwick, J. C., 1970, Sand waves and tidal channels in the entrance to Chesapeake Bay: Va. Jour. Sci., v. 21, p 178-184.

Lynch-Bloss, M. A., 1976, Currents and sediment migration in Brigantine Inlet, New Jersey, in Halasi-Kun, G. and K. Widmer, eds., Proceedings of University seminar on Pollution and Water Resources (selected papers on special problems in ocean engineering), v. 7, (1972-1974): N. J. Bur. Geol. Topo. Bull. 75-A, p 106-134.

Lynch-Bloss, M. A., and N. Kumar, 1976, Evolution of downdrift-offset tidal inlets: a model based on the Brigantine Inlet system of New Jersey: Jour. Geology, v. 84, p 165-178.

McMaster, R. L., 1954, Petrography and genesis of New Jersey beach sands: State of New Jersey Dept. of Conservation and Economic Development, Bull. 63, Geologic Series, 239 p.

Milliman, J. D., and K. O. Emery, 1968, Sea levels during the past 35,000 years: Science, v. 162, p 1121-1123.

Nelsen, T. A., 1974, An Automated Rapid Sediment Analyser (ARSA): N.O.A.A. Technical Memorandum ERL AOML-21, U.S. Dept. Commerce, preliminary report 26 p.

Oertel, G. F., 1972, Sedimentary transport of estuary entrance shoals and the formation of swash platforms: Jour. Sed. Petrology, v. 42, p 857-863.

____1975, Post-Pleistocene island and inlet adjustment along the Georgia coast: Jour. Sed. Petrology, v. 45, p 150-159.

Oertel, G. F., and J. Howard, 1972, Water circulation and sedimentation at estuary entrances on the Georgia coast: in Swift, D.J.P., D. B. Duane, and O. H. Pilkey, eds., Shelf Sediment Transport: Process and Pattern: Dawden, Hutchinson and Ross, Stroudsburg, PA, 656 p.

Passega, R., 1964, Grain size representation by CM patterns as a geological tool: Jour. Sed. Petrology, v. 34, p 830-847.

Pettijohn, F. J., P. E. Potter, and R. Siever, 1973, Sand and Sandstone: Springer-Verlag, New York.

Plusquellec, P. L., 1966, Coastal geomorphology and change of an area between Brigantine and Beach Haven Heights, New Jersey: unpubl. Master's thesis, Univ. Ill., 67 p.

Price, W. A., 1963, Patterns of flow and channeling in tidal inlets: Jour. Sed. Petrology, v. 33, p 279-290.

Rittschof, W. F., 1976, Coastal geomorphology of Brigantine Inlet, New Jersey: history and prediction, 1877-1977, in Halasi-Kun, G. and K. Widmer, eds., Proceedings of University Seminar on Pollution and Water Resources (selected papers on special problems in ocean engineering), v. 7, (1972-1974): N.J. Bur. Geol. and Topo. Bull. 75-A, p 73-105.

Sandford, R. B., and D.J.P. Swift, 1971, Comparison of sieving and settling techniques for size analysis, using a Benthos Rapid Sediment Analyser: Sedimentology, v. 17, p 257-264.

Schlee, J., 1966, A modified Woods Hole Rapid Sediment Analyser: Jour. Sed. Petrology, v. 36, p 403-413.

Simons, D. B., E. V. Richardson, and C. T. Nordin, Jr., 1966, Sedimentary structures generated by flow in alluvial channels: in Middleton, G. V., ed., Primary Sedimentary Structures and Their Hydrodynamic Interpretations: Soc. Econ. Paleontologists and Mineralogists, spec. publ., no. 12, Tulsa, 265 p.

Stubblefield, W., J. Lavelle, D.J.P. Swift, and T. F. McKinney, 1975, Sediment response to the present hydraulic regime on the central New Jersey shelf: Jour. Sed. Petrology, v. 45, p 337-358.

Swift, D.J.P., 1969, Inner shelf sedimentation: process and product: in Stanley, D. J., ed., The New Concept of Continental Sedimentation, p DS-4-1 to DS-4-46.

Todd, T. W., 1968, Dynamic diversion: influence of longshore current-tidal flow interaction on chenier and barrier island plains: Jour. Sed. Petrology, v. 38, p 734-746.

U.S. Army Corps of Engineers, 1959, Shore of New Jersey-Barnegat Inlet to Cape May Canal: Beach Erosion Control Study: 86th Congress, 1st Session, House Doc. 208.

Visher, G., 1969, Grain size distribution and depositional processes: Jour. Sed. Petrology, v. 39, p 1074-1106.

Visher, G., and J. Howard, 1974, Dynamic relationship between hydraulics and sedimentation in the Altamaha Estuary: Jour. Sed. Petrology, v. 44, p 502-521.

Wicker, C., 1965, Computation of tides and currents, in Wicker, C., ed., Evaluations of Present State of Knowledge of Factors Affecting Tidal Hydraulics and Related Phenomena: Rept. no. 3, U.S. Army Committee on Tidal Hydraulics, CE, 251 p.

Wolff, M. P., 1972, Growth and migration of digitate spits (April-September, 1971) at Democrat Point, Fire Island, Long Island, New York: An example of a naturally occurring modified sanitary landfill system (abs): Geol. Soc. America, N.E. Sec. Mtg., Abs. with Programs, vol. 4, no. 1, p 53-43.

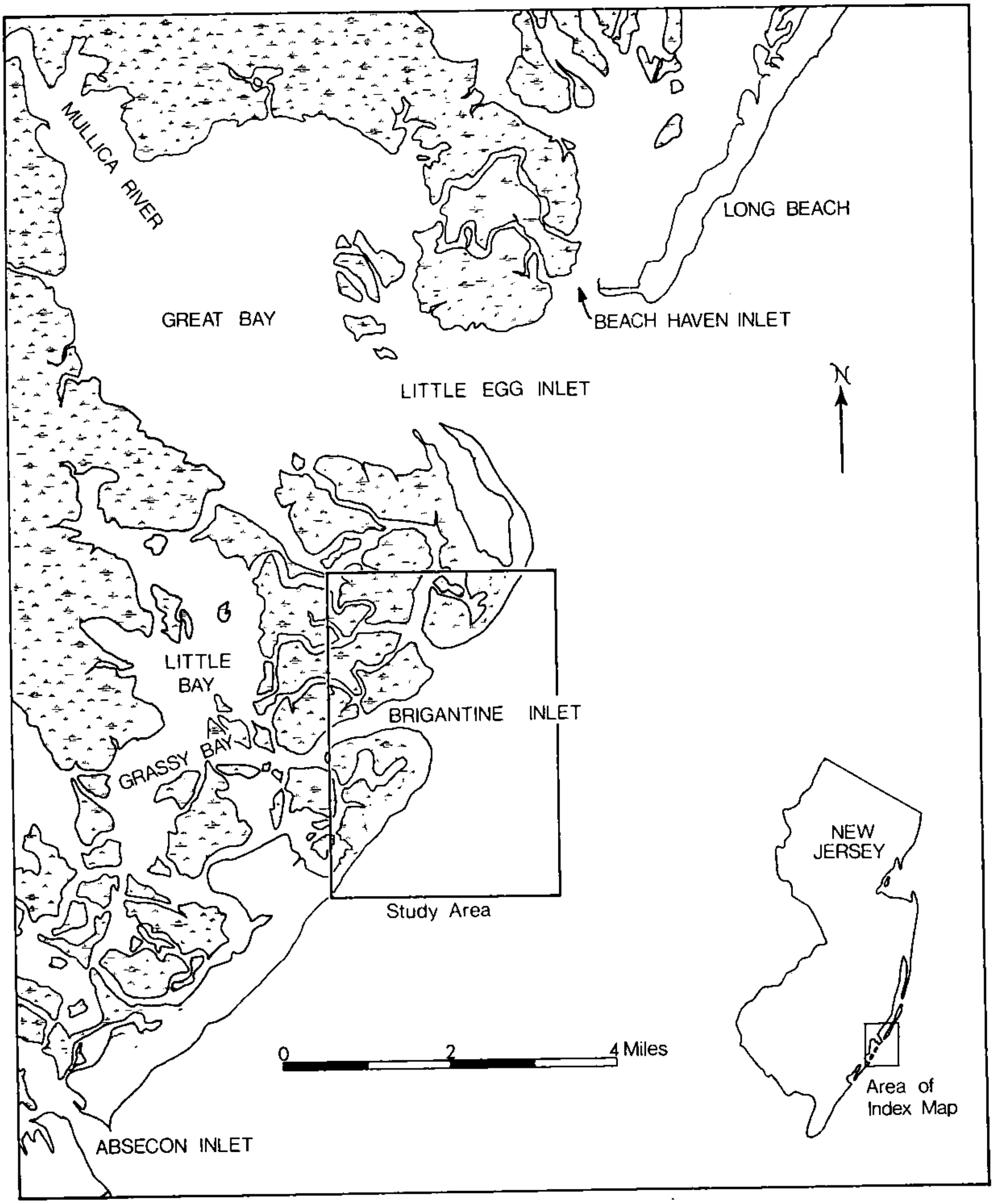


Figure 1. Index map of a part of the coast of southern New Jersey. The map is modified from U.S. Coast and Geodetic Survey Chart No. 826-SC (1961).

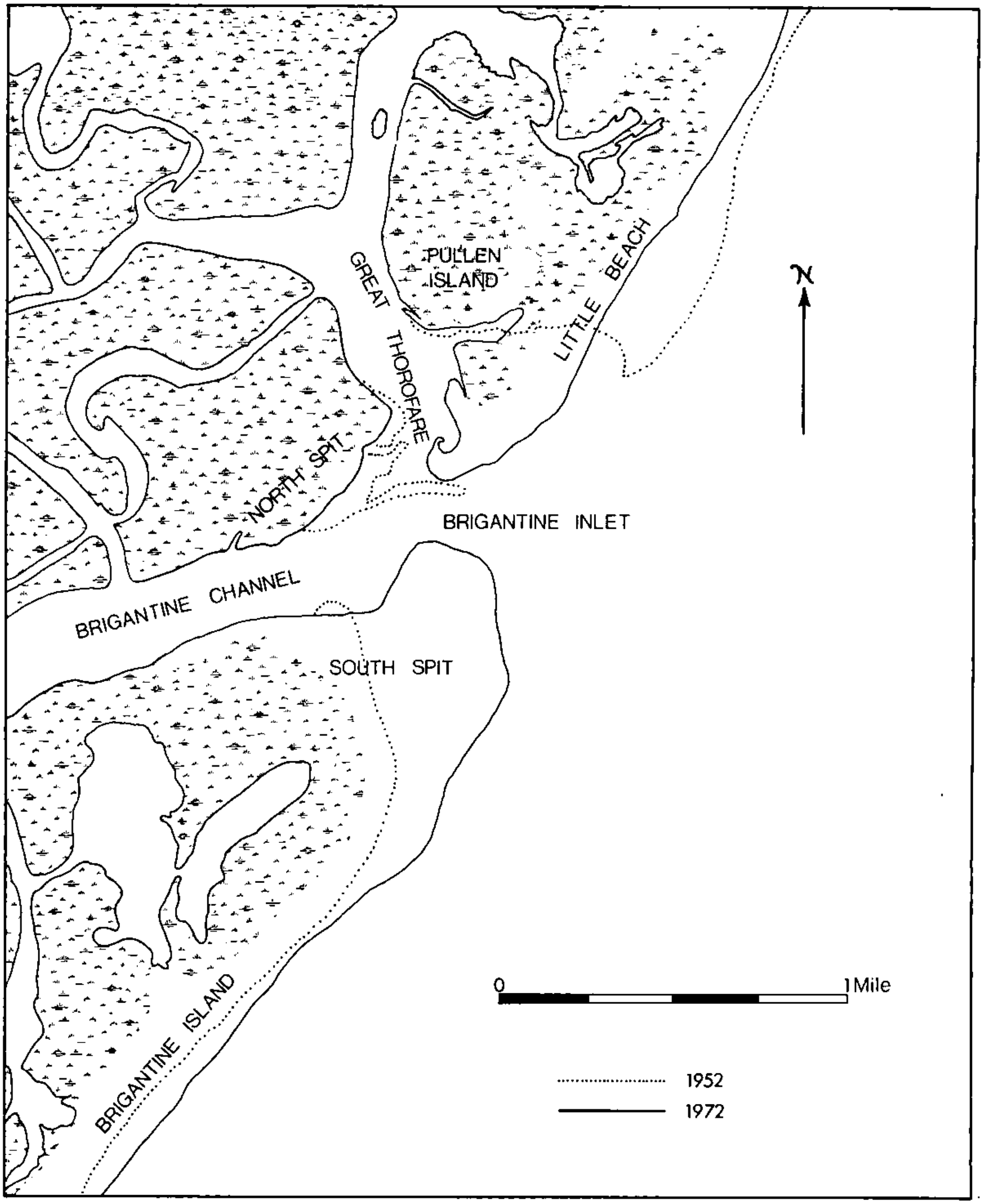


Figure 2. Map of the study area showing geographical place names and the change in shoreline configuration from 1952 to 1972. The 1952 shoreline is drawn from the Brigantine Inlet 7-1/2 minute quadrangle (U.S.G.S.), and the 1972 shoreline is traced from an aerial photograph (New Jersey Department of Geology and Topography).

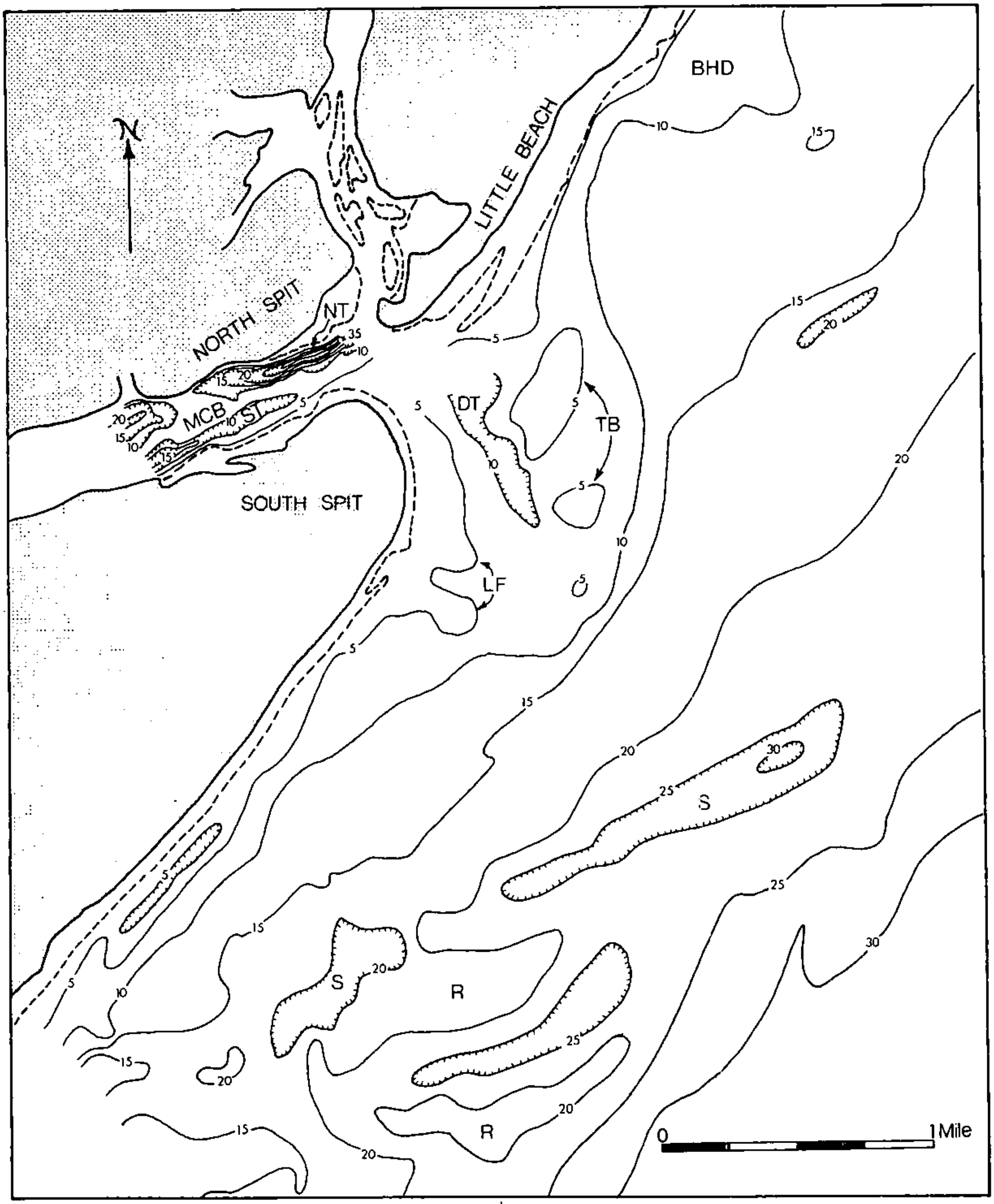


Figure 3. Bathymetry. The contour interval is 5 feet. Map abbreviations are: BHD - Beach Haven Inlet Delta; DT - Delta Trough; LF - Lobate Forms; MCB - Mid-Channel Bar; NT - North Trough; R - Ridge; S - Swale; ST - South Trough; TB - Transverse Bar.

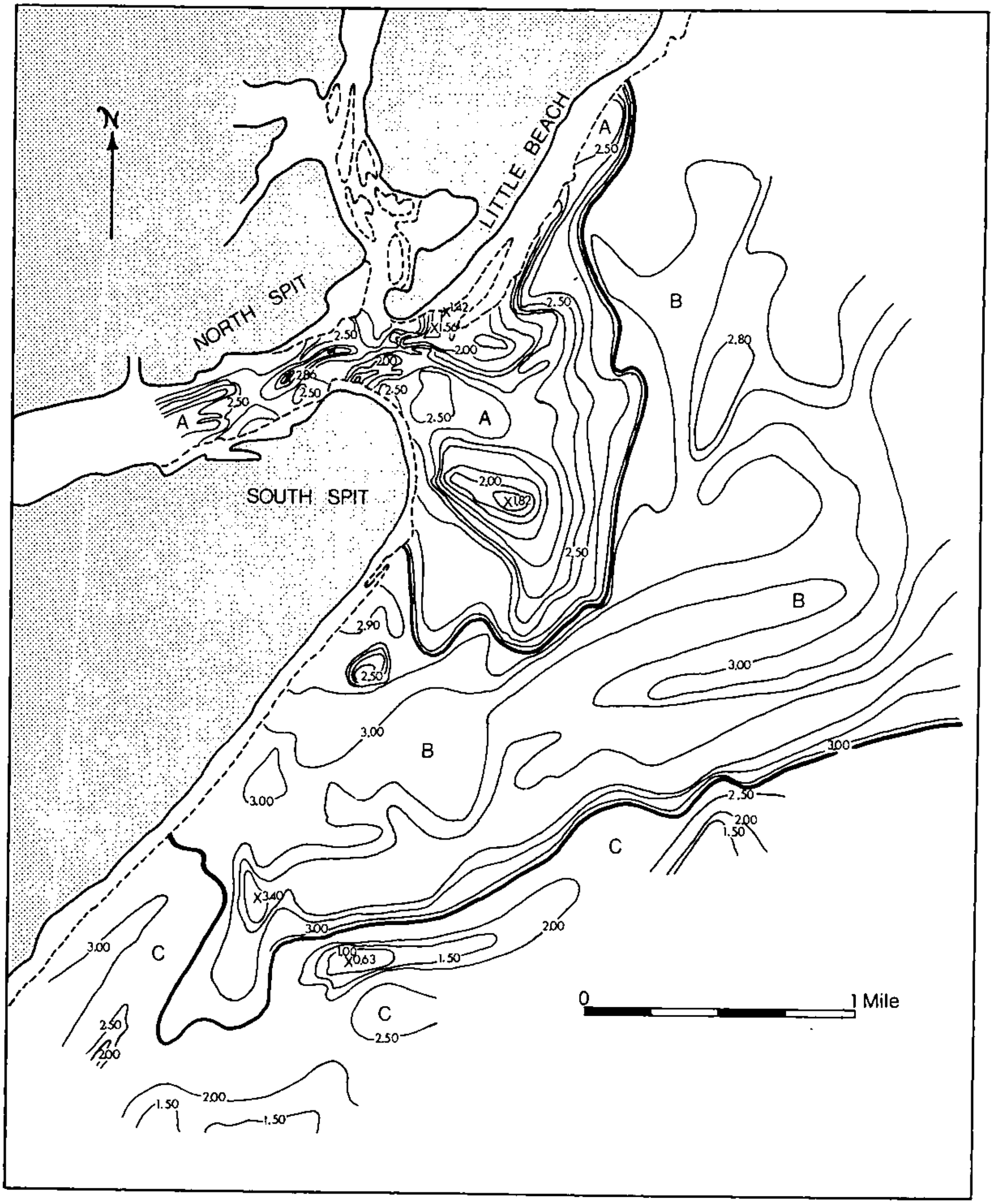


Figure 4. Mean grain size distribution. The contour interval is 0.10 phi. Only every fifth contour is drawn in area C.

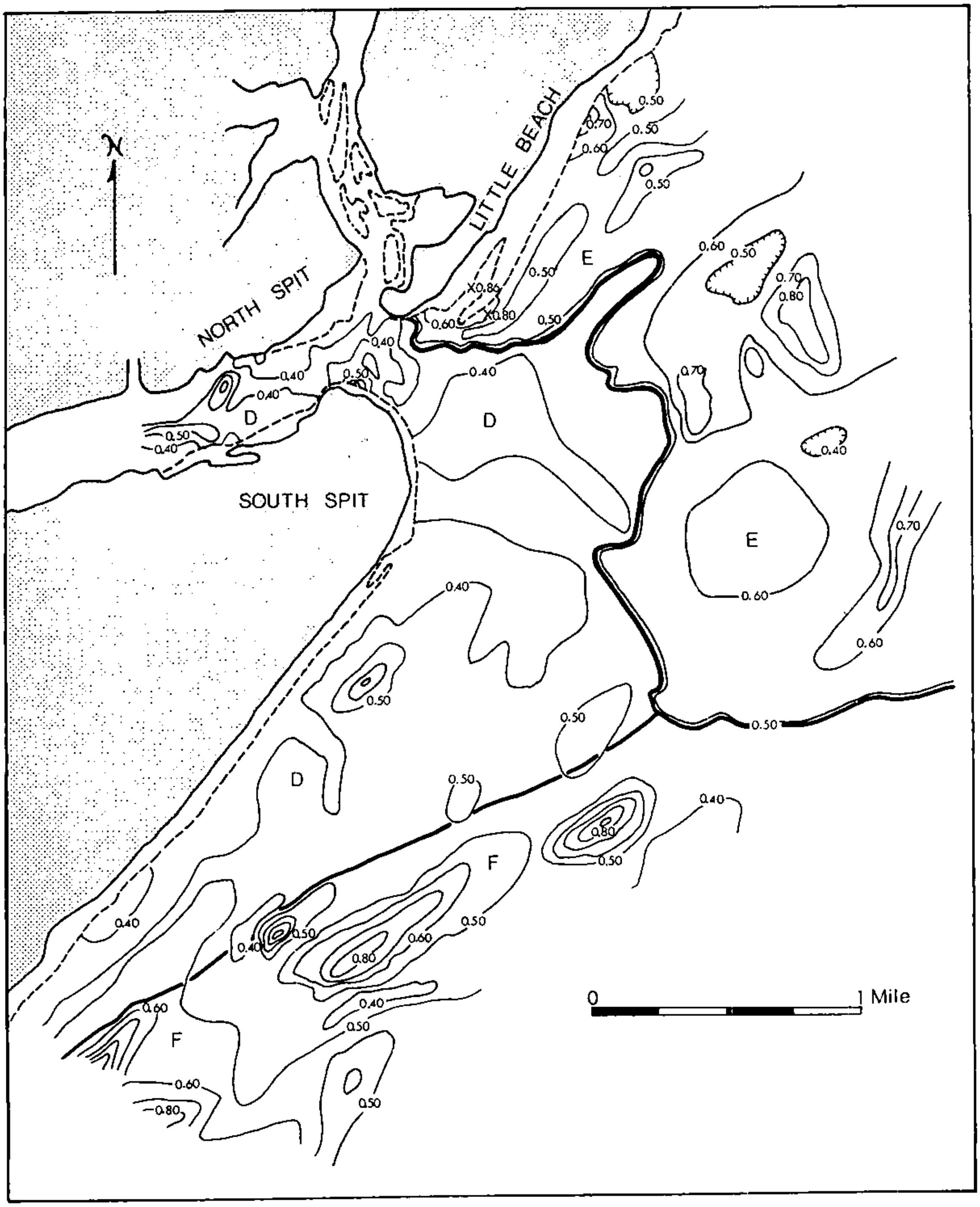


Figure 5. Standard deviation distribution. The contour interval is 0.10 phi.

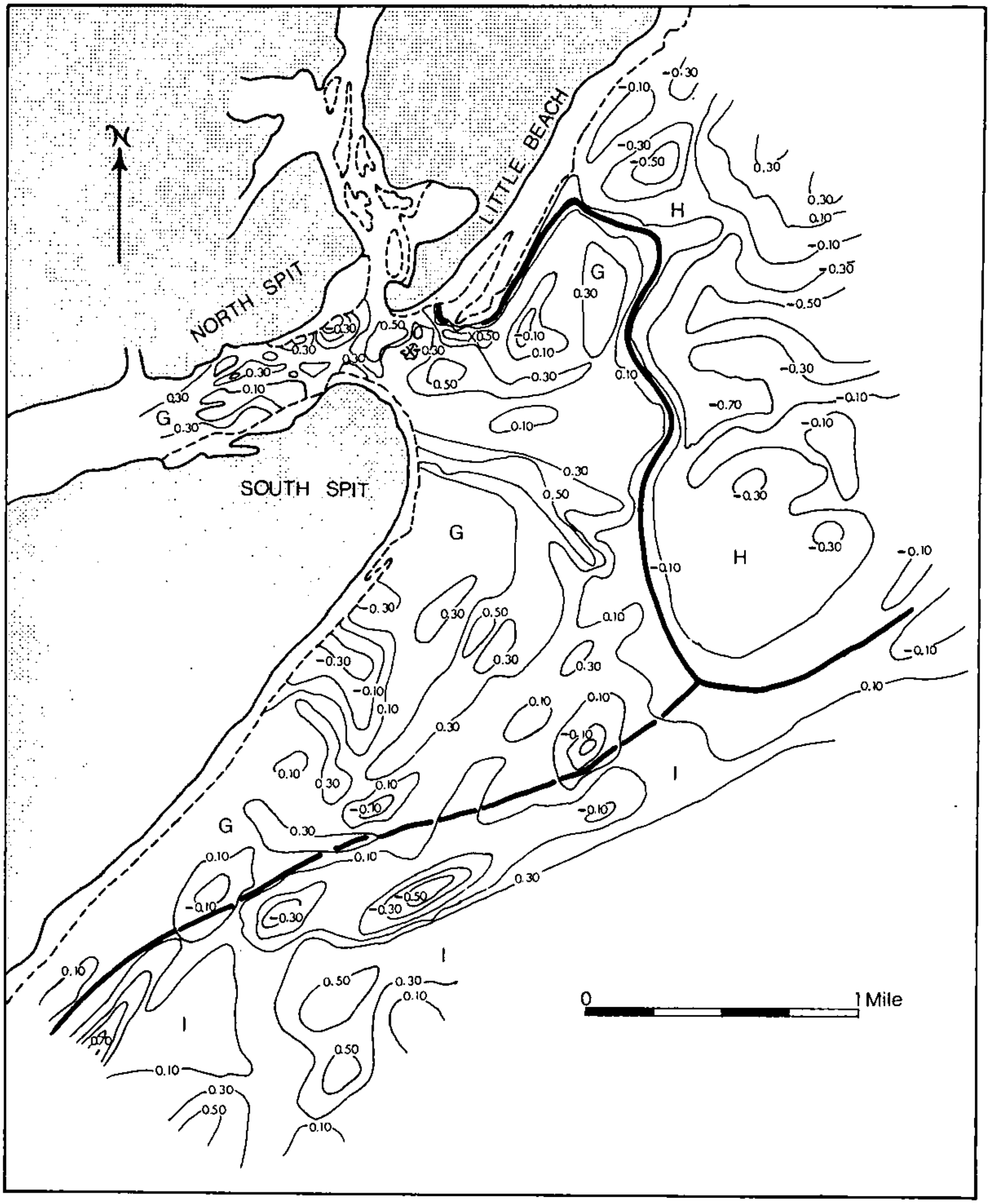


Figure 6. Skewness distribution. The contour interval is 0.20.

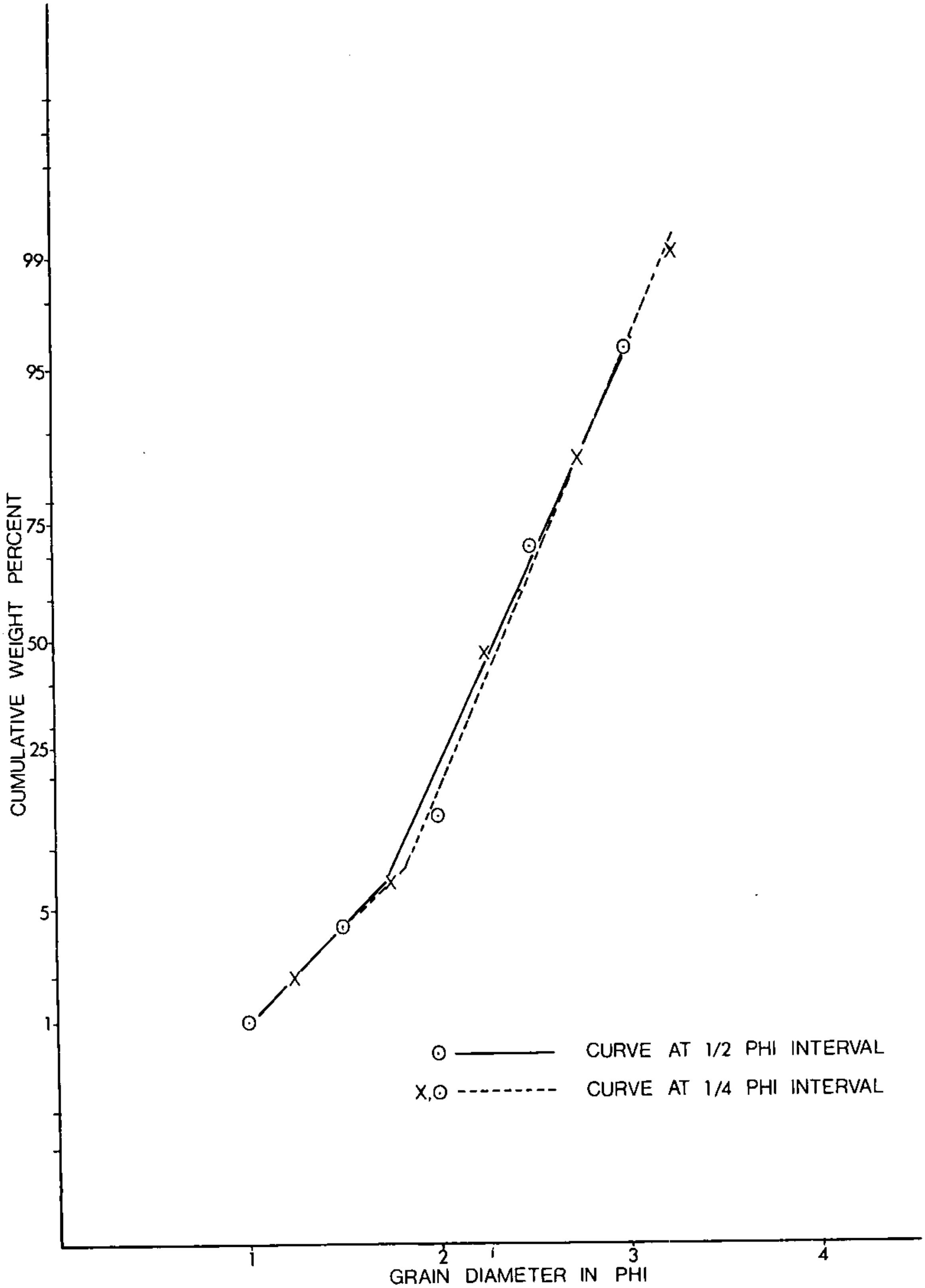


Figure 7. Log-probability curves plotted at 1/4 phi and 1/2 phi intervals.

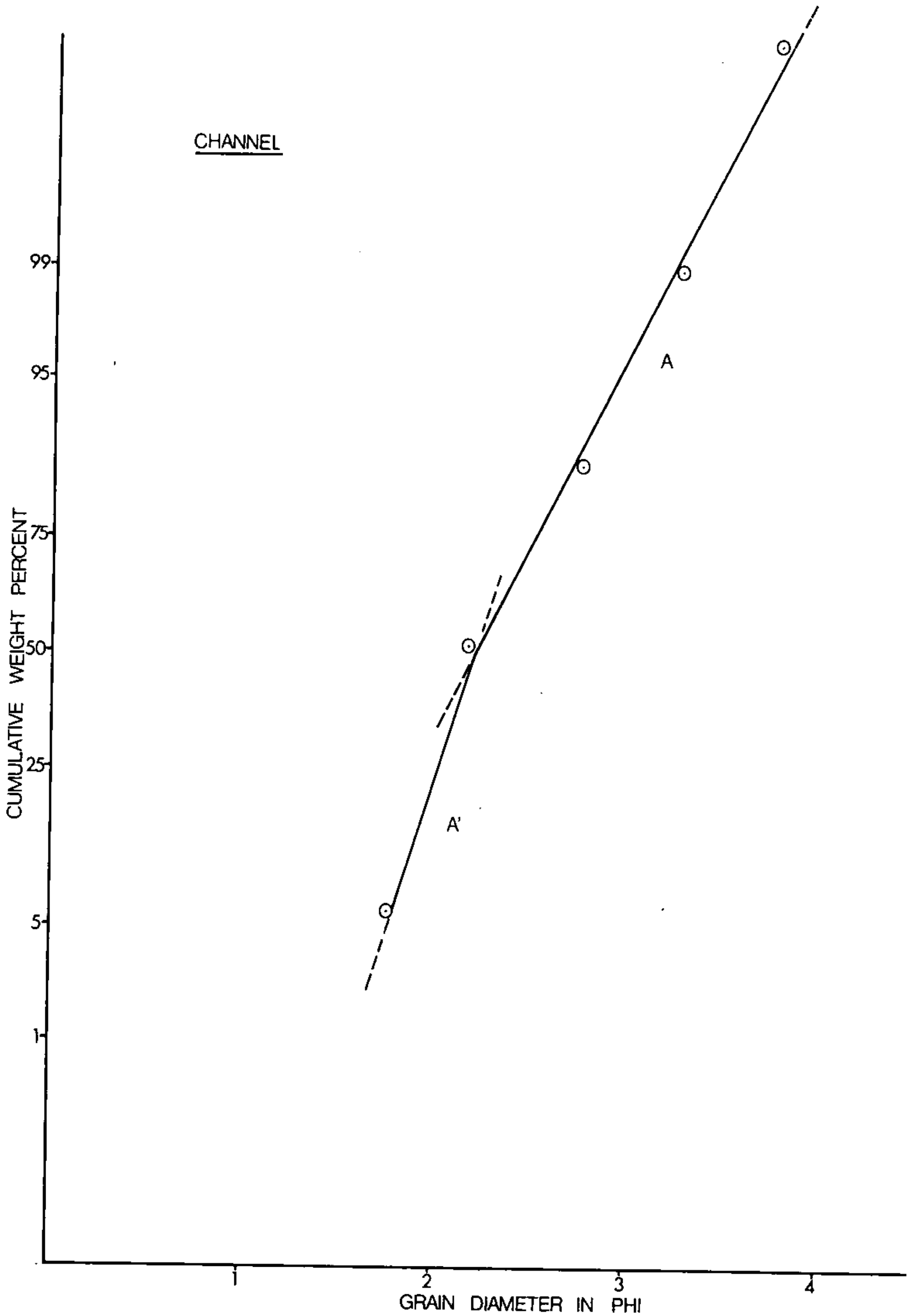


Figure 8. Log-probability curve of a Brigantine Channel sample.

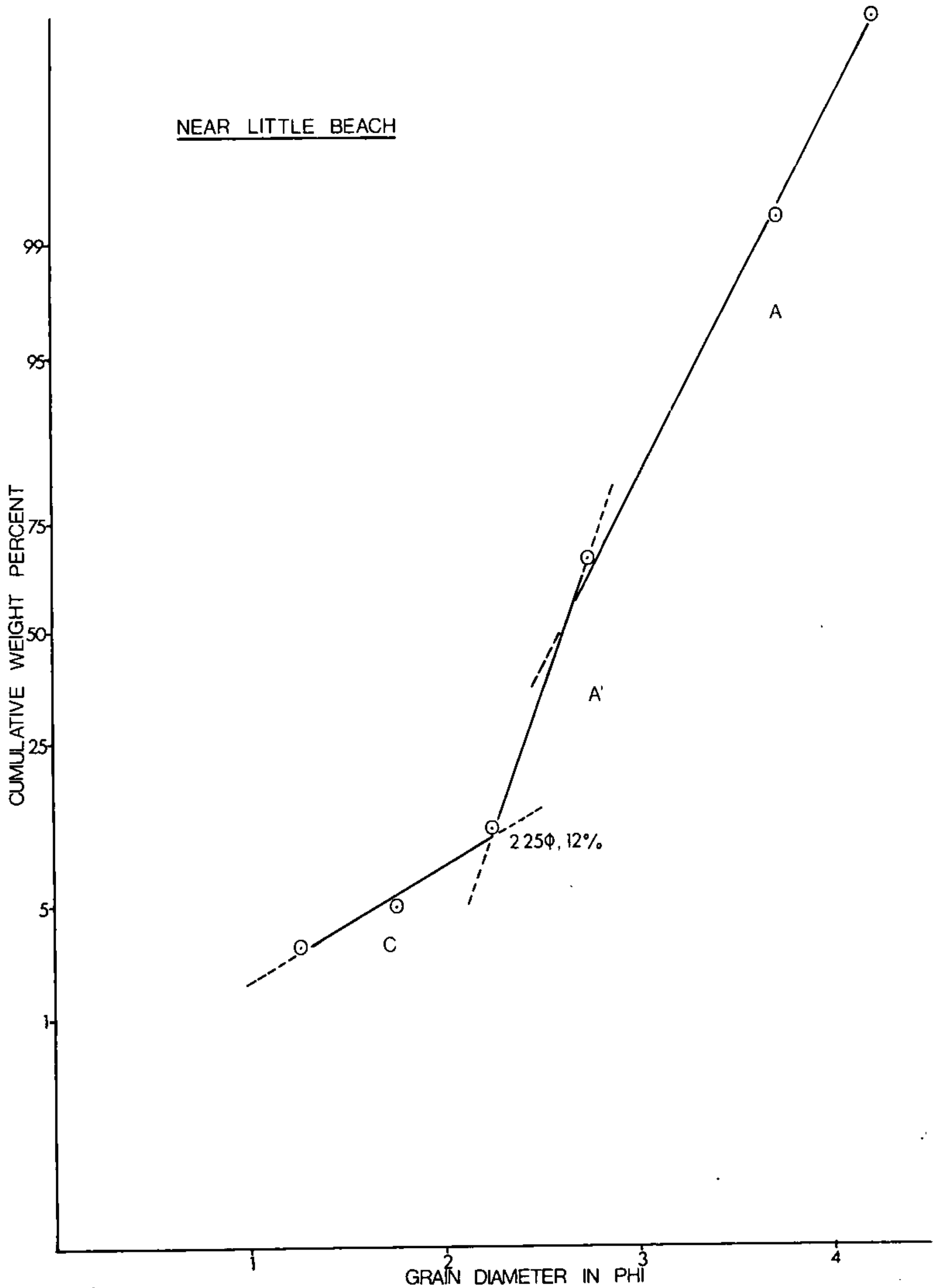


Figure 9. Log-probability curve of a sample near Little Beach.

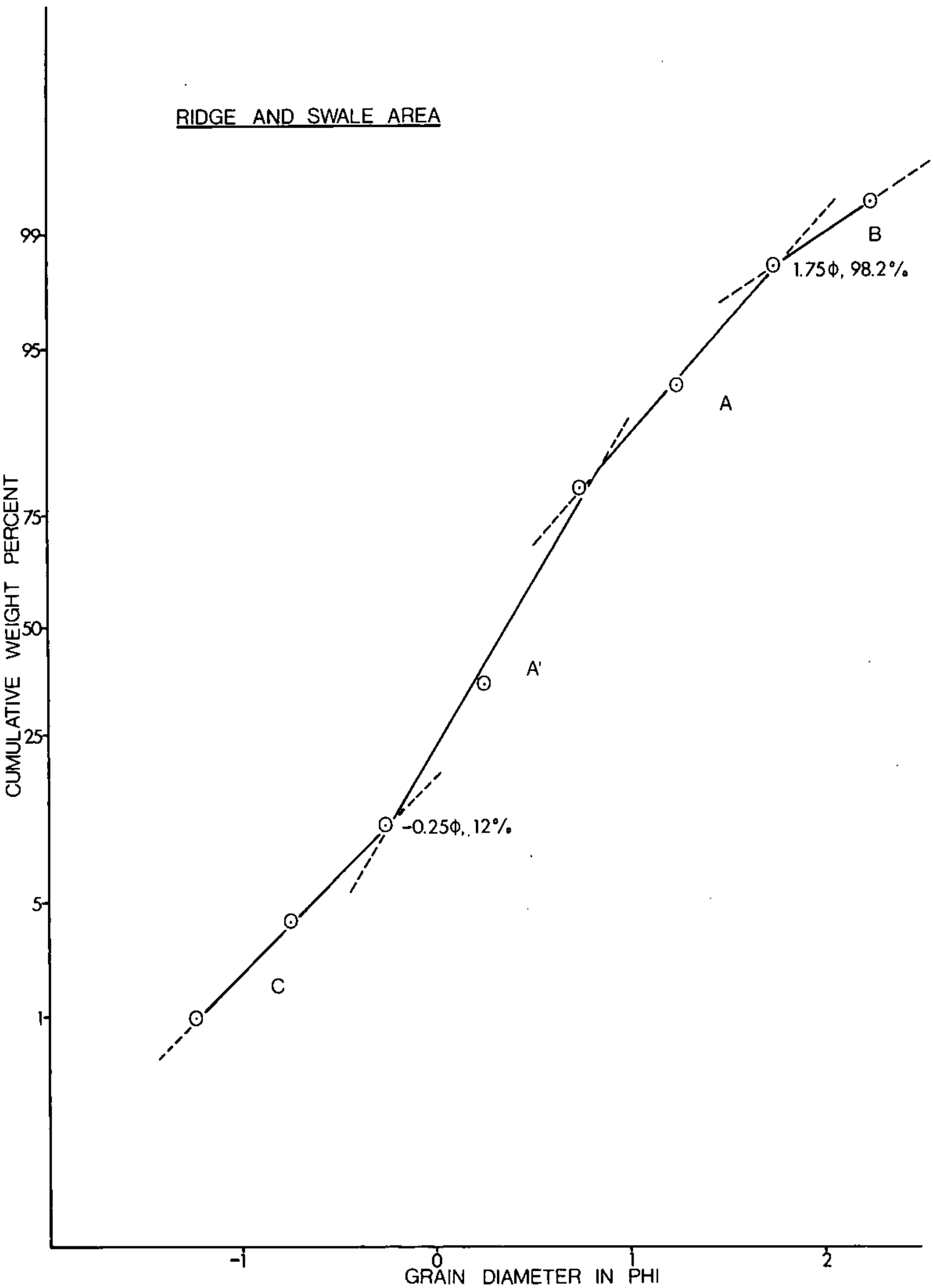


Figure 10. Log-probability curve of a sample from the ridge and swale area.

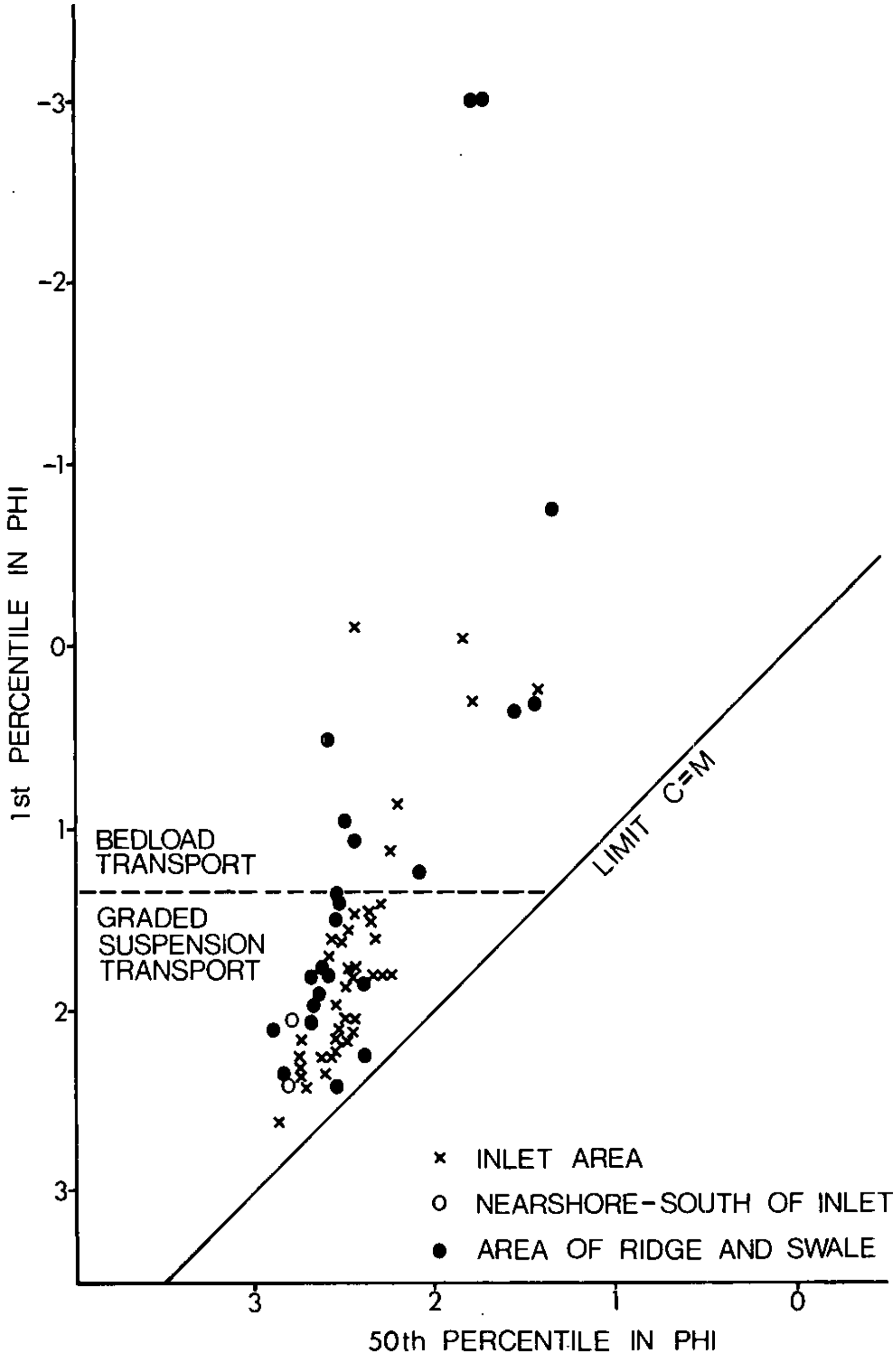


Figure 11. CM diagram for sediments from the inlet area, nearshore area south of the inlet, and ridge and swale area.

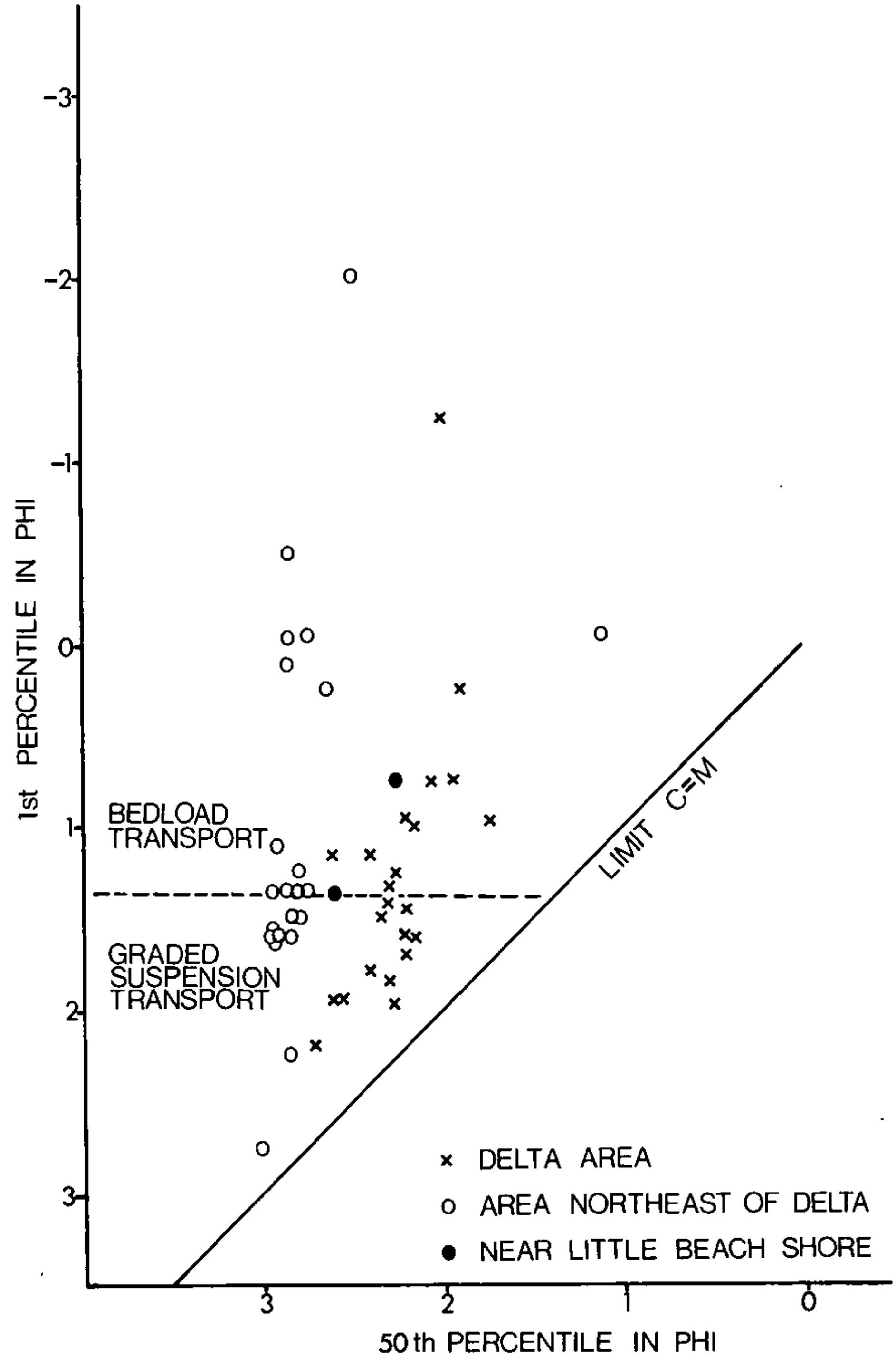


Figure 12. CM diagram for sediments from the delta area, area northeast of the delta, and area near the shore of Little Beach.

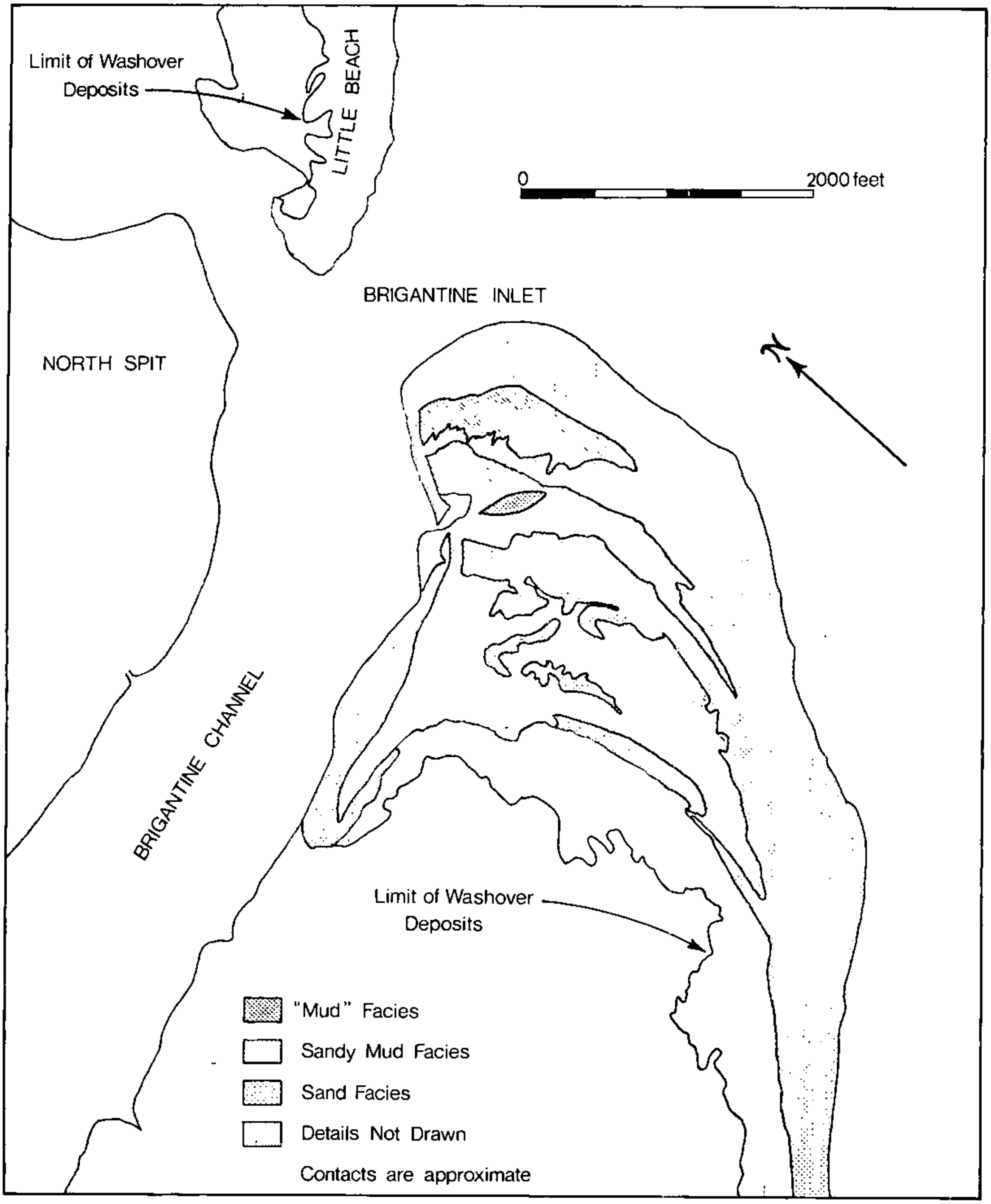


Figure 13. Facies map of South Spit. The map is modified from a 1972 aerial photograph (New Jersey Department of Geology and Topography).

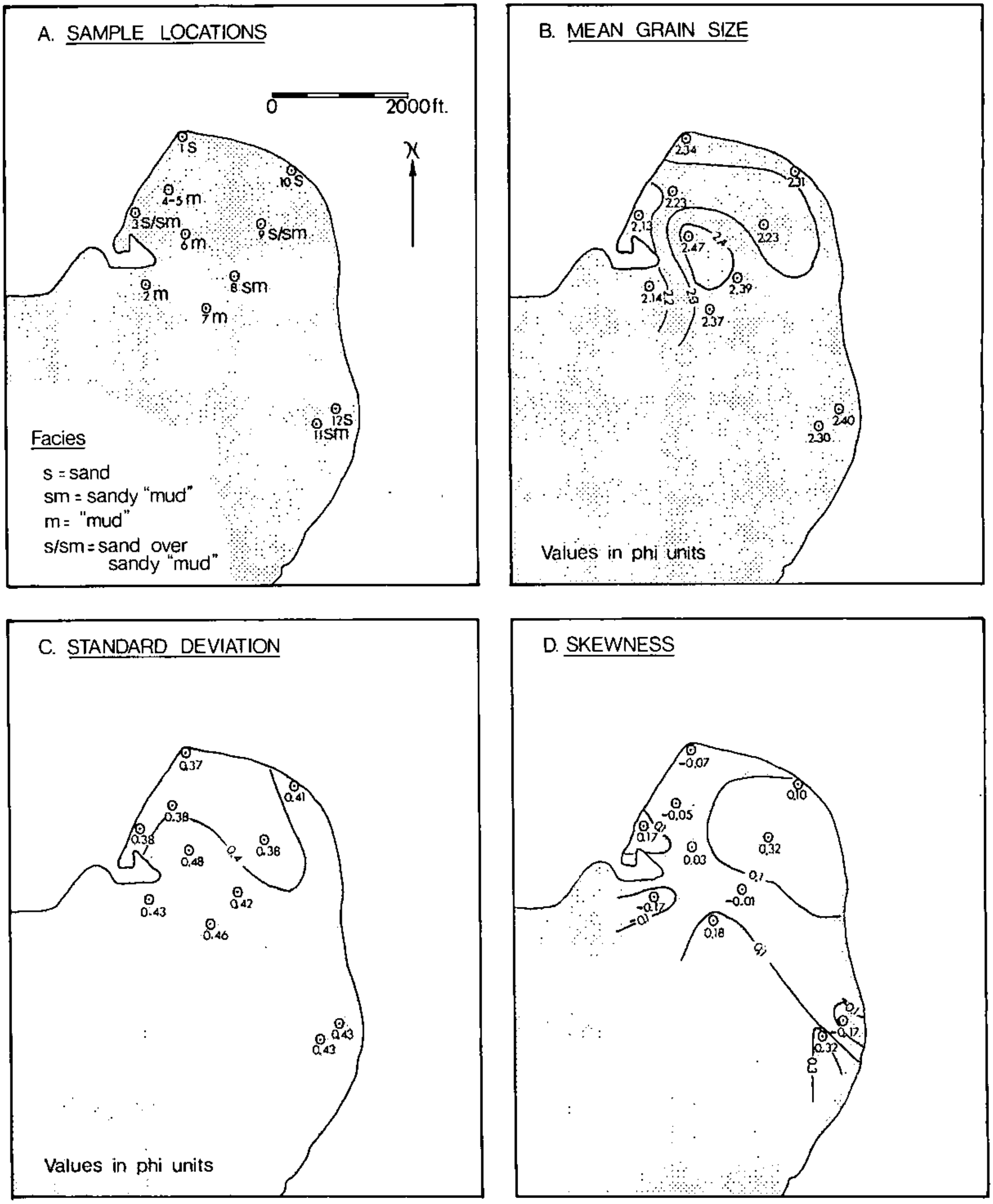


Figure 14. Distribution of facies samples and textural parameters on South Spit.

Plate 1. <u>Clean sand (middle view) encroaching on algalmats developed on organic-rich sand.</u>

The photograph was taken at sample location #4, looking north towards Little Beach in the far view. The width of the tire tracks in the middle distance (4 feet) gives the scale. The algal mats are peeled up, apparently by tidal currents.

Plate 2. Surficial structures from small standing waves - laminar structure seen in cross-section.

The cross-section trends almost due east, which is normal to the shoreline, and is near sample station 12. The knife is about two feet long. Dark minerals can be seen segregated into dark laminae which are expressed on the surface as broad dark bands. As can be seen at the intersection of the cross-section with the surface, the surface relief is very subdued.

Plate 3. Linguloid ripples in drainage channel.

The channel is the main drain of the low lying "mud" and sandy "mud" facies. The photograph was taken near sample station 3 and looks to the northwest. In the far distance, breakers can be seen from waves refracted around South Spit. In the middle distance, a channel point bar can be seen on the left and an undercut slope on the right. This shows the meandering nature of the channel. Linguloid ripples indicate that the velocity of water is high relative to depth. The width of the ripples is 4-6 inches.

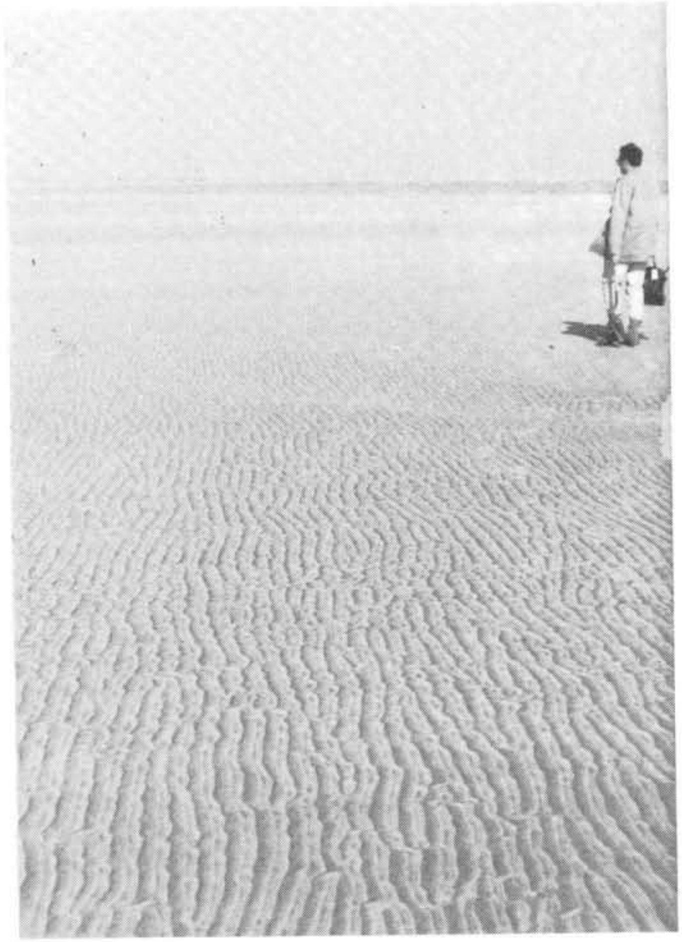


Plate 4. <u>Flat topped, asymmetrical ripples with straight to slightly undulating crest lines.</u>

The view is looking towards the northeast, from a location midway between sample stations 8 and 9. In the far distance, waves can be seen breaking on the seaward margin of the ebb delta. The land to the left in the far distance is Little Beach.

Plate 5. Example of pattern of encroachment of sand from spit margin - linguloid ripples on surface.

Linguloid ripples and the sand encroachment pattern shows a mechanism of spit platform buildup by relatively fast moving tidal currents. The shovel is five feet long.

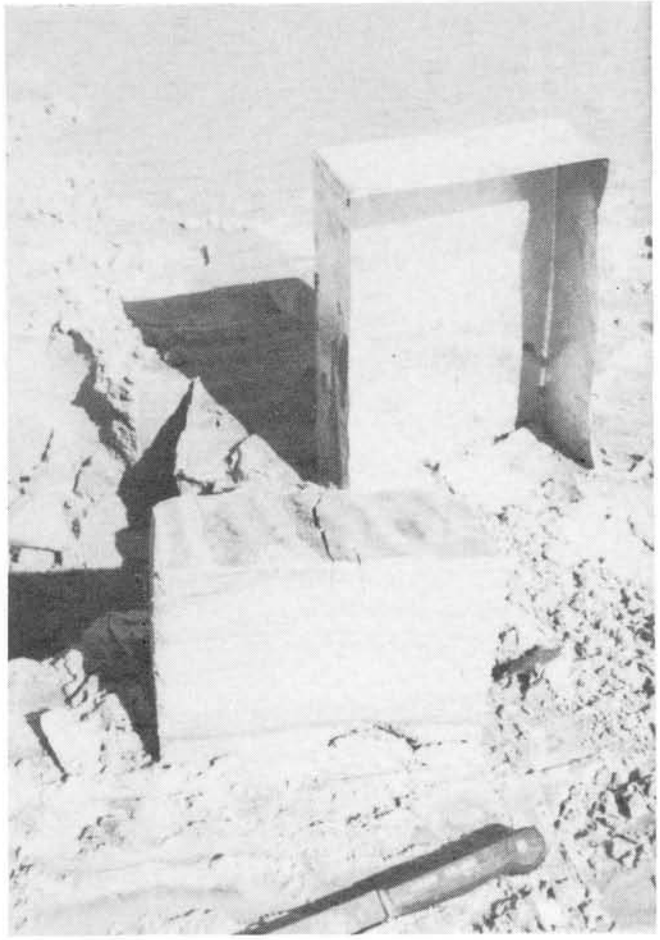


Plate 6. Box core showing cross bedding in cross-section through flat topped, asymmetrical ripples.

The box core was taken near the site of Plate 4 (midway between sample stations 8 and 9). The proper orientation of the box core face is east-west. The width of the core is one foot.

MEMBERS OF THE SEMINAR, 1975-1978

Chairman of the Seminar:

George J. Halasi-Kun
Hydrologist
Columbia University

Steering Committee:

Charles H. Behre, Jr.
Professor Emeritus of Geology
Columbia University

Courtney C. Brown
Professor Emeritus of Business
Columbia University

George Claus
Rutgers University, Medical School

Kemble Widmer
State Geologist of New Jersey
Trenton, N.J.

Members:

Thad P. Alton
International Financial Research
633 W. 115 St., New York City

Conrad M. Arensberg
Professor of Anthropology
Columbia University

Armando Balloffet, Consultant
Tippetts-Abbett-McCarthy-Stratton
Engineers & Architects, N.Y.

Jeanette A. Behre
Retired Asst. Professor of Biochemistry
Columbia University

Chaba Benedek*, Chief Engineer
Swindell-Dressler Pan American Co.
Washington, D.C.

Maciej P. Bieniek
Professor of Civil Engineering
Columbia University

Paul Bock
Professor of Hydrology
University of Connecticut

Stephen K. Breslauer
NUS Corp. Environmental Safeguard Div.
Rockville, Md. 20850

Wallace S. Broecker
Professor of Geology
Columbia University

Joseph H. Butler
Professor of Geography
State University of New York at Binghamton

William S. Butcher
National Science Foundation,
Washington, D.C.

David L. Campbell
Asst. Professor of Mining
Columbia University

Bertrand H. Chatel
United Nations
New York City

Joseph S. Cragwall, Jr.
Chief Hydrologist
U.S. Dept. of the Interior
Geological Survey, Reston, Va.

*died while engaged in a governmental project in Venezuela in 1976.

Laszlo Czirjak
Consultant, Greenwich, Conn.

Donald V. Dunlap
State Meteorologist of N. J.
New Brunswick

Augustine O. Esogbue
Professor of Industrial & Systems Engineering
Georgia Institute of Technology

John Fabianek
Professor of Life Sciences
N.Y. Institute of Technology

Rhodes W. Fairbridge
Professor of Geology
Columbia University

James J. Geraghty
Groundwater Geologist
Port Washington, N.Y.

Robert D. Gerard
Research Associate in Physical Oceanography
Columbia University

Alvin S. Goodman
Professor of Civil Engineering
Polytechnic Institute of N.Y.

Richard W. Goodwin
Manager
Research-Cottrell, Bound Brook, N.J.

Isadore S. Grossman
Board of Water Supply of
New York City

William A. Hance
Professor of Geography
Columbia University

Steve Hartman
Biologist Consultant
Sea Cliff, N.Y.

Colin High
Asst. Professor of Geography
Columbia University

Allan Hirsch
U.S. Dept. of the Interior
Fish & Wildlife Service
Washington, D.C.

Robert Hordon
Professor of Geography
Rutgers University

Raphael Hurwitz
Board of Water Supply of
New York City

William Jamieson
Consultant
Amityville, N.Y.

John A. Jones
Professor of Earth Sciences
Miami-Dade Junior College

William C. Kennard, Director,
Institute of Water Resources
University of Connecticut

Walter Kiechel, Jr.
Deputy Asst. Attorney General
Land & Natural Resources Div.
U.S. Dept. of Justice
Washington, D.C.

Adolfo Korn
Mining & Mechanical Engineer
United Nations, New York City

Grogory Lazarcik
Professor of Economics
State University of New York at Genesee

Richard LoPinto
Director, Marine Biology Program
Fairleigh Dickinson University

Daniel P. Loucks
Professor of Water Resources Eng.
Cornell University

Ulrich A. Maniak
Professor of Hydrology
Tech. University of Brunswick
F. R. Germany

Vincent E. McKelvey
Former Director
U.S. Geological Survey
Washington, D.C.

H. William Menard
Director of U.S. Geological Survey
U.S. Dept. of the Interior (1978-)
Washington, D.C.

James Miller
Professor of Oceanography
Rutgers University

David Miller
Groundwater Geologist
Port Washington, N.Y.

Francis C. Monastero, Oceanographer
U.S. Dept. of the Interior
Bureau of Land Management
Washington, D.C.

Alfred A. Porro, Jr.
Tidal Water Law Expert,
Lyndhurst, N.J.

Norbert Psuty
Director, Marine Sciences Center
Rutgers University

Habib S. Rahme
Consultant
Syosset, N.Y.

George Redey
Civil Engineer
Englewood, N.J.

Peter P. Remec
Professor of Political Sciences
Fordham University

Hugh B. Ripman, Dir. of Administration International Bank for Reconstruction & Development
Washington, D.C.

Gerald W. Robin
State University of New York
Stony Brook, N.Y.

H. James Simpson
Asst. Professor of Geology
Columbia University

Richard Skalak
Professor of Civil Engineering
Columbia University

Victor T. Strinfield
USGS Water Resources Div.
U.S. Dept. of the Interior
Washington, D.C.

Emil Szebeny
Professor of Biology
Fairleigh Dickinson University
Rutherford, N.J.

Martin S. Tanzer
Manager, Business Development
Edgerton, Germeshausen & Grier Co.
Waltham, Mass.

Grant F. Walton
Professor of Environmental Sciences
Rutgers University

James P. Weidener
Director of Survey
Pandullo & Quirk Assoc.
Wayne, N.J.

George W. Whetstone
Asst. Chief Hydrologist
U.S. Dept. of the Interior
Geological Survey
Reston, Va.

Guirquis Yassa
Director
Robinson Aerial Survey Inc.
Newton, N.J.

Warren E. Yasso
Professor of Natural Sciences
Columbia University

Leonard B. Zobler
Professor of Geology and Geography
Columbia University

Recording Member:

Elisabeth Sorad H.-K. Consultant
Pennington, N.J.

Guest Members:

Frank Basile
Bureau of Land Management of U.S. Dept. of the Interior
New York City

E. L. Bourodimos
Professor of Civil Engineering
Rutgers University

Kareen Bolander Claus
Consultant
Sommerville, N.J.

Nicholas De Kun
Consultant
Bruxelles, Belgium

M. Grant Gross
Professor of Oceanography
The Johns Hopkins University

Michael Hermel
Director
Broadway Medical Lab.,
New York City

Gerald R. Iwan
Sect. Leader of Field Studies
Union Carbide Env. Services

Martin Lang
Former First Deputy Administrator
Environmental Protection Agency
New York City

Peter P. Madri
Chief Chemical Lab.
New Brunswick Memorial Hospital,
Amityville, N.J.

Jules Markofsky
Researcher
Goldwater Memorial Hospital
New York City

Michael J. Passow
Professor of Natural Sciences
Horace Mann HS,
New York City

George Pinder
Professor of Civil Engineering
Princeton University

Edith B. Weiss
Asst. Professor of Civil Engrng. & Political Sciences
Princeton University

Junior Members:

from Columbia University

David Harper

Yeshwant K. Purandare (also State University of New York)
Frank Pecenka (also New York University)
Charles Szilagyi

from City University of New York

Richard Krauser (Queens College)

from Princeton University

Deborah Konopko

from Rutgers University

Vladimir Michna