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ALTERNATIVES FOR STORMWATER RUNOFF CONTROL IN SOUTHEASTERN MICH--ETC(U)
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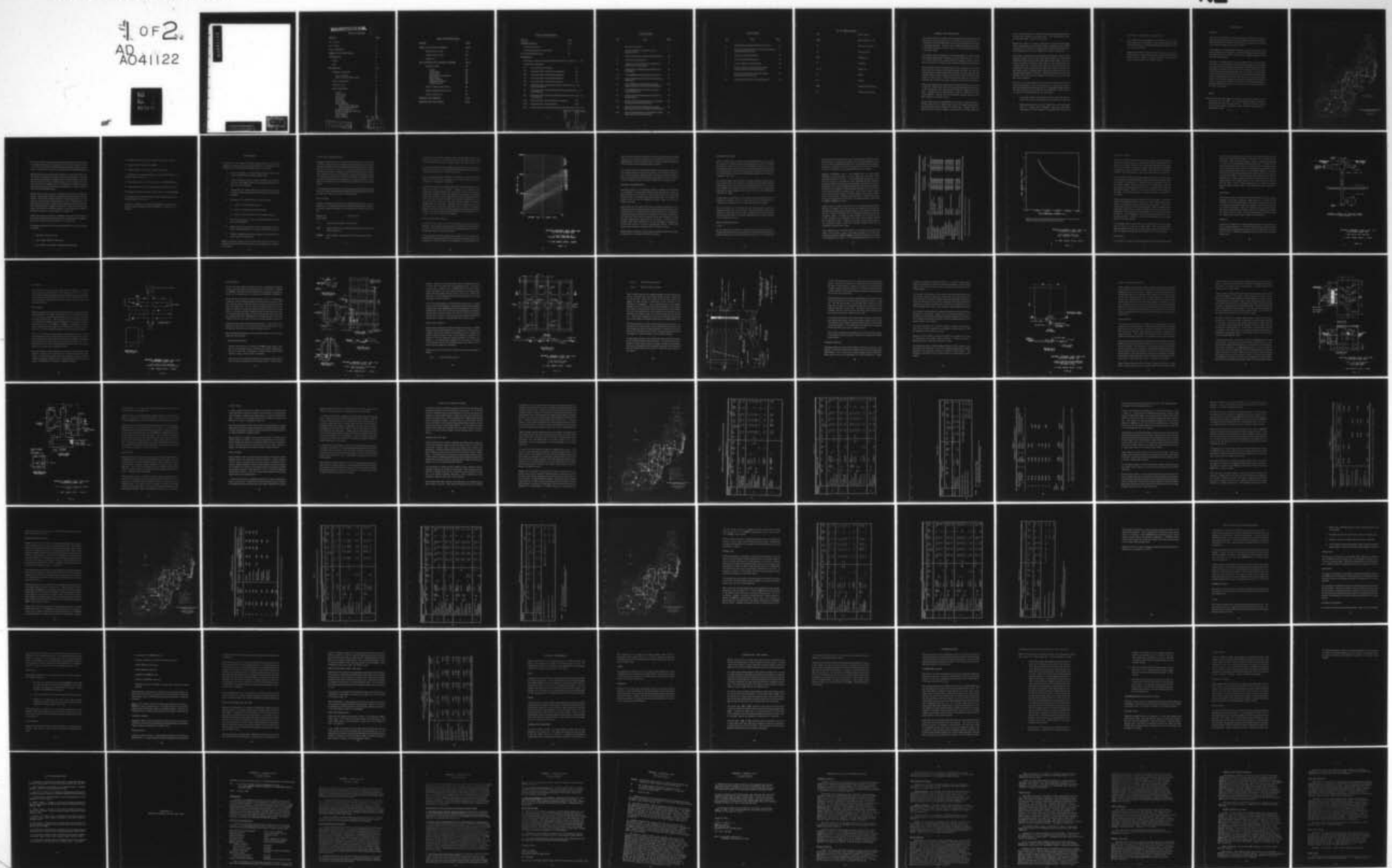

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LIST OF ABBREVIATIONS

MG	Million gallons
MGD	Million gallons per day
cfs	Cubic feet per second
fps	Feet per second
kwh	Kilowatt-hour
LF	Lineal feet
sq. mi	Square mile
inf.	Influent
eff.	Effluent
ENR	Engineering News Record
psi	Pounds per square inch

SUMMARY AND CONCLUSIONS

Five alternate schemes of collection and storage facilities for combined sewer and separate storm sewer overflows have been evaluated for the study area which is comprised of the Detroit Metropolitan area and other neighboring communities in southeastern Michigan. The study area is divided into seven sub-areas based on drainage characteristics as shown in Figure I. The total drainage area studied is 1741 square miles.

The collection system is designed for peak flows generated from a 10-year storm. The regional storage system is designed to contain a volume equal to a run-off of 2.1 inches, and the local storage facilities are designed to contain a volume equal to a run-off of 2.7 inches over their respective contributing drainage areas.

All five schemes provide an integrated system utilizing interceptors, force mains, deep tunnels and surface and mined storage reservoirs to collect and contain the combined sewer and separate storm sewer overflows. Urbanized areas with high population density and low availability of vacant land are being served with deep tunnels and large surface or mined storage reservoirs while the more sparsely populated areas are being served with interceptors and local surface reservoirs.

The proposed collection and storage system for Schemes One and Two is shown in Figure XII. Both schemes utilize local and regional surface reservoirs for storage, as well as interceptors, force mains and deep tunnels for transportation of storm water. Treatment plants for Scheme One are located at Algonac and the two regional reservoirs. Scheme Two has two additional treatment plants for storm water treatment in sub-areas E and G.

Schemes Three and Four have essentially the same type of collection system as the two previous schemes. Mined storage is used for the regional storage system, and surface reservoirs are employed for outlying areas. Treatment points for Scheme Three are located at Algonac, near the mouth of the Huron River and near the two mined storage sites. Scheme Four has two additional treatment plants for storm water treatment in sub-areas E and G. The proposed system layout for these two schemes is shown in Figure XIII.

Scheme Five is based on providing a combination of mined and surface storage for the urbanized areas along with surface storage for outlying areas. Three regional treatment plants are located at the same places as in Schemes Three and Four. The proposed system lay out for Scheme Five is shown in Figure XIV.

Total project cost estimates for all five schemes are summarized in Table 8. These estimates are based on January, 1972, costs which correspond to an Engineering News-Record Construction Cost Index for the Detroit area of 1,960. Total annual capital cost estimates are based on interest rates of 5-1/2,7 and 10 percent with a 50-year project life. Total annual cost based on a 5-1/2 percent interest rate is 159.6 million dollars for Scheme One, 157.7 million dollars for Scheme Two, 282.0 million dollars for Scheme Three, 279.9 million dollars for Scheme Four and 183.3 million dollars for Scheme Five. Schemes Two and Four do not include additional costs of providing local treatment for sub-areas E and G as compared with regional treatment.

Scheme Five is the recommended scheme for the various advantages it offers over the other four schemes. The cost of Scheme Five is more than Schemes One and Two and less than Schemes Three and Four. The advantages offered by Scheme Five over Scheme Two far outweigh the cost disadvantage. A brief outline of the reasons for selecting Scheme Five are given below:

1. The proposed system under Scheme Five is best suited with respect to construction timing and the projected service needs of the study area.

2. Mined storage and surface storage in Scheme Five can be optimized to arrive at a system which considerably reduces the peak power requirements for influent pumping to the regional surface reservoirs and

thus reduces the capital cost of supplying power.

3. Cost estimates for all the schemes do not include the cost of a power supply. When this cost is included, the cost differential between Scheme Five and Scheme One is considerably reduced, thus bringing them, into a more equal cost basis.

4. Mined storage in Scheme Five can be used to operate the Conners Creek treatment plant on a continuous annual basis with other regional plants being operated as needed. This type of operation should reduce the annual operation costs of the treatment facilities.

INTRODUCTION

PURPOSE

The purpose of this study is to analyze and evaluate the technical and economical feasibility of various collection and storage facilities for separate and combined sewer overflows in the study area. The study area is comprised of communities in southeastern Michigan and is shown in Figure I.

The significance of combined sewer overflows as a source of pollution has been widely recognized in the past decade. The accelerated aging process of the nation's fresh water lakes can be reduced considerably by adequate treatment of these combined sewer overflows.

This report is a continuation of the studies undertaken by the U. S. Army Corps of Engineers in an effort to identify the present and future water pollution problems of the study area and to evaluate feasible solutions to these problems. The specific schemes that are evaluated in detail in this report are based on a preliminary report completed by Ayres, Lewis, Norris and May, Inc. in June, 1972 (1). The preliminary report considered several alternatives for storm water collection and storage based on 2-5-10-and 25-year storm frequencies and two pump out rates to the treatment facilities. This preliminary report was reviewed by the Detroit District Office of the U. S. Army Corps of Engineers in context with the total Southeastern Michigan Wastewater Management Study. At the completion of the review, the scope of this report was finalized.

SCOPE

The scope of this report includes the evaluation of five alternate schemes of storm water collection and storage. An integrated collection system consisting of interceptors, force mains and deep tunnels is utilized in all schemes. Storage for the various schemes is provided by surface reservoirs, mined reservoirs or a combination of both.

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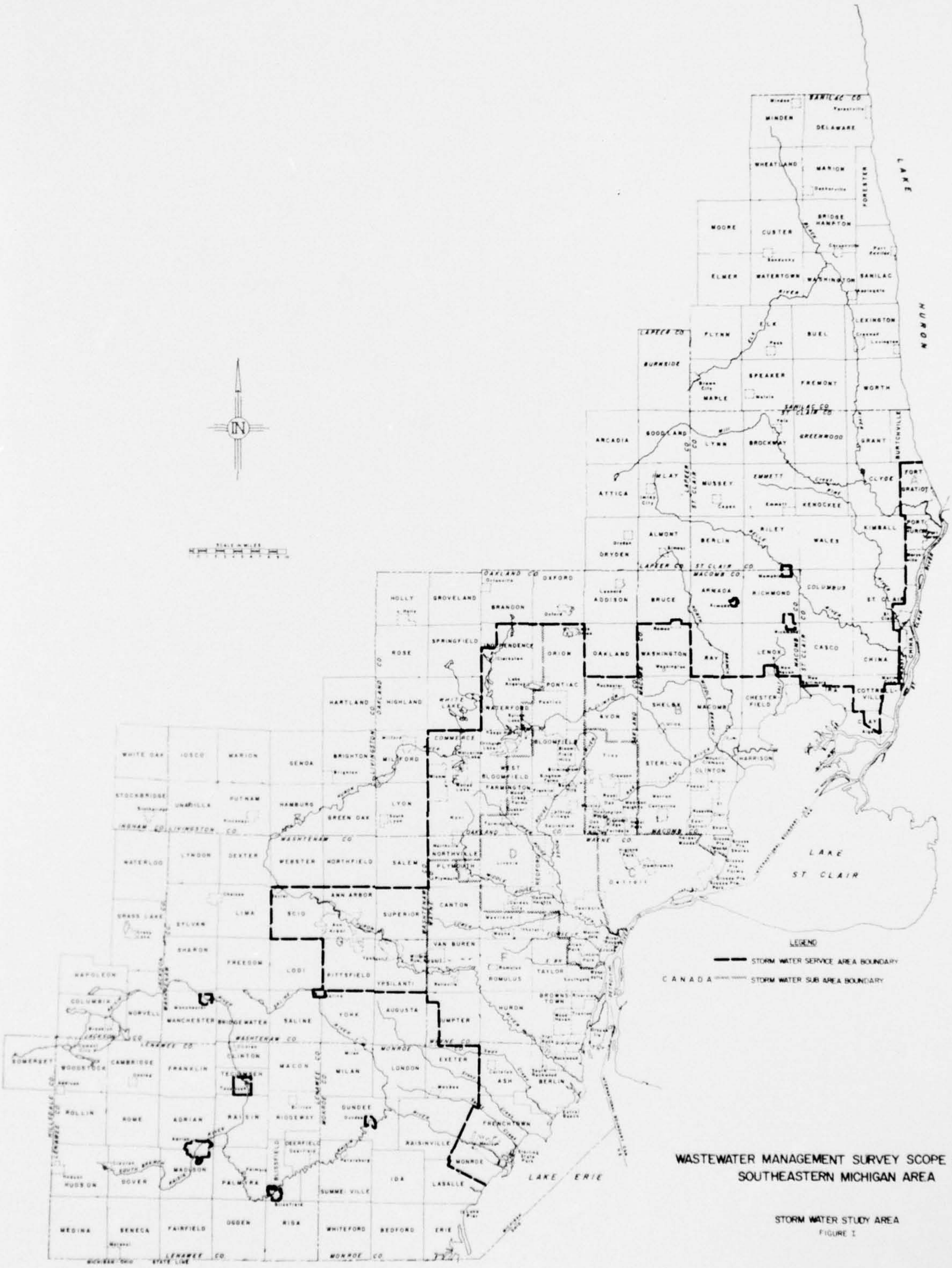


WASTEWATER MANAGEMENT SURVEY SCOPE STUDY
SOUTHEASTERN MICHIGAN AREA

STORM WATER STUDY AREA
FIGURE I

cont →

The collection system is designed for peak flows generated from a 10-year storm. The regional storage system is designed to contain a volume equal to a run-off of 2.1 inches, and the local storage facilities are designed to contain a volume equal to a run-off of 2.7 inches over their respective contributing drainage areas.

Schemes One and Two employ surface storage only. Scheme Two differs from Scheme One with regards to the location of the treatment facilities. In Scheme One, treatment is provided at two regional plants with one located along the North Branch of the Clinton River in Macomb County and the second at the mouth of the Huron River in Monroe County. For Scheme Two, in addition to the two regional plants, two local treatment plants are included in the upper portions of the Huron and Rouge River basins.

Schemes Three and Four are based on providing mined storage for the urbanized areas and surface storage for sparsely populated outlying areas. Under these two schemes, three regional treatment plants will be located as follows: (1) at the mouth of the Huron River in Monroe County, (2) by the Detroit River at the confluence of Conners Creek in Wayne County and (3) at the mouth of the Clinton River in Macomb County. Schemes Three and Four differ from each other with respect to the location of the treatment facilities. Local treatment plants in Scheme Four will be located at the same places as in Scheme Two.

Scheme Five is based on providing a combination mined and surface storage for the urbanized areas along with the surface storage for outlying areas. Three regional plants will be located at the same places as in Scheme Three .

The following information for this study was furnished by the U. S. Army Corps of Engineers:

1. Base Map of the Study Area

2. List of Major Outfalls in Study Area

3. List and Map of Combined and Separate Sewered Areas

4. SEMCOG Water, Sewage and Storm Drainage Facilities and Plans

5. Projected Runoff Information for 1990

6. Network Diagram for Conduct of Survey Scope Study

7. Alternatives for Managing Wastewater for Southeastern Michigan and attendant technical appendices

8. Water Resources Data for Michigan, Part 1 and 2, 1966-1970 editions

9. Southeastern Michigan Water Resources Study Technical Paper No. 3

10. Geologic and Hydrologic Studies of Three Areas in Southeast Michigan

11. Standard Project Flood Determination, Civil Engineering Bulletin No. 52-8, Department of the Army.

12. Survey, Investigations and Reports, Computation of Financial Costs Economic Costs, Engineering Manual 1120-2-104, U. S. Army Corps of Engineers.

METHODOLOGY

The first step in the process of evaluating alternate schemes of storm water collection and storage was to review the available literature. The following sources provided much of the data and information utilized in this report:

1. Various publications of the Environmental Protection Agency listed under the Water Pollution Control Research Series.

2. "Flood and Pollution Control, A Deep Tunnel Plan for the Chicago Land Area", May, 1966, published by Harza Engineering Company and Bauer Engineering Company.

3. "Development of a Flood and Pollution Control Plan for the Chicago Land Area," August, 1972, published by the Flood Control Coordinating Committee.

4. Proceedings of the American Society of Civil Engineers:

   a) Journal of the Construction Division

   b) Journal of the Sanitary Engineering Division

   c) Journal of the Soil Mechanics and Foundations Division

5. Storm Drainage Reports, prepared by Southeast Michigan Council of Governments (SEMCOG).

6. Varous reports on the geology of the study area prepared by Dr. A.J. Mozola, consultant geologist and professor at Wayne State University.

7. Telephone conversations with several pollution control equipment and mining equipment manufacturers.

Specific information obtained from the above listed sources has been duly referenced through the text of the report and a list of references cited is included in this report.

HYDROLOGIC CONSIDERATIONS

Hydrologic considerations form an important basis for the design of a storm water collection and storage system. Peak flow rates and the storage volume requirements for design frequencies of rainfall are the two main hydrologic parameters of interest. Based on the preliminary report (1) and a statistical analysis of stream records performed by the Corps of Engineers, it has been determined that a collection system designed for a 10-year storm frequency, a regional storage system designed to provide storage equivalent to 2.1 inches of runoff from its contributing drainage area and local storage facilities designed for 2.7 inches of runoff from their contributing drainage areas should provide the desired degree of storm water control.

The hydrologic design basis used for arriving at design peak flow rates was discussed with Dr. E.F. Brater of the University of Michigan. The following discussion relative to design peak flow rates is based on those discussions.

Peak Flow Rates

Methods of estimating peak flow rates vary greatly depending on the size of the drainage area. The American Society of Civil Engineers Committee on Hydrology has given the following breakdown on the methods used for peak flow estimations (2):

Drainage Areas (Square Miles)	Present Practice
< 1	Overland flow hydrograph; rational method
1-100	Rational method; unit hydrograph; flood frequencies; flood peaks versus drainage area.
100-2000	Unit hydrograph; flood frequencies; flood peaks versus drainage area.

Conventionally, the rational method has been used for design of storm water systems for drainage areas of less than five square miles. Development of data for application of unit hydrograph methods usually is warranted on larger areas.

For the large areas, storage and subsurface drainage flow cause an attenuation of the runoff hydrograph so that rates of flow tend to be overestimated by the rational method unless these effects are taken into account.

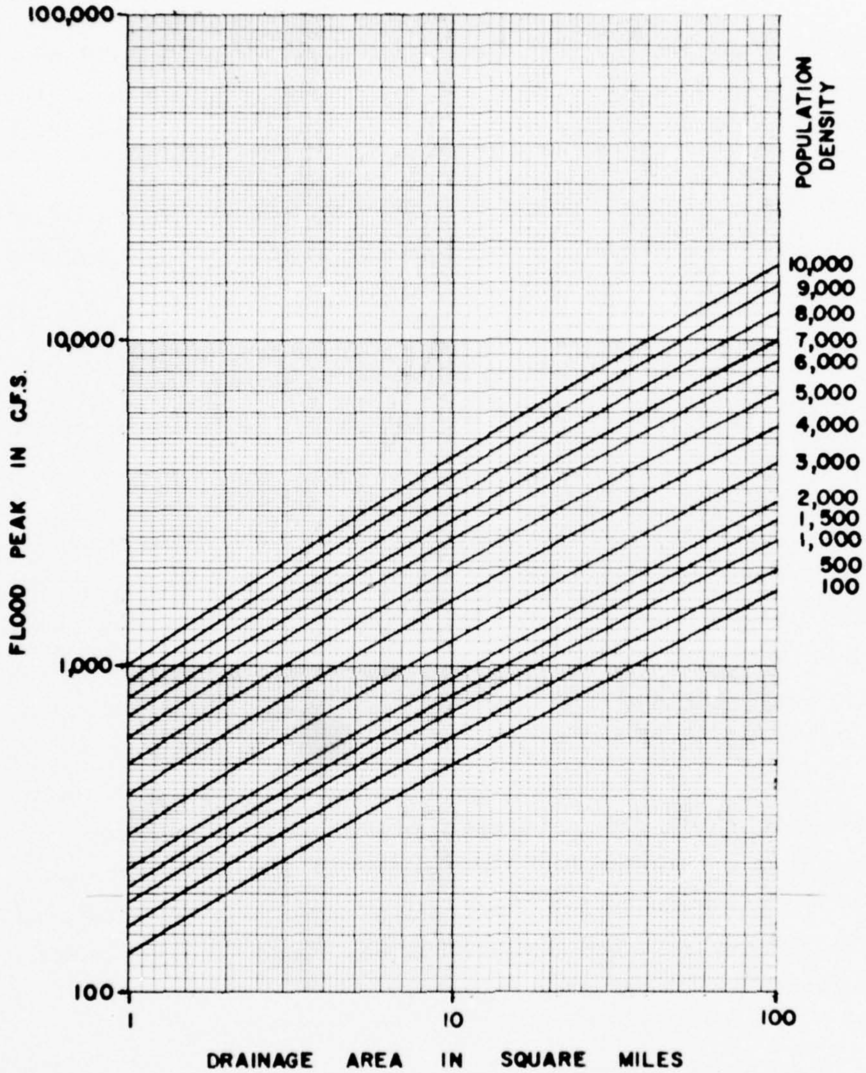
Since the drainage areas being considered in this study are much larger than the normal upper limit for the application of the rational method, the lack of applicability of the method is self-evident.

The method of estimating peak flows used in this report was developed by Dr. Brater as discussed in the publication, "Prediction of the Magnitudes and Frequencies of Floods in Michigan" (3). This method is known as the infiltration capacity-unit hydrograph method and requires that information on infiltration capacity and hydrograph shape be obtained from the analysis of rainfall and surface runoff events. In his report, Dr. Brater used data from drainage basins varying in size from 0.02 to 734 square miles and in population density from 100 to 13,000 persons per square mile. A frequency curve of rainfall plus snow melt was prepared from the analysis of 535 station-years of records in southeastern Michigan. With this information and stream gauging records, curves were developed relating peak discharge to area and population density. Figure II shows an example of such a curve for a 10-year storm frequency.

Volume of Storm Water Runoff

The volume of storm water runoff to be stored was provided by the Corps of Engineers. They analyzed stream records and concluded that a storage volume equivalent to 2.1 inches of runoff from the contributing drainage area results in an acceptable degree of storm water control.

It was recognized that small drainage areas are subject to more localized storm conditions and consequently require more storage than larger areas to achieve the same degree of control. Analysis of the information in the Department of the



WASTEWATER MANAGEMENT SURVEY SCOPE STUDY
SOUTHEASTERN MICHIGAN AREA

10-YEAR FLOOD PEAK VS.
DRAINAGE AREA & POPULATION DENSITY

U. S. ARMY ENGINEER DISTRICT, DETROIT

FIGURE II

Army Civil Engineer Bulletin No. 52-8 (4) reveals that smaller drainage areas (30-50 square miles) may experience 20-30 percent more rainfall than larger drainage areas (800-1000 square miles) for a particular storm. Therefore upland storage reservoirs serving smaller areas are sized for higher amounts of runoff.

The proposed storm water storage system designed in this report is divided into two categories based on the size of the service area. The first category serves very large, urbanized areas and is designed to store 2.1 inches runoff from the tributary area. The second category serves small areas, approximately the size of a township. These are designed to store 2.7 inches of runoff from the tributary area.

GEOLOGIC CONSIDERATIONS

Complete information of the subsurface conditions is essential for an evaluation of the feasibility of the alternate schemes for storm water collection and storage. Soils conditions must be known to properly design surface and underground reservoirs as well as interceptor sewers and shallow tunnels. The condition and location of bed rock must be investigated to properly design rock tunnels and mined storage areas.

Several reports on the geology of the study area have been prepared by Dr. A. J. Mozola, consultant geologist and professor at Wayne State University (5,6). These reports were used as a primary sources of geological information. Two additional reports were prepared specifically for this project and are included in Supplement A of this report. Profiles along the proposed tunnel routes showing the expected subsurface conditions also were prepared by Dr. Mozola. In addition, the City of Detroit Water Supply Department is currently conducting an investigation of the bed rock conditions to a depth of approximately 700 feet. These borings should provide additional information when they become available.

Specific geologic considerations as they apply to various components of the project are discussed in the respective sections of this report.

CONSTRUCTION COSTS

Cost is an essential factor in selecting the appropriate alternative to be used for the abatement of combined sewer and separate storm sewer overflows. Estimates are made of the costs involved in each of the alternatives considered in this report. An engineering, legal and construction contingency of 30 percent has been included in all of the estimates. The higher contingency figure is considered to be appropriate in the present stage of planning and includes some additional cost for factors not considered in the report.

Unit costs are based, wherever possible, on actual construction costs for similar types of construction. All cost estimates are based on January, 1972, costs which correspond to an Engineering News Record Construction Cost Index for Detroit area of 1,960. The construction costs for any other year can be determined by multiplying the costs presented in this report by the ratio of the corresponding ENR index to 1,960.

Annual capital, annual operation and maintenance, and total annual cost have been estimated for all alternate schemes. Interest rates of 5-1/2, 7 and 10 percent and a project life of 50 years have been used in computing annual costs.

The cost estimates do not include costs for surveying, soils and geologic investigations, and right-of-way acquisition. Property acquisition costs are only included for surface reservoir sites. Also, cost estimates do not include costs for constructing storm sewers in the presently unsewered areas and costs for treatment of the collected storm water.

DESIGN CONSIDERATIONS

Tunnels

At the present state of technology, tunnels varying from 6 feet to 36 feet in diameter have been drilled using boring machines. The maximum size of the tunnel depends primarily on the compressive strength of the rocks. It is anticipated that technology will sufficiently advance to permit tunnel diameters up to 50 feet within the next decade. For the purpose of design in this report, tunnel diameters varying in size from 18 feet to 48 feet have been used. It is recognized that the geological formations in some areas may limit the maximum size of the tunnel diameters. In such cases construction of two parallel tunnels may be necessary.

Geological considerations form a very important part of tunnel design. Conventionally, various parameters of tunnel design have been related to the compressive strengths of the rocks. The non homogeneous characteristics of the rock mass results in a wide variation of the compressive strengths. Therefore, compressive strength forms a poor criteria with regards to "borability" of the rocks. Nevertheless, this is the best available parameter which can be easily established. At present it is not possible to obtain compressive strengths for the type of rocks to be encountered along the proposed tunnel routes. Table 1 shows estimated minimum and maximum values of compressive strengths and also gives a median range. From this table it is evident that a wide variation in compressive strengths will be encountered along the tunnel routes. For design purposes, a median range of 15,000 to 20,000 psi is used.

Advance rates on a project of this size form a very important design parameter. Carsdens and Davidson (7) in their report on the existing tunneling technology concluded that advance rates are directly related to the compressive strengths of the rocks. Figure III shows the relationship between penetration rate and rock compressive strength. For design purposes an advance rate of 35 feet per day is used. Advance rate data published in the literature varies anywhere from 20 feet to 300 feet per day. A lower figure has been used for design because of the uncertainties involved in the rock compressive strengths which may be encountered along the tunnel routes.

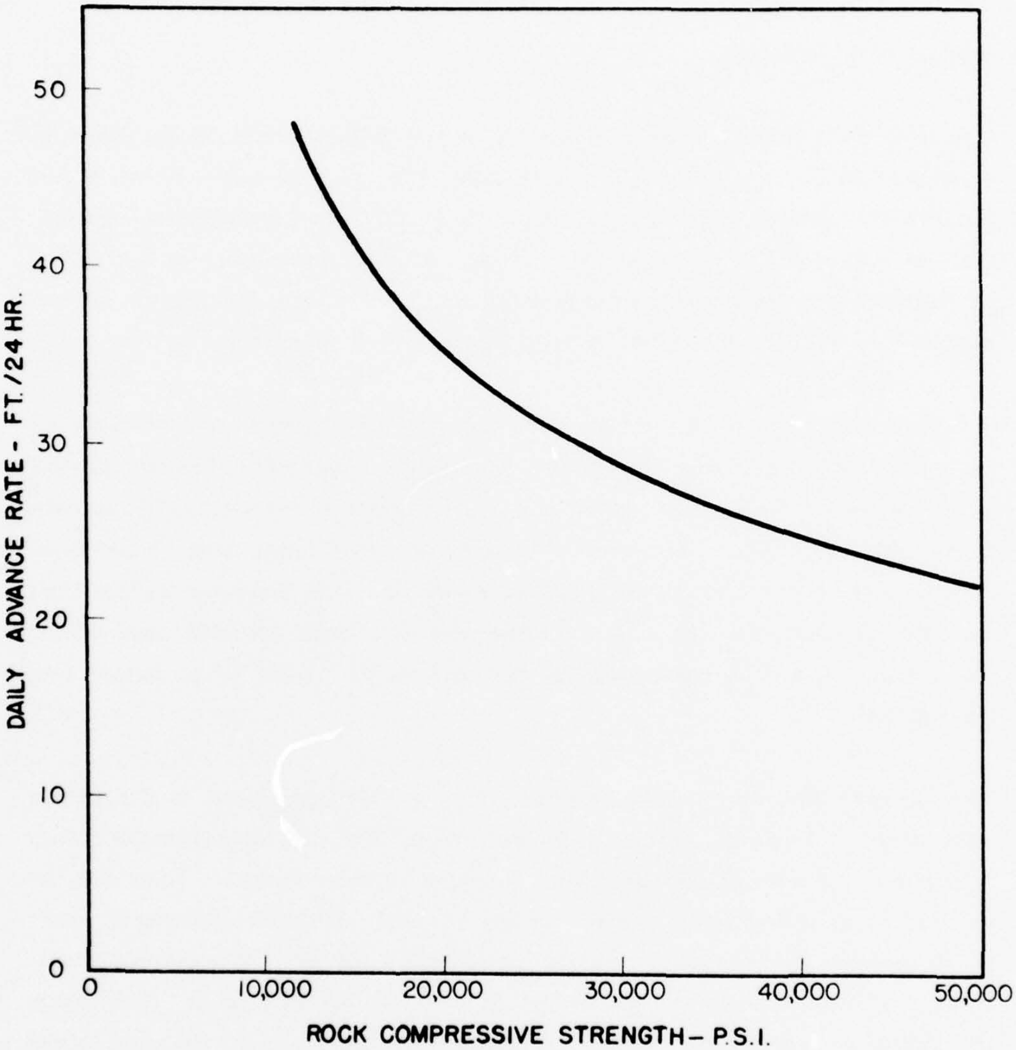
Power requirements for the boring machines are expressed in terms of specific energy of rock removal. Based on the design assumption of a median rock compressive strength of 15,000 to 20,000 psi, the specific energy of rock removal can be expected to vary from 1.1 to 1.4 horsepower applied per hour per cubic

TABLE 1
ESTIMATED COMPRESSIVE STRENGTHS OF ROCK FORMATIONS

Rock Formation*	Type*	Expected Range of Compressive Strength+ (psi)	Expected Median Compressive Strength+ (psi)
Coldwater formation (youngest)	shale, some sandstone	8,000 to 29,000	15,000 to 20,000
Sunbury formation	shale, dark brown to black	8,000 to 29,000	15,000 to 20,000
Berea formation	sandstone, shale	8,000 to 29,000	15,000 to 20,000
Bedford formation	shale	8,000 to 29,000	15,000 to 20,000
Antrim formation	shale, dark brown to black	8,000 to 29,000	15,000 to 20,000
Traverse group	shales, limestone, dolomite	10,000 to 35,000	17,000 to 28,000
Dundee formation	limestone, some dolomite	10,000 to 45,000	17,000 to 28,000
Detroit River group			
Anderdon formation	limestone	10,000 to 45,000	17,000 to 28,000
Lucas formation	dolomite	10,000 to 45,000	17,000 to 28,000
Amherstberg formation	dolomite	10,000 to 45,000	17,000 to 28,000
Sylvania formation	sandstone, dolomitic sandstone	8,000 to 35,000	17,000 to 25,000
Bois Blanc formation	dolomite	10,000 to 45,000	18,000 to 28,000
Bass Islands group			
Raisin River formation	dolomite	10,000 to 45,000	18,000 to 28,000
Put-in-Bay formation	dolomite	10,000 to 45,000	18,000 to 28,000
Salina Group (upper portion)	dolomite, shale dolomite, shale	8,000 to 35,000	17,000 to 25,000

* From Dr. A. J. Mozola's report included in Supplement A.

\+ Compressive strength data from the published literature.



SOURCE: Report on heat-assisted tunnel boring machines, prepared by United Aircraft Research Laboratories, E.Hartford, Connecticut.

WASTEWATER MANAGEMENT SURVEY SCOPE STUDY
SOUTHEASTERN MICHIGAN AREA

DAILY ADVANCE RATE VS.
ROCK COMPRESSIVE STRENGTH

U.S. ARMY ENGINEER DISTRICT, DETROIT

FIGURE III

foot of rock removed.

Lining of the tunnels will depend directly on the geological formations. Based on experience in Chicago tunnels, it is concluded that lining of these tunnels is not required for hydraulic purposes. In areas of structurally weak geological formations, such as antrim shales, or possibilities of ground water infiltration or occurances of methane gas, lining of tunnels is necessary. Lining costs for the tunnels are included in the cost estimates for those areas where lining may be required.

A limited amount of work has been done regarding the hydraulics of tunnels drilled by boring machines. Some data has been published on hydraulics of blasted tunnels by Huval (8). The values of "n" in Manning's formula as reported by Huval vary from 0.027 to 0.041. Based on experience in the Chicago area, it has been concluded that the boring machines will render a much smoother surface than the blasting methods. Therefore, a lower value of 0.022 has been assumed for the design. The design velocities for the tunnels vary from six to sixteen feet per second.

Material excavated during tunneling operations will be transported to the surface either through a vertical shaft or an inclined ramp. With the large diameter boring machines, a skip-elevator cannot move material rapidly enough. Therefore, an inclined ramp with a belt conveyor should be used. Conveyor systems as much as 20 miles in length may be required to transport the rock to a removal point. Depending on rock quality, the excavated material can be used for such things as landfill or concrete aggregate. If so used, it could reduce the cost of the tunneling operation. However, no value has been assumed for the excavated material in the cost estimates.

It is anticipated that the construction on the project will be carried out in three shifts per day on a seven day per week basis. Based on this assumption approximately two miles of tunnel will be constructed per boring machine in one year. This assumes an availability of 35 percent for the boring machines.

Vertical Drops

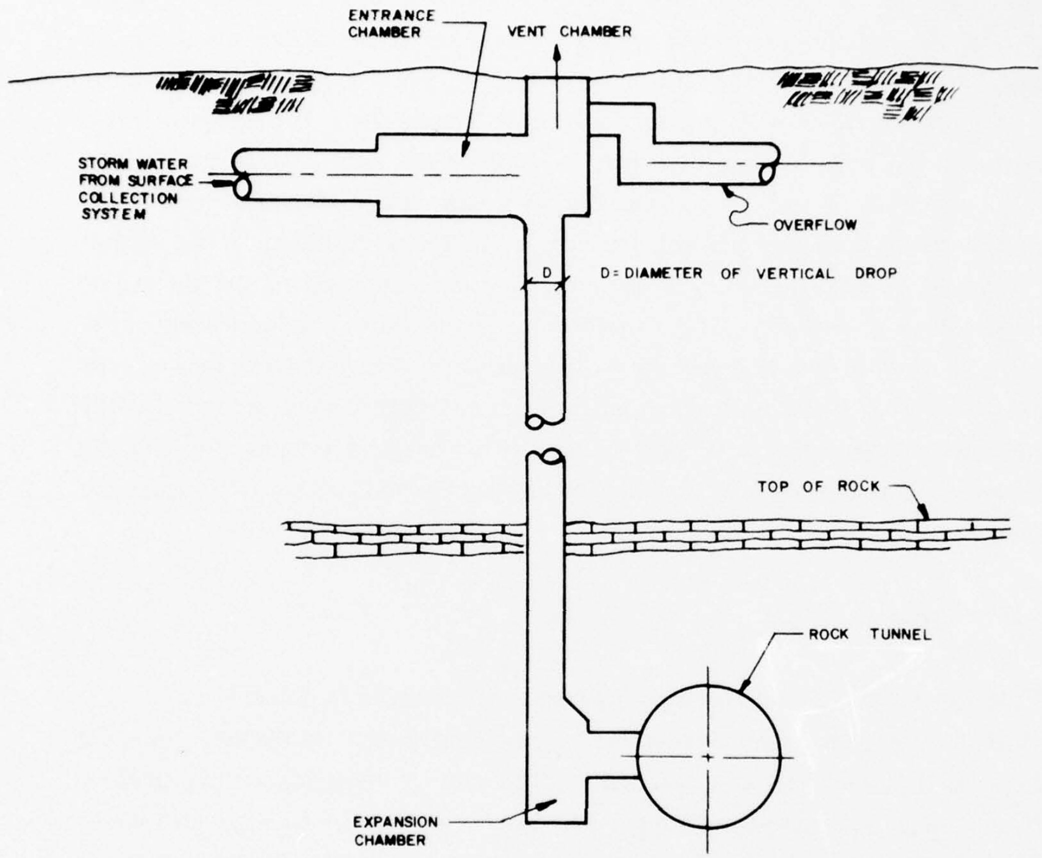
In the design of a tunnel and mined storage system each of the overflow points from the existing collection system requires a vertical drop for transporting the flow to the underground tunnel system. These shafts vary in diameter from 2.5 to 6.5 feet. Sizing of the vertical shafts is based on a design criteria suggested in a report by the Environmental Protection Agency (9). The design of these vertical drops assumes that they will be running full with a surcharge head on the inlet of about five feet. Based on these assumptions the capacities of the vertical shafts have been estimated to vary from 460 to 2,000 cfs. The vertical shafts will be constructed by augering down from the grade to the tunnels or by raise-boring methods. These shafts will be lined with a casing for structural purposes and to minimize seepage of ground water. Provision will be made to dissipate energy in an expansion chamber at the junction of these vertical drops with the tunnels. Figure IV shows a typical lay out of a vertical drop and the expansion chamber. A water cushion in the chamber will be used to dissipate the energy.

Access Shafts

Access shafts are used for transporting men and equipment as well as for conveying ventilation air and power conductors. These shafts vary in diameter from 20 to 35 feet. Larger sizes of access shafts will be used for the major pumping stations to be located near the regional reservoirs. Access shafts will be constructed either by conventional methods of drilling and blasting or by jacking and slip-form construction. These shafts will be encased in concrete. One shaft should be provided for every five miles of tunnel. This is the average distance a boring machine can traverse before requiring major overhaul and reconditioning.

Interceptors

Interceptors are designed on the basis of Manning's formula for pipe flowing full with a roughness coefficient, "n" , of 0.013. These interceptors follow the natural grade along the proposed interceptor routes as much as possible with an average cover of 12 feet. Interceptors considered in this report are Class IV reinforced concrete pipe.



TYPICAL LAYOUT OF VERTICAL DROP

NOT TO SCALE

WASTEWATER MANAGEMENT SURVEY SCOPE STUDY
SOUTHEASTERN MICHIGAN AREA

TYPICAL VERTICAL DROP STRUCTURE

U.S. ARMY ENGINEER DISTRICT, DETROIT

FIGURE IV

Force Mains

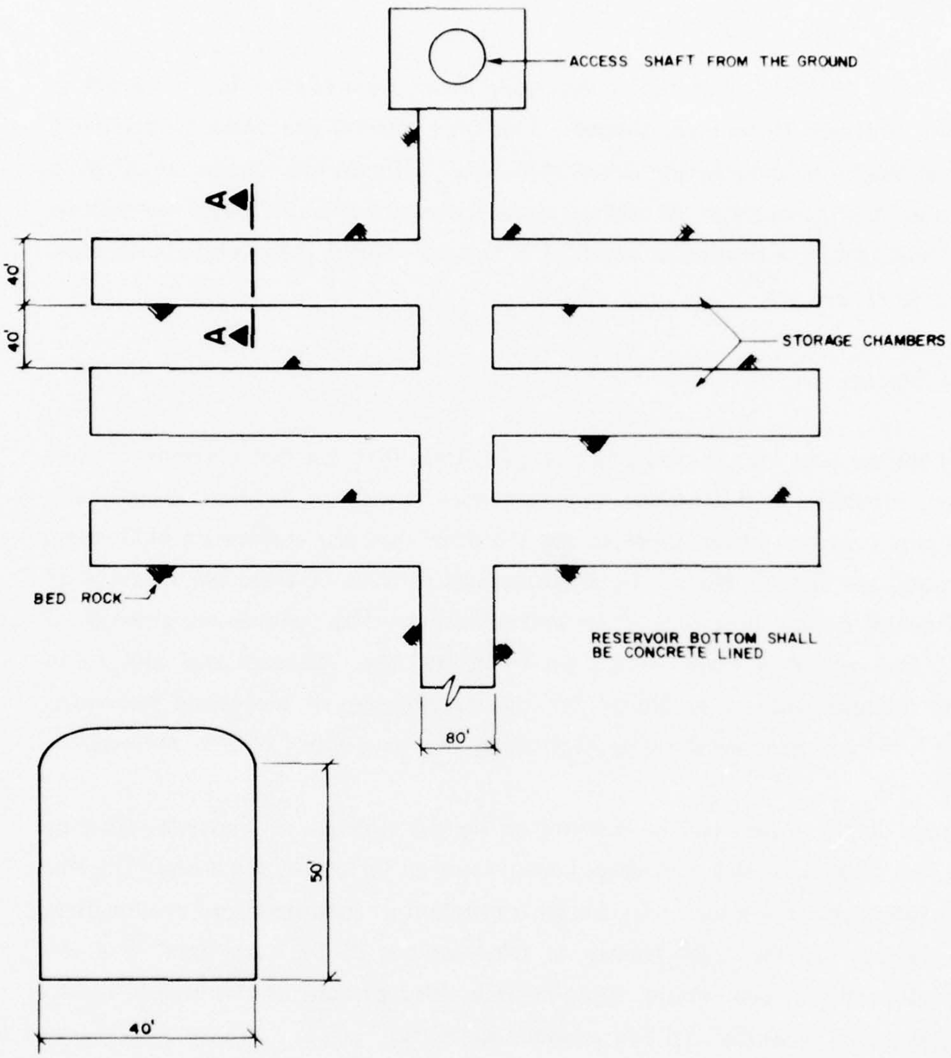
Force mains that are used to convey peak flows are designed for a maximum velocity of about 15 feet per second. This high velocity will occur for relatively short periods of time during periods of peak flow. Effluent force mains are designed for a maximum velocity of 10 feet per second. Force mains will follow the existing grade maintaining a minimum cover of 5 feet to prevent interference with local underground utilities.

Mined Storage

Mined storage reservoirs are used to store the flows from the tunnels under various schemes discussed in this report. Two reservoirs are to be located beneath Lake St. Clair, with one at Mt. Clemens and the other near the confluence of Conners Creek and the Detroit River. Rock formations in both of these areas consist of the Traverse Group, limestone, shale and dolomite. The compressive strength of these rocks will vary from 10,000 psi to 35,000 psi. Conventional long room mining methods will be employed for the construction of the mined reservoirs. Figure V is a schematic drawing illustrating the long room mining method.

The size of the rooms will be determined by the stability of the rock. Rooms forty feet wide and fifty feet deep have been used for estimating costs. The size of the intermediate supports also will be a function of rock stability. Intermediate supports may occupy from twenty to fifty percent of the total area. For the design purposes of this report, approximately fifty percent of the area has been assumed to be acquired for intermediate supports.

Drilling and blasting or boring machines will be used for the construction of these reservoirs. Reservoirs will be concrete lined on the bottom to facilitate solids removal. Concrete lining also may have to be provided on the sides in cases of excessive ground water infiltration, low compressive strength of the rock or rocks subject to deterioration by exposure to intermittent wetting.



SECTION A-A

NOT TO SCALE

WASTEWATER MANAGEMENT SURVEY SCOPE STUDY
SOUTHEASTERN MICHIGAN AREA

TYPICAL LAYOUT OF LONG ROOM MINING TECHNIQUE FOR CONSTRUCTION OF A MINED STORAGE

U.S. ARMY ENGINEER DISTRICT, DETROIT

FIGURE V

Surface Reservoirs

Two types of surface reservoirs are used in this report. Large reservoirs are designed to store runoff from highly urbanized areas and vary in capacity from 7,500 MG to 11,000 MG. Smaller reservoirs are designed to serve upland areas approximately the size of one township and vary in capacity from 300 MG to 2,500 MG.

Surface reservoirs are designed as multiple cell units in order to allow flexibility in operation. Only the required number of cells will be used to contain the runoff from a particular storm, thereby eliminating the necessity of operating the entire facility for smaller storms. Also, the multiple cell concept allows one cell to be empty for cleaning or maintenance without affecting the service of the entire facility. For estimating purposes, rectangular shaped cell modules have been used. It is recognized that other shapes may be more aesthetically appealing and they can be incorporated into the detailed design. For design purposes a water depth of twenty feet and a free board of four feet has been assumed for each cell.

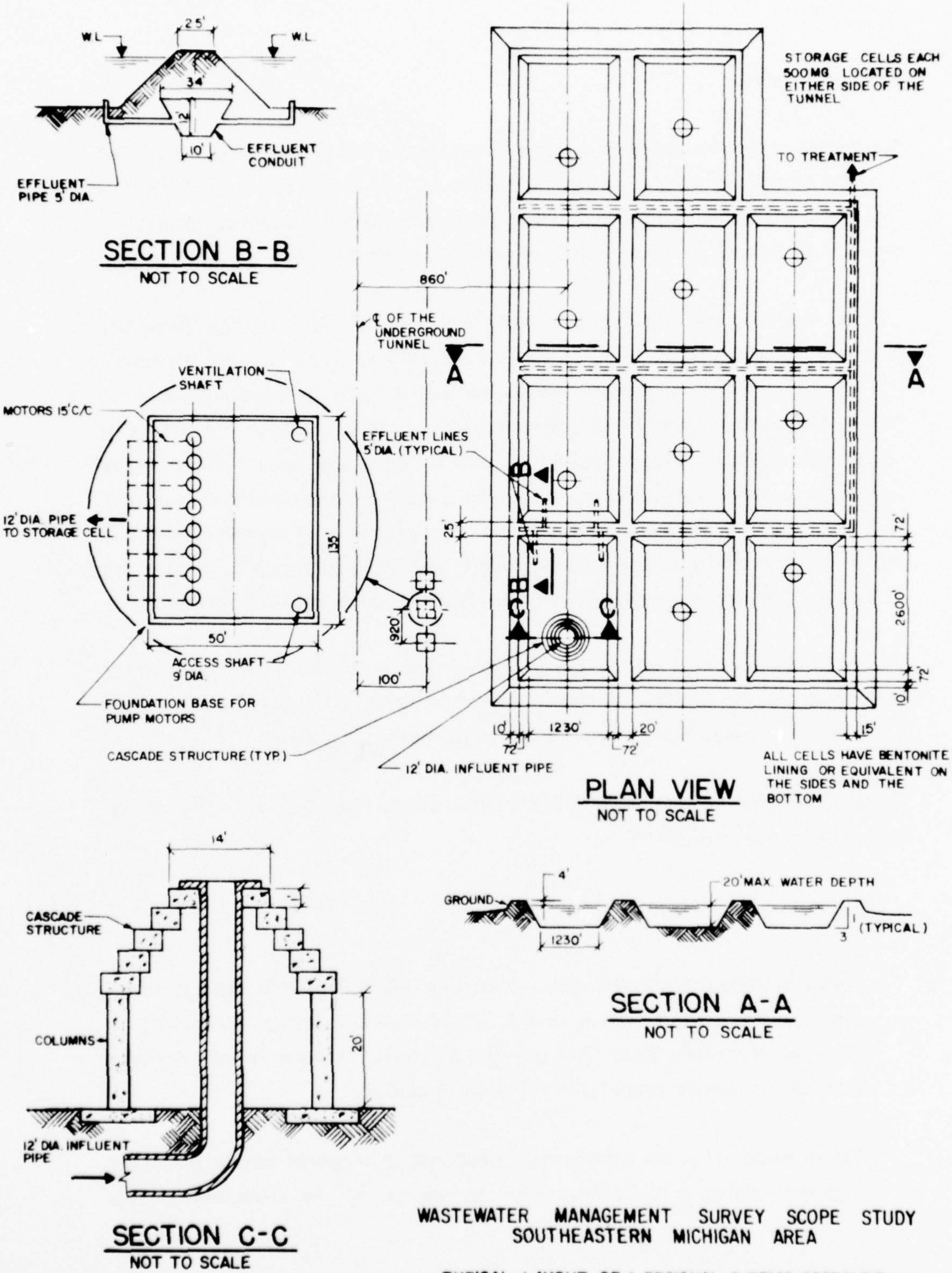
Individual reservoir cells will be constructed of earthen dikes with a slope of three horizontal on one vertical. Each cell should be lined at the bottom and along the sides with bentonite or some other impermeable material.

Design considerations as applicable to the large regional reservoir and smaller upland reservoirs are discussed below:

Regional Surface Reservoirs

Regional surface reservoirs are divided into 500-MG storage capacity cells. Each cell is 2,750 feet long and 1,375 feet wide covering approximately 85 acres of surface area. This provides a sufficient number of cells for each reservoir to ensure proper flexibility in operation.

Storm water from the tunnels is pumped into the regional surface reservoirs. Figure VI shows a typical layout of the storage cells for a regional surface



WASTEWATER MANAGEMENT SURVEY SCOPE STUDY
SOUTHEASTERN MICHIGAN AREA

TYPICAL LAYOUT OF A REGIONAL SURFACE RESERVOIR AND PUMP MOTORS

U.S. ARMY ENGINEER DISTRICT, DETROIT

FIGURE VI

reservoir. As shown in the figure, storage cells are symmetrically located on either side of the center line of the underground tunnel. Each cell or a pair of cells is served by a set of 100-MG pumps which are located in the wet well adjacent to the tunnel. All pumps discharge to a common header which carries storm water into each cell or a pair of cells. Influent water flows over a concrete cascade structure which provides aeration to increase the oxygen content of the water.

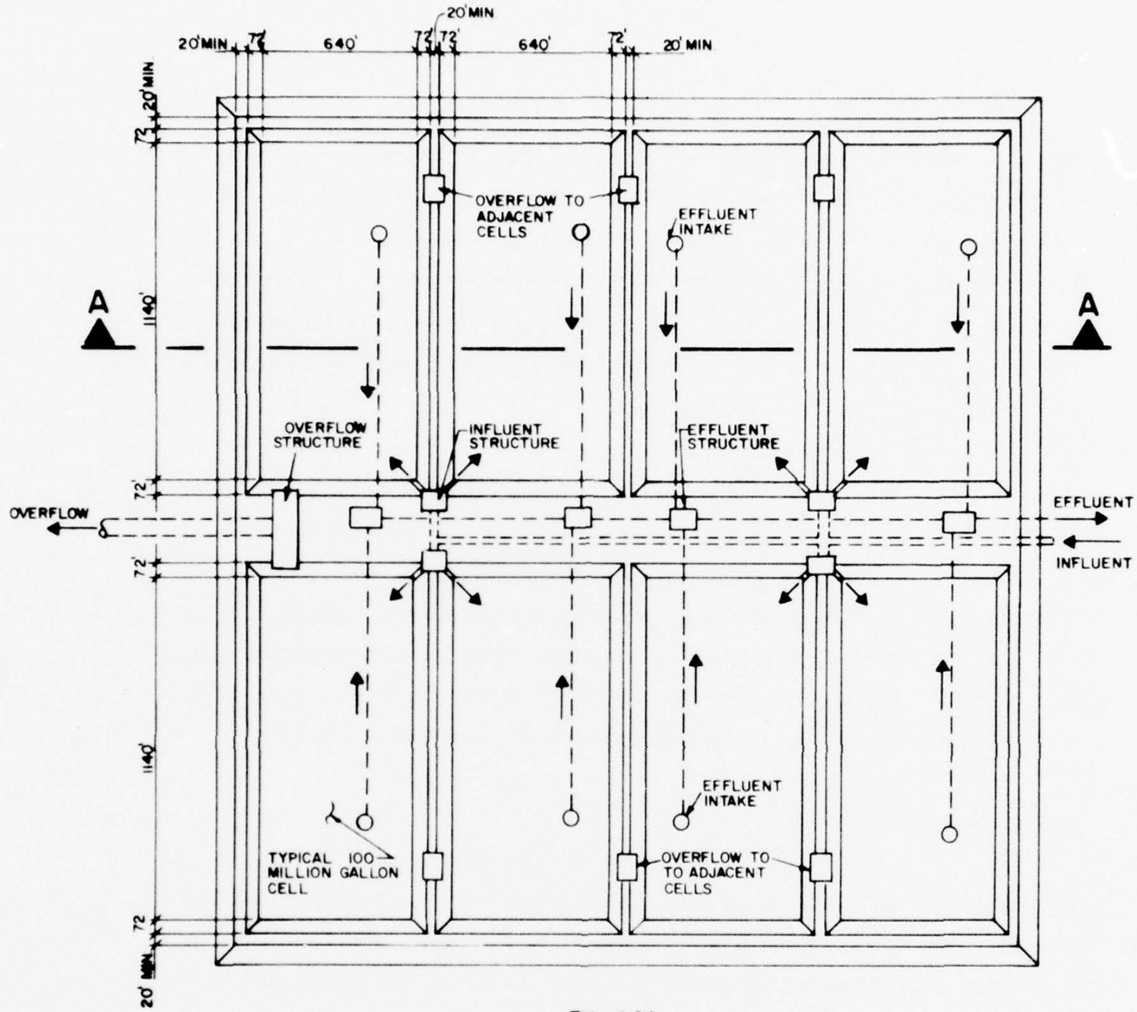
Effluent from each storage cell is taken through two pipes into a concrete conduit. Each of these conduits is connected to six storage cells and designed to carry approximately 1,000 MGD which is the design capacity of the receiving treatment plant. Each of the conduits serving six cells discharges into another concrete conduit along the sides of the cells which serves all storage cells on one side of the tunnel. The concrete conduits are designed as trapezoidal channels with a velocity of approximately seven feet per second.

Upland Surface Reservoirs

Smaller upland reservoirs are divided into multiple cells, each with a 100-MG capacity covering approximately 20 acres of surface area. Figure VII shows a reservoir with a typical multiple cell arrangement. The use of 100-MG cells provides a sufficient number of cells to insure flexibility in operation of the facility but does not necessitate excessive duplication of equipment and facilities. It is recognized that an optimum size and number of cells exist for each reservoir and that future detailed analysis of each reservoir and its service area will provide this information.

Upland reservoirs with three types of influent structures are considered as follows:

Type 1 Gravity influent structures



PLAN

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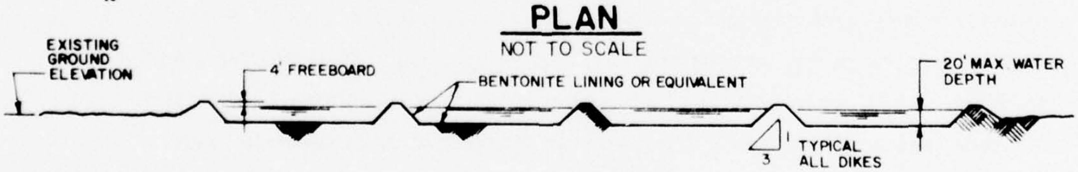


SECTION A-A

NOT TO SCALE

WASTEWATER MANAGEMENT SURVEY SCOPE STUDY
SOUTHEASTERN MICHIGAN AREA

TYPICAL 800 MILLION GALLON
UPLAND SURFACE RESERVOIR

U.S. ARMY ENGINEER DISTRICT, DETROIT

FIGURE VII

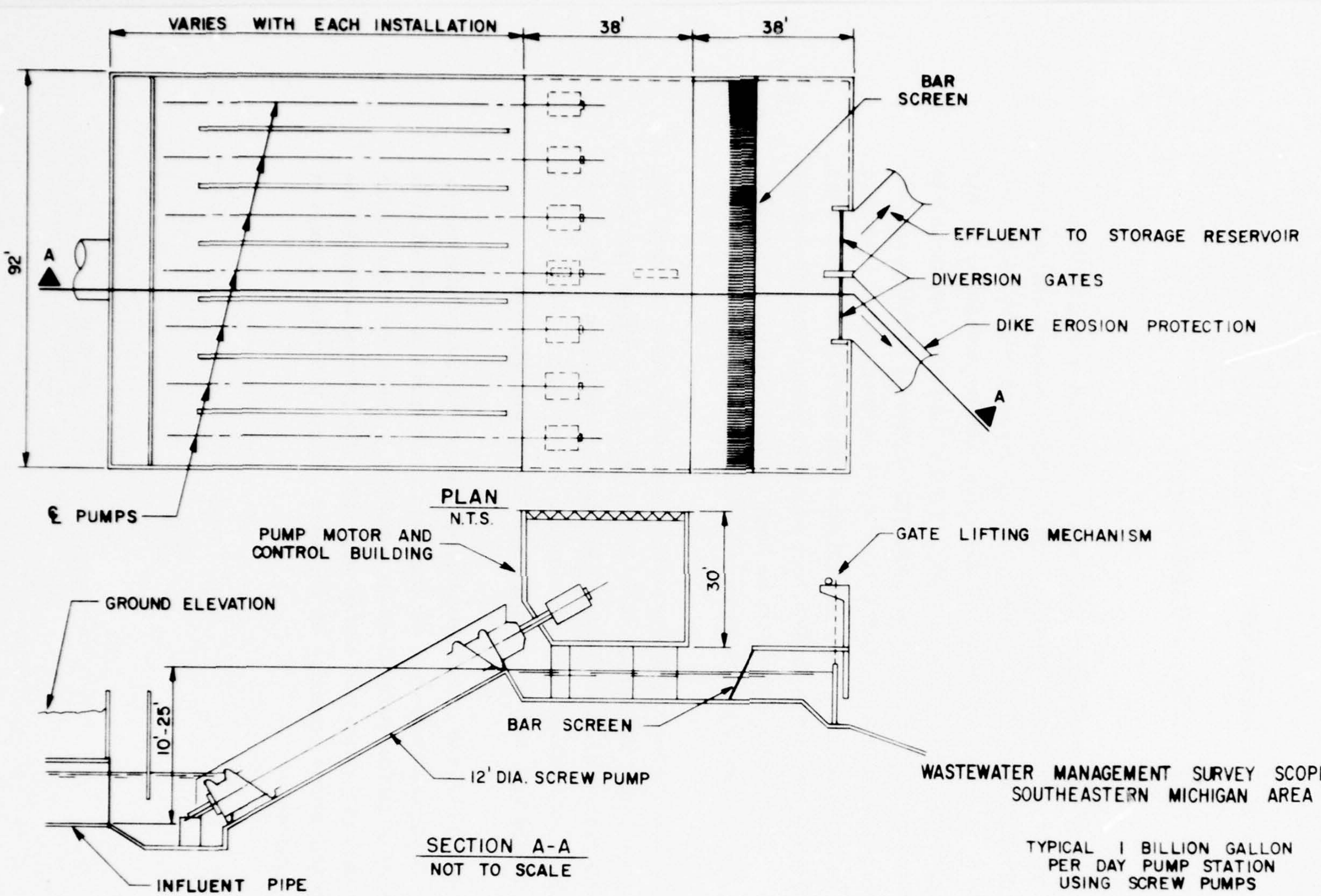
Type 2 Pumped influent structures

Type 3 Diversion influent structures

Type 1 influent structures are considered wherever the relief is sufficient for the use of reservoirs with gravity influent without excessive encroachment on the flood plain. Many more facilities of this type may be used if it is possible to locate reservoirs in flood plains, but the desirability of this arrangement is questionable. Type 2 influent structures are considered wherever the relief is small, thus reducing the possibility of finding reservoir sites suitable for gravity influent. Type 3 influent structures are considered for currently developed areas or areas near lakes and large streams and are used where the pumping station is at a location remote from the reservoir site. Storm water interceptors are likely to be constructed in these areas and the flow would be intercepted and pumped to a suitable reservoir site.

Two cells are served by a common influent structure as shown in Figure VII. A typical Type 1 influent structure contains mechanically cleaned trash racks for removing large solids and large slide gates for controlling the flow into either or both cells served by the structure. Erosion protection for the dikes is provided by a concrete structure near the influent discharge.

A Type 2 influent structure is used in conjunction with a reservoir that requires low lift influent pumping at the reservoir site. A typical influent structure consists of pumps, pump structure, a building to house the pump motors and controls, mechanically cleaned trash racks, slide gates for controlling the flow and erosion protection for the dikes. Figure VIII shows a detail of the structure.



WASTEWATER MANAGEMENT SURVEY SCOPE STUDY
SOUTHEASTERN MICHIGAN AREA

TYPICAL 1 BILLION GALLON
PER DAY PUMP STATION
USING SCREW PUMPS

U. S. ARMY ENGINEER DISTRICT, DETROIT

FIGURE VIII

A Type 3 influent structure is used in conjunction with a remote pumping station. Storm water is pumped at a pumping station and transported to the reservir influent structure by means of a force main. A typical influent structure includes a diversion structure for controlling the flow into either or both cells served by the structure as well as provision for erosion protection for the dikes near the structure.

Effluent structures consist of a wet well and necessary pumps or control valves. Two cells are served by a common effluent structure as shown in Figure VII. The reservoir cells drain to the wet well where the storm water will either flow by gravity to an interceptor system or be pumped to a major collection interceptor or force main. The effluent rate is governed by an automatic flow rate control valve with the gravity effluent system and by the pumping rate with the pumped effluent system.

It is assumed that reservoirs with pumped influent have gravity effluent and that reservoirs with gravity influent have pumped effluent, except in areas where force mains are required to transport the storm water from the reservoirs to treatment facilities. In these areas reservoirs are required to have pumped effluent regardless of the type of influent structure.

Each reservoir is equipped with overflow weirs to prevent the design capacity of the reservoir from being exceeded. Overflows are discharged to the nearest receiving stream.

Underground Reservoirs

Underground reservoirs will be concrete structures with nominal earth cover. Each reservoir is divided into several small chambers from which the overflow enters large chambers. This is similar to the concept proposed by Roy F. Weston for certain areas in the vicinity of Washington, D.C., (10).The smaller grit removal chambers are designed for maximum velocity of one foot per second at peak flows and equipped with mechanical solids removal equipment. These chambers allow the grit and heavier solids to settle out before the flow reaches the larger storage chambers.

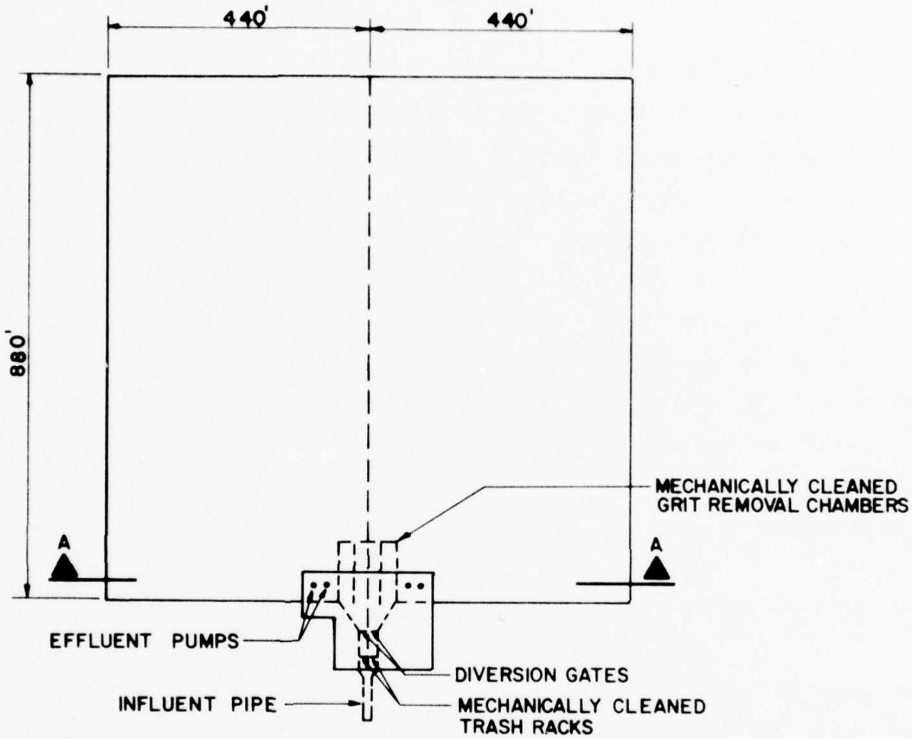
It is assumed that these reservoirs have gravity influent and pumped effluent with each reservoir containing mechanically cleaned trash racks, large slide gates for diverting flows to the different chambers, mechanically cleaned grit chambers, and pumps for emptying the facility. Also it is assumed that all major equipment is housed within a suitable building for this type of facility is being located in more highly developed areas or parks. Figure IX shows a typical underground reservoir.

Each reservoir must be adequately ventilated before personnel can enter the facility for cleaning or maintenance. Because of the intermittent requirements for this ventilation and the high cost of duplicating ventilation equipment at each reservoir site, it appears that ventilation equipment mounted on portable trailers is the most feasible solution to the problem.

The required ventilation fans are eight to ten foot in diameter. Approximately eight of these units are required for each 100-MG of storage capacity in order to ventilate the entire facility at one time.

Aeration could be included in this type of facility if it is necessary to insure that the storm water remain aerobic under all conditions. Aeration could best be accomplished with a low pressure diffused air system.

It is possible that many of these underground reservoirs may be located in areas with high ground water tables. In such cases it requires extensive dewatering during construction and necessitates protecting the reservoirs against flotation. This increases the construction costs for these facilities as no submergence has been assumed.



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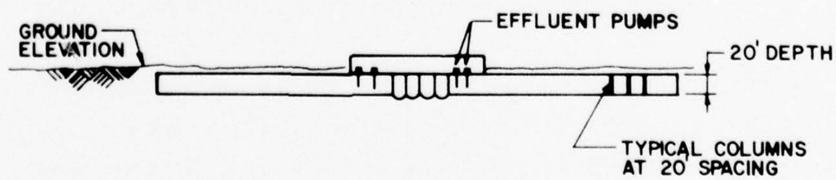


SECTION A-A
NOT TO SCALE

WASTEWATER MANAGEMENT SURVEY SCOPE STUDY
SOUTHEASTERN MICHIGAN AREA

TYPICAL 100 MILLION GALLON UNDERGROUND STORAGE RESERVOIR WITH GRAVITY INFLUENT AND PUMPED EFFLUENT

U.S ARMY ENGINEER DISTRICT, DETROIT

FIGURE IX

Surface vs. Underground Reservoirs

Surface reservoirs will be used where they do not conflict with existing and planned land use patterns. It is not expected that there will be any major nuisance problems associated with this type of facility. However, the large land requirements, of approximately 225 acres per 500-MG facility (100 acres surface area), prevent its use in more densely populated areas. The land required for a surface reservoir facility may be developed into a park, but the necessity of emptying or nearly emptying the reservoir after each storm would reduce its desirability as a park area. Underground reservoirs require less land than an equivalent surface storage facility, and they may be located under parks and open spaces. This would allow their use in more densely populated areas, but in many cases, their high cost makes it more desirable to intercept and pump the storm water to a remote surface storage facility.

Pumping Facilities

The required pumping facilities are divided into two major groups: (1) influent pumping and (2) effluent pumping. Influent pumping is provided to handle peak flows into the upland and regional surface reservoirs. Effluent pumping is provided from the upland reservoirs, when necessary, to discharge to interceptors or treatment facilities. Also, facilities are provided for pumping water from the tunnels and mined storage reservoirs to the treatment facilities at the ground level.

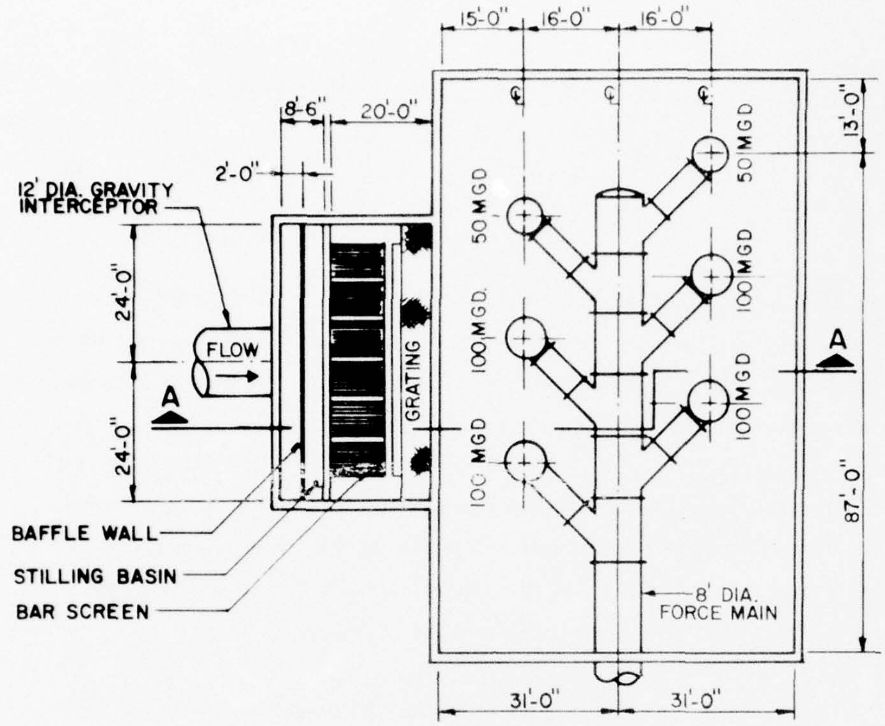
Many upland storage reservoirs will be located such that conditions do not permit gravity influent of all runoff from the reservoir service area. In these cases influent pumping is required. The peak flows to be pumped are based on the area served and its population density as discussed in the Hydrologic Considerations section. Upland reservoir service areas where the required lift is small (less than 25 feet), are best served by screw pumps because of their ability to efficiently pump widely varying flows at these small heads. Figure VIII shows a typical installation using screw pumps. These screw pumps are ten to twelve feet in diameter.

Upland reservoir service areas where the head is higher than 25 feet or in areas where the pumping station must be located remote from the storage reservoir are best served by vertical turbine pumps. Figure X shows a typical turbine pumping station. These pumps are 4 to 4.5 feet in diameter. An emergency by-pass must be located in the vicinity of each pumping station to prevent flooding of the station in case of power failure.

Influent pumps for regional surface reservoirs are vertical turbine type and located in wet wells adjacent to the tunnels. Figure XI shows a typical lay out of a wet well, pumps and screen chamber for influent pumping. A screen chamber is provided ahead of the pumps in order to retain large solids and other materials which might cause problems in the operation of the pumps. The screen chamber is sized for an approach velocity of five feet per second. The screen will be cleaned using a 5-foot travelling rake mechanism. The motor and other accessories for the rake mechanism are located above the screen chamber in a room which is kept under positive pressure to avoid entrance of water.

As shown in Figure XI, an entrance gallery is used to connect the tunnel with the wet well. The entrance gallery is designed to keep the approach velocities in the wet well around two feet per second. The wet well is designed according to the Hydraulic Institute Standards for multiple pump suction wells. Both the wet wells and entrance galleries are concrete lined. A power operated slide gate is provided in the entrance gallery for stopping the flow into the well during maintenance operations. Wet wells are to be located on either side of the tunnel on approximately 460-foot centers.

Four-stage vertical turbine pumps with a capacity of 100 MGD have been used for this design. These pumps are located 15 feet on centers with the pump motors located directly above the pumps on a concrete base at the ground surface. Each pump is operated by a 5,000 horsepower motor. Figure VI shows the lay-out of the motors. The design peak flows for influent pumping into the regional surface reservoirs are very high. Therefore, one set of pumps is used for pumping storm water into each cell on the surface. The size of the wet well is adjusted to accomodate the number of pumps in each set used with a particular design. Each set of pumps discharges into a common header near the surface which empties



PLAN VIEW
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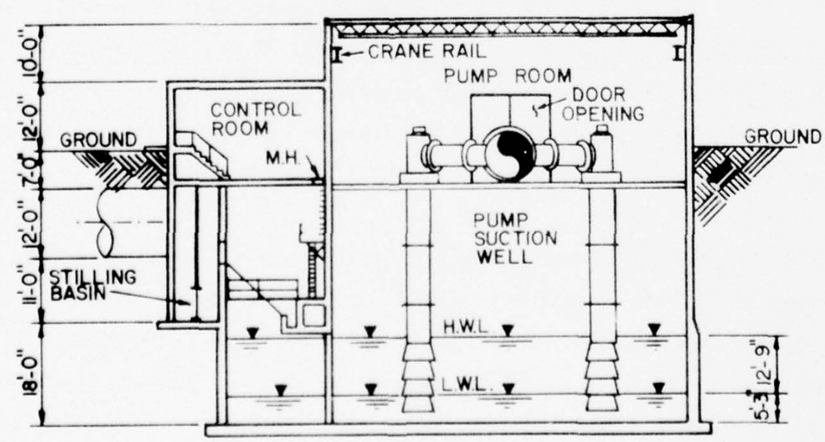


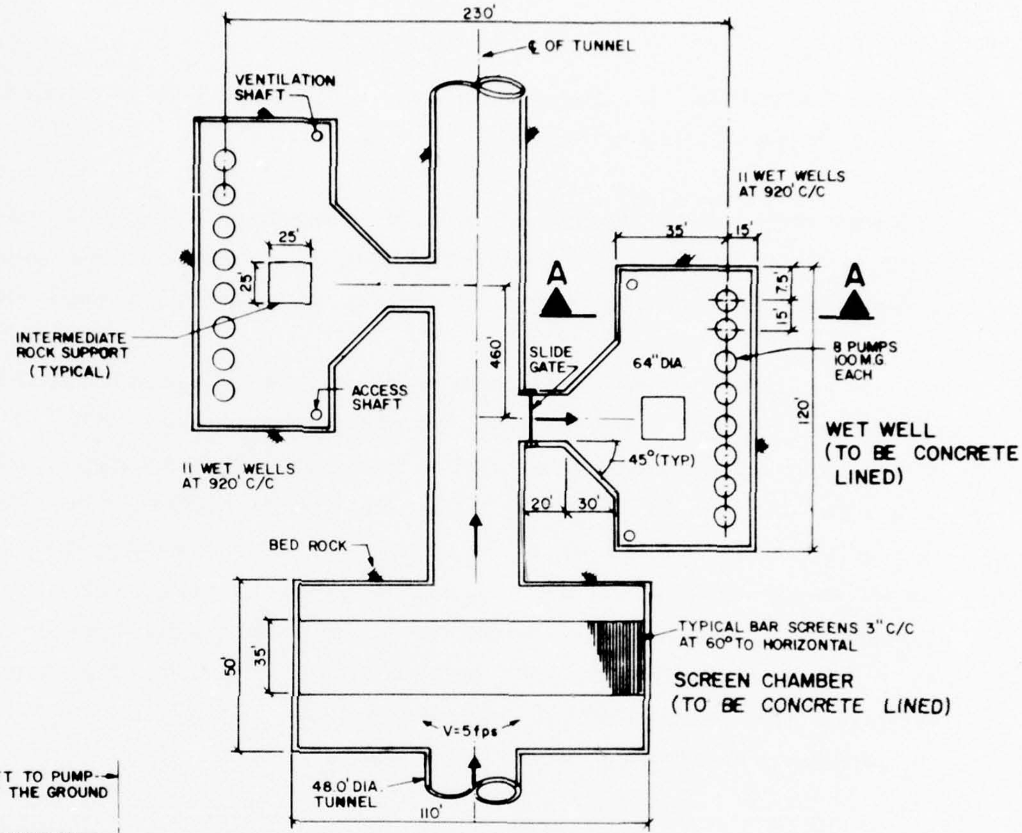
SECTION A-A
NOT TO SCALE

WASTEWATER MANAGEMENT SURVEY SCOPE STUDY
SOUTHEASTERN MICHIGAN AREA

TYPICAL 500 MILLION GALLON
PER DAY PUMP STATION
USING TURBINE PUMPS

U.S. ARMY ENGINEER DISTRICT, DETROIT

FIGURE X



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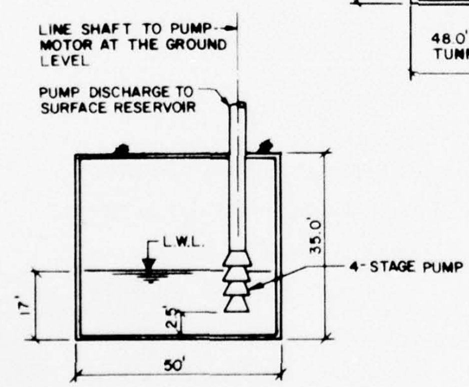


SECTION A-A

NOT TO SCALE

WASTEWATER MANAGEMENT SURVEY SCOPE STUDY
SOUTHEASTERN MICHIGAN AREA

TYPICAL LAYOUT OF WET WELLS AND SCREEN CHAMBER FOR PUMPING STATIONS

U.S. ARMY ENGINEER DISTRICT, DETROIT

FIGURE XI

into the reservoir cell. In some cases of influent pumping, one set of pumps can be used for two surface storage cells.

Effluent pumps may be required with the upland reservoirs for pumping storm water to the interceptors or the treatment facilities. The capacity of these pumps is based on 0.003 inches per hour of run off from the contributing drainage area.

Effluent pumps also are used for pumping storm water from the tunnels and mined storage reservoirs to the treatment facilities at the surface. A set of 100-MGD, four-stage, vertical turbine pumps are used for this purpose. Total pumping capacity at any one treatment facility may vary from 400 MGD to 1,000 MGD depending on the scheme and the location of the facility. The basic design considerations for the entrance galleries and wet wells are the same as discussed under influent pumping. The pump motors are located in a sealed chamber adjacent to the wet well. The chamber is concrete lined at the bottom and the sides. Each chamber is provided with an access shaft and ventilation shaft. An overhead crane is provided for performing maintenance work on the motors.

Solids Handling

Storm water contains a significant amount of suspended material (500- 1,500 ppm of suspended solids) of which a large percentage is expected to settle out in the storage facilities. Also, solids will accumulate in collection tunnels as the tunnels are not designed to maintain adequate velocities at all times to keep solids in suspension. Force mains and interceptors used for transporting collected storm water to treatment facilities are designed to maintain adequate velocities which prevent appreciable solids accumulation.

Periodic maintenance of the tunnels will include the removal of accumulated solids. This can be accomplished by using a remotely controlled machine capable of loosening and transporting solids to collection points near regional storm water treatment plants. The solids then will be pumped to existing solids handling facilities at the treatment plants. This is more desirable than providing separate solids handling facilities. Mined and underground reservoirs can be cleaned by a similar method.

In surface reservoirs solids will be allowed to accumulate to a depth of several inches before they are removed. Nuisance problems of these accumulating solids may be reduced by keeping them covered with one or two feet of water at all times. A similar type of operation has been very successful in reducing odor problems in a facility in Springfield, Illinois (11).

Preliminary investigations indicate that the required cleaning frequency in surface reservoirs will be no more than once every few years. Cleaning may be accomplished by rubber tired machinery capable of scraping, loading and hauling the solids to the regional treatment or disposal facilities.

Coarse screening is provided in the storm water collection and storage system wherever pumping is required. The screens are placed ahead of the pumps in order to protect the pumps from large objects which may clog or damage the pumps. These screens will be self cleaning and, as part of a regular maintenance program, the screenings will be hauled to suitable disposal locations.

System Reliability

System reliability refers to the safety features provided in the design to handle situations arising from mechanical failures, the occurance of storms producing runoff of greater magnitudes than the system capacity or unforeseen shifts or failures in geological formations. Maximum system reliability has been incorporated into the design of all schemes of storm water collection and storage by providing various design features for each component in order to insure their operational and functional reliability. Some of the major design features from the system reliability aspect are discussed below:

1. Upland storage facilities are designed as multiple cells in order to protect against failure of any one cell. Flooding of the influent pumping stations is prevented by the diversion structures included within their design. Storage cells are protected

against accidental flooding by the overflow structures. All the storage cells will be lined in order to prevent any contamination of the ground water.

2. Diversion structures are included at each of the vertical drops for bypassing flows. Tunnels are sized and sloped such that flow can be taken to any one of the two regional reservoir sites in Schemes One, Two and Five and any one of the two mined storage sites in Schemes Three and Four. Lining of tunnels is provided wherever rock strength is questionable. The use of control gates or bulkheads at the junction of two tunnels in order to isolate sections of tunnels for maintenance was investigated . However, due to their high cost and their use only during an anticipated rare occurance of failure of a section of the tunnel, they are not included in the tunnel design. If such an emergency does occur it will be more economical to construct a temporary bulkhead to perform the needed maintenance on the system.

3. A continuous source of power supply for all the pumping facilities is of utmost importance. Power failure at any of these pumping facilities will seriously hinder the functioning of the system. Two independent sources of power supply are necessary for each of these facilities wherever practical. In case of influent pumping facilities, dual power sources may be economically provided only for a portion of the facilities.

The operational reliability aspects of the entire system should be considered in detail in the future phases of planning. A centrally controlled program is necessary for monitoring the flow conditions at any point in the collection system. Suitably located sensing devices can accomplish this purpose. The locations and the type of suitable sensing devices should be evaluated.

DESIGN OF ALTERNATE SCHEMES

Five alternate schemes of collection and storage systems for combined and separate storm sewer overflows have been evaluated for the study area. All five schemes provide an integrated system utilizing interceptors, force mains, deep tunnels, and surface and mined storage reservoirs to collect and contain the combined sewer overflows and separate storm sewer overflows from the 1990 projected sewered areas of southeastern Michigan. Urbanized areas with high population densities and low availability of vacant lands are being served with deep tunnels and remotely located large surface or mined storage reservoirs. The more sparsely populated areas are being served with interceptors and local surface reservoirs. The service area for this report has been divided into seven drainage sub-areas as shown in Figure I.

SCHEMES ONE AND TWO

Under these schemes, two types of a collection and storage system are proposed. In highly urbanized areas, large deep-tunnel interceptors, capable of handling peak storm flows, transport runoff to two large, regional surface reservoirs and subsequently to treatment facilities located along the North Branch of the Clinton River in Macomb County and near the mouth of the Huron River in Monroe County. The remaining areas are served by a multiple storage-interceptor system in which smaller intermittent storage facilities are used to absorb peak storm flows. Effluent from the storage facilities is discharged into the regional interceptors and treated at the local or regional treatment facilities.

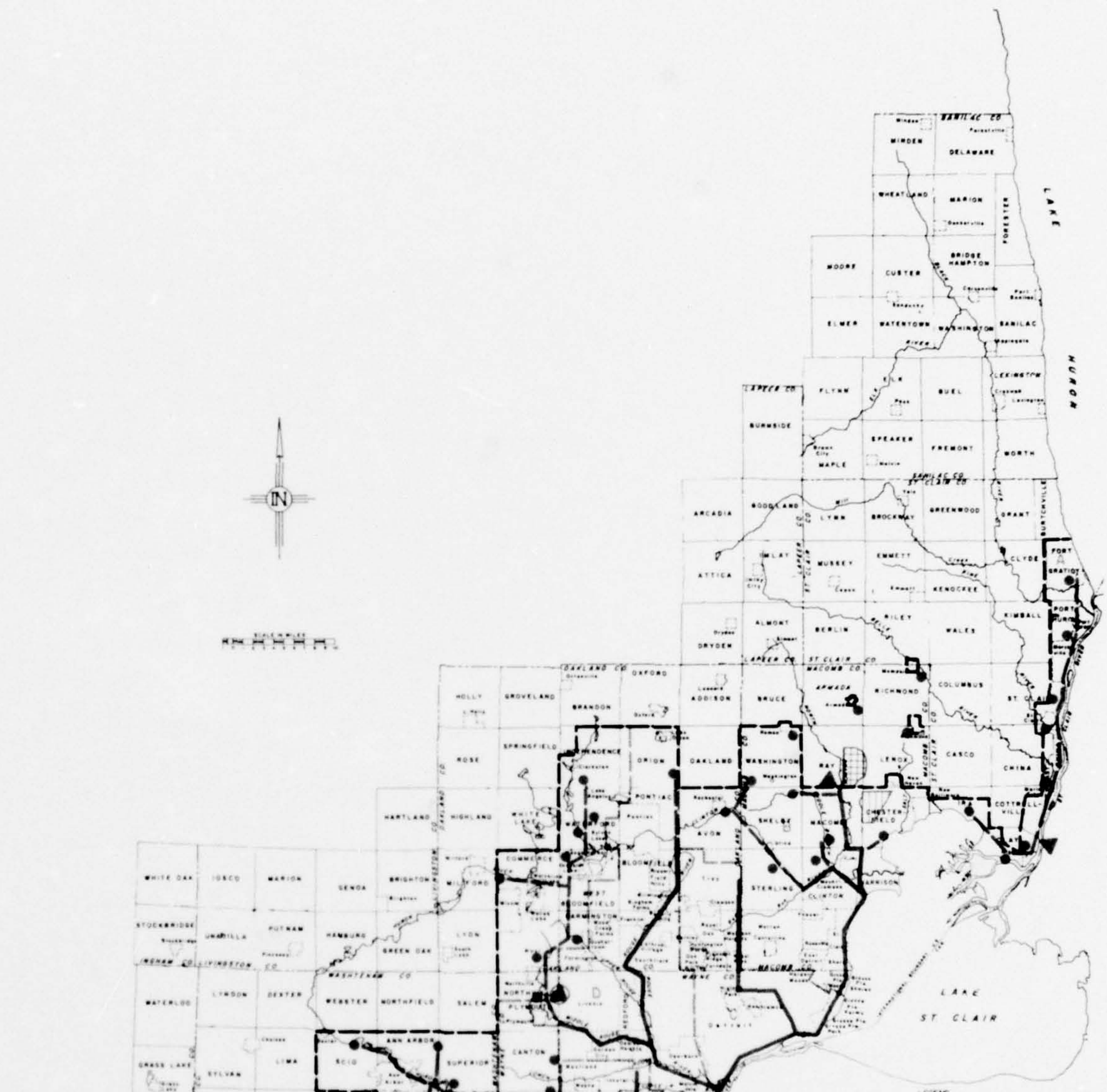
The communities of Armada, Richmond, Memphis, Romeo, Manchester, Adrian, Tecumseh, Blissfield and Dundee are provided with individual storage reservoirs, and are not included as part of the total collection system because of the high cost of the required connecting interceptors. These communities are more economically served by some type of local treatment.

The proposed storm water collection and storage system for Schemes One and Two is shown in Figure XII. Both schemes provide pick-up points for treatment at Algonac and the two regional surface reservoirs. In addition, Scheme Two also provides two additional pick-up points for treatment of storm water collected from drainage sub-areas E and G. These pick-up points are located near Plymouth and Ypsilanti as shown in Figure XII. Treatment at these two points reduces the sizes and lengths of the interceptors required for transporting storm water to the tunnels. This does not result in any change of tunnel sizes for Scheme Two from Scheme One. Another significant change between these schemes occurs in the total quantity of annual power consumption for pumping storm water from the tunnels to the surface reservoirs. The annual power cost for Scheme Two is less, because this scheme has less total quantity of storm water to pump than Scheme One.

Table 2 summarizes several major components of the collection and storage system for Schemes One and Two for each drainage sub-area. These are tunnels, vertical drops, access shafts, interceptors, force mains, surface reservoirs and pumping requirements. This table shows length, size, capacity, number of units, power requirements and land requirements as they are applicable to the various components.

A total of 134 miles of tunnels are required in Schemes One and Two . They vary in size from 18 to 48 feet in diameter. Approximately 34.4 miles of tunnels require concrete lining because of the structurally weak geologic formation, and the remainder may require lining in some areas. Design velocities for the tunnels vary from 6 feet to 16 feet per second. The tunnels provide approximately twenty percent of the total storage required for the areas being served by the tunnels. The remaining storage is provided in two regional surface reservoirs located in Macomb and Monroe counties.

Schemes One and Two each require 51 surface reservoirs of which 49 are small upland surface reservoirs serving the sparsely populated outlying areas and two are large regional surface reservoirs serving the urbanized areas. Upland reservoirs vary in capacity from 300 to 2400 million gallons. Table 3 summarizes the storage requirements for the various drainage sub-areas along with the amount of storage being provided in the reservoirs and the tunnels. Each of the two regional surface reservoirs has a storage capacity of 11,000 million gallons. Two alternate sites



WASTEWATER MANAGEMENT SURVEY SCOPE STUDY
SOUTHEASTERN MICHIGAN AREA

SCHEMES 1 AND 2 PROPOSED LAYOUT
STORM WATER COLLECTION SYSTEM WITH
SURFACE STORAGE
FIGURE XII

TABLE 2

SUMMARY OF VARIOUS COMPONENTS OF STORM WATER COLLECTION SYSTEM

SCHEMES ONE AND TWO

DRAINAGE SUB-AREA	COMPONENTS OF COLLECTION SYSTEM							COSTS+						
	Description	Length (miles)	Size (ft.)	Capacity	No. of Units	Power kwh x10^6	Land (acres)	Land x10^6	Component x10^6	Engin. Admin. Legal & Cont. x10^6	Total Capital x10^6	Annual Capital++ x10^3	Annual O & M x10^3	Total Annual x10^3
A	Upland Surface Reservoir			320-980 MG	8		1965	$ 9.84	$ 27.69	$ 8.31	$ 45.84	$ 2,707	$ 480	$ 3,187
	Force Mains	59.5	2-12						30.91	9.27	40.18	2,373		2,373
	Pumping Requirements													
	Upland Reservoir Inf.			350-970 MGD		6.6			11.01	3.30	14.31	845	66	911
	Upland Reservoir Eff.			13-26 MGD		6.6			0.25	0.08	0.33	19	66	85
B	Tunnels													
	Lined	4.4	34	10000 cfs					31.23	9.37	40.60	2,398	5	2,403
	Partially Lined	27.1	48	27000 cfs					212.75	63.83	276.58	16,335	27	16,362
	Vertical Drops		2.5-6.5	500-4000 cfs	26				1.39	0.42	1.81	107		107
	Access Shafts		20-35		6				7.11	2.13	9.24	546		546
	Regional Surface Reservoir			11000 MG	1		3210	16.05	70.28	21.08	107.41	6,343	150	6,493
	Upland Surface Reservoirs			710-1500 MG	7		3145	15.73	49.23	14.77	79.73	4,709	420	5,129
	Interceptors	35.8	2-7						17.12	5.14	22.26	1,315		1,315
	Force Mains	3.5	6-11						3.85	1.16	5.01	296		296
	Pumping Requirements													
	Regional Reservoir Inf.			17800 MGD		128.0			122.30	36.70	159.00	9,390	1,640 (1,280)	11,030 (10,670)
	Upland Reservoir Inf.			250-905 MGD		2.3			3.20	0.96	4.16	246	23	269
	Upland Reservoir Eff.			29-40 MGD		12.5			0.41	0.12	0.53	31	125	156
C	Tunnels													
	Partially Lined	33.9	18-48	2500-27000cfs					222.13	66.64	288.77	17,055	34	17,089
	Vertical Drops		3.0-6.5	700-4000 cfs	41				2.34	0.70	3.04	180		180
	Access Shafts		20		7				6.70	2.01	8.71	514		514

TABLE 2 (Con'd)

DRAINAGE SUB-AREA	COMPONENT OF COLLECTION SYSTEM							COSTS +						
	Description	Length (miles)	Size (ft.)	Capacity	No. of Units	Power kwh x10^6	Land (acres)	Land x10^6	Component x10^6	Engin Admin. Legal & Cont. x10^6	Total Capital x10^6	Annual Capital++ x10^3	Annual O & M x10^3	Total Annual x10^3
D	Tunnels													
	Lined	24.3	20-46	3500-17000cfs					$174.56	$52.37	$226.93	$13,402	$ 24	$13,426
	Partially Lined	25.2	34-48	5500-27000cfs					182.24	54.67	236.91	13,992	25	14,017
	Vertical Drops		2.5-6.5	500-4000 cfs	46				1.93	0.58	2.51	148		148
	Access Shafts		20		10				10.28	3.08	13.36	787		787
	Upland Surface Reservoirs			970 MG	1		370	$ 1.85	5.75	1.73	9.33	551	60	611
	Force Mains	7.5	3						2.18	0.65	2.83	167		167
	Pumping Requirements													
	Upland Reservoir Eff			26 MGD		1.4			0.05	0.02	0.07	4	14	18
E	Upland Surface Reservoirs			380-2010 MG	8		3345	16.74	53.59	16.08	86.41	5,103	480	5,583
	Force Mains	49.5	4-15						37.86	11.36	49.22	2,907		2,907
	Interceptors	9.5	5-7						6.43	1.93	8.36	494		494
	Pumping Requirements													
	Upland Reservoir Inf.			650-1520 MGD		4.3			13.81	4.14	17.95	1,060	43	1,103
	Upland Reservoir Eff.			10-54 MGD		11.7			0.29	0.09	0.38	22	117	139
F	Tunnels													
	Lined	5.7	30	6000 cfs					36.29	10.89	47.18	2,786	6	2,792
	Partially Lined	26.2	30-38	6000-17000 cfs					152.02	45.61	197.63	11,672	26	11,698
	Vertical Drops		2.0-6.5	300-4000 cfs	19				0.56	0.17	0.73	43		43
	Access Shafts		20-35		6				5.95	1.79	7.74	457		457
	Regional Surface Reservoir			11000 MG	1		3210	16.05	63.50	19.05	98.60	5,827	150	5,977
	Upland Surface Reservoirs			800-2480 MG	9		4640	23.21	75.49	22.65	121.35	7,167	540	7,707
	Interceptors	44.5 (32.0)	4-11 (4-7)						35.16 (19.71)	10.55 (5.91)	45.71 (25.62)	2,700 (1,513)		2,700 (1,513)
	Force Mains	25.5	3-12						19.95	5.99	25.94	1,532		1,532
	Pumping Requirements													
	Regional Reservoir Inf.			11000 MGD		164.0			75.96	22.79	98.75	5,832	1,640 (1,280)	7,472 (7,112)
	Upland Reservoir Inf.			470-1066 MGD		16.6			14.65	4.40	19.05	1,125	166	1,291
	Upland Reservoir Eff			21-66 MGD		12.6			0.44	0.13	0.57	34	126	160
G	Upland Surface Reservoirs			770-1620	7		2820	14.11	44.01	13.20	71.32	4,212	420	4,632
	Interceptors	50.0	3-8						21.99	6.60	28.59	1,689		1,689
	Force Mains	7.0	8-12						13.23	3.97	17.20	1,016		1,016
	Pumping Requirements													
	Upland Reservoir Inf.			375-1810 MGD		4.4			12.11	3.63	15.74	930	44	974
	Upland Reservoir Eff.			20-43 MGD		8.0			0.27	0.08	0.35	21	80	101

TABLE 2 (Cont'd)

DRAINAGE SUB-AREA	COMPONENT OF COLLECTION SYSTEM							COSTS+						
	Description	Length (miles)	Size (ft.)	Capacity	No. of Units	Power kwh x10^6	Land (acres)	Land x10^6	Component x10^6	Engin. Admin. Legal & Cont. x10^6	Total Capital x10^6	Annual Capital++ x10^3	Annual O&M x10^3	Total Annual x10^3
Rural Communities+++	Upland Surface Reservoirs			30-140 MG	9		795	$ 4.00	$ 5.37	$ 1.61	$10.98	$649	$ 135	$ 784
	Force Mains	5.5	6-9						4.08	1.22	5.30	313		313
	Pumping Requirements													
	Upland Reservoir Inf.			220-590 MGD		0.7			5.51	1.65	7.16	423	7	430
	Upland Reservoir Eff.			1-4 MGD		0.3			0.04	0.01	0.05	3	3	6
TOTAL COSTS FOR STUDY AREA								$117.58 ($117.58)	$1895.45 ($1880.00)	$568.68 ($564.04)	$2581.71 ($2561.62)	$152,477 ($151,290)	$7,142 ($6,422)	$159,619 ($157,712)
ANNUAL CAPITAL COST @ 7% for 50 YR												$187,071 ($185,615)	$7,142 ($6,422)	$194,213 ($192,037)
ANNUAL CAPITAL COST @ 10% for 50 YR												$260,391 ($258,365)	$7,142 ($6,422)	$267,533 ($264,787)

NOTES: No.'s in parentheses are for Scheme Two only.

+ All costs are based on ENR of 1,960.

++ Annual capital cost is based on 5-1/2 percent interest rate and 50-year project life.

+++ Consists of communities not served by major storm water interceptors

TABLE 3

SUMMARY OF STORAGE REQUIREMENTS

Sub Area	Contributing Drainage Area (Sq. Miles)	Total Storage Required (MG)	Storage Provided in Upland Reservoirs+ (MG)	Storage Provided in Regional Surface or Mined Storage Reservoirs and Tunnels ++ (MG)
A	97.70	4,620	4,620	
B	334.50	14,090	8,690	5,400
C	177.70	6,400		6,400
D	322.80	11,830	970	10,860
E	194.30	9,130	9,130	
F	438.80	18,830	13,030	5,800
G	161.10	7,570	7,570	
Rural Communities	14.70	695	695	
Total	1741.60	73,165	44,705	28,460

\+ Storage based on a runoff of 2.7 inches over the contributing area

++ Storage based on a runoff of 2.1 inches over the contributing area. Tunnels provide approximately 6,400 MG storage in Schemes One, Two and Five and 5,400 MG in Schemes Three and Four.

for these reservoirs have been shown in the Figure XII. Field investigations will be necessary in order to determine final sites.

The basic configuration of the storage cells for the regional reservoirs is shown in Figure VI. Twenty-two cells of 500 million gallons each, provide the total storage of 11,000 million gallons. The tunnel coming to the reservoir site is located below the center-line of the site with storage cells symmetrically located on either side. Each reservoir site requires approximately 3,200 acres of land including isolation of 1,000 feet on all sides from the surrounding areas. Storage site locations for the upland surface reservoirs are very general. Specific sites will have to be investigated for each of the reservoirs.

Vertical drops are used wherever necessary to direct the storm water flows from the surface collection system into the tunnels. These vertical drops have not been shown on the map of the proposed facilities for Schemes One and Two. An estimate has been made for the total number of vertical drops required and is included in the summary tables 2, 6 and 7. This estimate is based on the known overflow points in the existing combined sewer systems and the additional points required to collect storm water from the separate sewer systems.

Access shafts are provided every five miles of the tunnel length. Twenty-foot diameter access shafts are provided for transporting men and equipment during construction. Larger thirty-five-foot diameter shafts are used for pumping stations at the two regional surface reservoirs.

The interceptors included in Table 2 are required to transport stored storm water from upland surface reservoirs to pick-up points for treatment or to the tunnel interceptors.

The force mains refered to in Table 2 summarize both influent and effluent force mains. Influent force mains are provided to carry flows between pumping stations and upland surface reservoirs in cases where the pumping stations are located remote from the storage sites. Effluent force mains are required to transport collected storm water from upland surface reservoirs in areas where there is not enough available ground slope to use gravity interceptors.

Pumping requirements are summarized in Table 2 for both upland and regional reservoirs. Influent and effluent pumping for upland reservoirs is provided as discussed in the Design Considerations section.

No effluent pumping is assumed to be required for either of the two regional surface reservoirs. Influent pumps for the Macomb County regional surface reservoir are sized to handle a peak flow of 17,800 MGD, and those for Monroe County regional reservoir are sized for 11,000 MGD. The pumping capacity of 17,800 MGD is provided to handle peak flows from the entire urbanized area in the event of any emergency failures in the Monroe county pumping or storage facilities.

Twenty-two wet wells, each housing eight vertical turbine pumps of 100-MGD capacity, are used for influent pumping at the Macomb County reservoir. These wet wells are located on alternate sides of the tunnel at 460-foot centers. Motors for the pumps are located at the ground level. Each set of eight pumps discharges into a 12-foot diameter force main which discharges into one storage cell. The layout of the wet wells and pumps is the same as discussed under Design Considerations section.

The Monroe County regional surface reservoir has eleven wet wells, each housing ten 100-MGD vertical turbine pumps, for influent pumping. Each set of ten pumps discharges into a 14-foot diameter force main which discharges into a pair of storage cells. Pump motors are located at ground level.

Land requirements have been estimated for surface reservoirs only. The estimates are based on the reservoir configurations discussed under Design Considerations and include an isolation zone of 800 feet on all sides for upland reservoirs and 1000 feet for regional reservoirs.

The total power requirements shown in Table 2 are based on pumping rates equivalent to 0.003 inches of runoff per hour over the contributing drainage areas for a period of 120 days per year. Peak power requirements have also been estimated for locations where they are of sufficient magnitude to have a large impact on the available power supply. These estimates are shown in Table 4.

TABLE 4
PEAK ELECTRICAL POWER REQUIREMENTS

Location	Peak Power in Kilowatts				
	SCHEME 1	SCHEME 2	SCHEME 3	SCHEME 4	SCHEME 5
Regional Surface Reservoir Macomb County	1,140,000	1,140,000			660,000
Regional Surface Reservoir Monroe County	720,000	720,000			350,000
Mouth of Huron River			67,000	53,000	
Confluence of Conners Creek and Detroit River			41,000	26,000	29,000
Mt. Clemens			26,500	26,500	
Typical Upland Reservoir with Influent Pumping*	8,500	8,500	8,500	8,500	8,500

* Assumes Peak Pumping Capacity of 900 MGD (Influent Pumping Capacities range from 220 MGD to 1,810 MGD)

Treatment rates for the various sub-area treatment facilities for Schemes One and Two are summarized in Table 5.

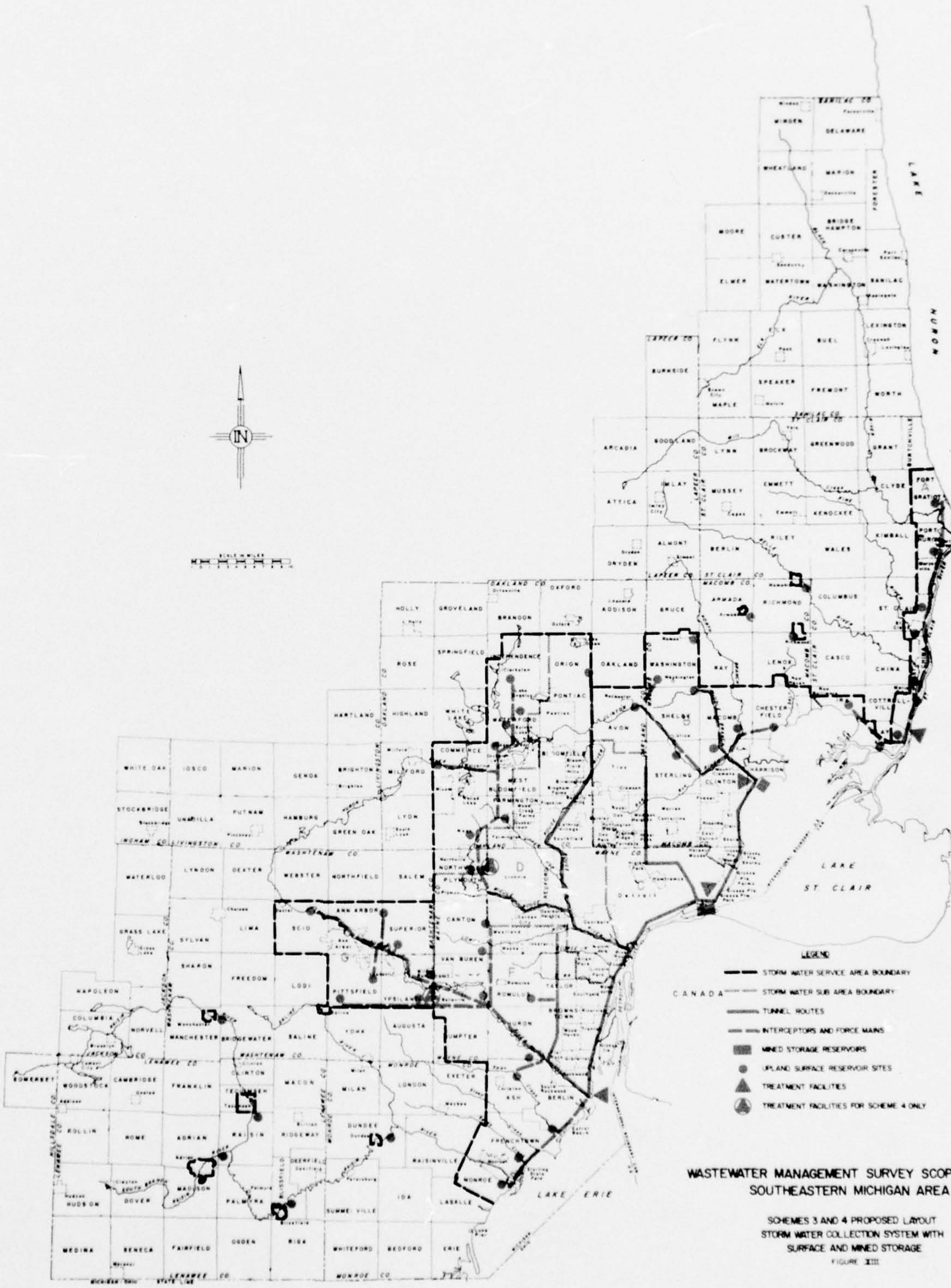
SCHEMES THREE AND FOUR

Schemes Three and Four are based on providing mined storage for the urbanized areas and surface storage for sparsely populated outlying areas. The collection system as well as the number and location of upland reservoirs for Schemes Three and Four are essentially the same as in Schemes One and Two. These schemes have been considered because of the large land requirements for the regional surface reservoirs in Schemes One and Two. In case of unavailability of such land areas or public opposition to the proposed large surface reservoirs, Schemes Three and Four offer an alternative to Schemes One and Two. Schemes Three and Four also differ from Schemes One and Two in regards to the location and capacity of the treatment facilities as shown in the Table 5.

The proposed storm water collection and storage system under Schemes Three and Four is shown in Figure XIII. Both schemes provide pick-up points for treatment at Algonac, each of the two mined storage sites and near the mouth of the Huron River. Scheme Four like Scheme Two also provides two additional pick-up points for sub-areas E and G.

Table 6 summarizes the major components of the proposed storm water collection and storage system for Scheme Three and Four. Mined reservoirs provide a total storage of 23,000 MG and the remainder is provided in the tunnels and upland surface reservoirs. Table 3 presents a breakdown of the storage provided in tunnels, upland reservoirs and mined storage. Storage capacity in the tunnels is based on zero surcharge on the mined storage reservoirs. Any surcharge on the system will result in additional storage within the tunnel system. Tunnels provide approximately 5,400 million gallons of storage.

Schemes Three and Four have two mined storage reservoirs which are located beneath Lake St. Clair. A 12,000 -MG mined storage reservoir is located in the vicinity of the confluence of Conners Creek and the Detroit River. A 11,000-MG mined storage reservoir is located near the mouth of the Clinton River. Assuming



WASTEWATER MANAGEMENT SURVEY SCOPE STUDY
SOUTHEASTERN MICHIGAN AREA

SCHEMES 3 AND 4 PROPOSED LAYOUT
STORM WATER COLLECTION SYSTEM WITH
SURFACE AND MINED STORAGE
FIGURE XIII

TABLE 5
TREATMENT RATES FOR VARIOUS SUB AREAS

Sub Area	Contributing Drainage Area (Sq. Miles)	Treatment Rates + (MGD)	TREATMENT FACILITIES					
			Location	Required Capacity (MGD)				
				Scheme 1	Scheme 2	Scheme 3	Scheme 4	Scheme 5
A	97.7	122	Algonac	120	120	120	120	120
B	334.5	418	Mt. Clemens	820	600	400	400	600
C	177.7	222	Conners Creek			620	400	440
D	322.8	404	Huron River (Monroe County)	1,220	1,000	1020	800	1,000
E	194.3	243	Huron River (Ypsilanti area)		240		240	
F	438.8	549	Middle Rouge (Plymouth Area)		200		200	
G	161.1	202						
Total	1726.9	2160						

+ Based on 0.003 inch/hour of runoff from the contributing drainage area.

TABLE 6

SUMMARY OF VARIOUS COMPONENTS OF STORM WATER COLLECTION SYSTEM

SCHEMES THREE AND FOUR

DRAINAGE SUB AREA	COMPONENTS OF COLLECTION SYSTEM							COSTS+						
	Description	Length (miles)	Size (ft.)	Capacity	No. of Units	Power kwh x10^6	Land (acres)	Land x10^6	Component x10^6	Engin. Admin. Legal & Cont. x10^6	Total Capital x10^6	Annual Capital++ x10^3	Annual O & M x10^3	Total Annual x10^3
A	Upland Surface Reservoir			320-980 MG	8		1965	$ 9.84	$ 27.69	$ 8.31	$ 45.84	$ 2,707	$ 480	$ 3,187
	Force Mains	59.5	2-12						30.91	9.27	40.18	2,373		2,373
	Pumping Requirements													
	Upland Reservoir Inf.			350-970 MGD		6.6			11.01	3.30	14.31	845	66	911
	Upland Reservoir Eff.			13-26 MGD		6.6			0.25	0.08	0.33	19	66	85
B	Tunnels													
	Lined	4.4	34	10000 cfs					31.23	9.37	40.60	2,398	5	2,403
	Partially Lined	14.2	48	27000 cfs					108.13	32.44	140.57	8,302	15	8,317
	Vertical Drops		2.5-6.5	500-4000 cfs	24				1.33	0.40	1.73	102		102
	Access Shafts		20-35		4				4.83	1.45	6.28	371		371
	Mined Reservoir			11000 MG	1				975.00	292.50	1267.50	74,859	275	75,134
	Upland Surface Reservoirs			710-1500 MG	7		3145	15.73	49.23	14.77	79.73	4,709	420	5,129
	Interceptors	35.8	2-7						17.12	5.14	22.26	1,315		1,315
	Force Mains	3.5	6-11						3.85	1.16	5.01	296		296
	Pumping Requirements													
	Mined Reservoir Eff.			400 MGD		64.6			3.59	1.08	4.67	276	646	922
				(400 MGD)		(64.6)			(3.59)	(1.08)	(4.67)	(276)	(646)	(922)
	Upland Reservoir Inf.			250-905 MGD		2.3			3.20	0.96	4.16	246	23	269
	Upland Reservoir Eff.			29-40 MGD		12.5			0.41	0.12	0.53	31	125	156
C	Tunnels													
	Partially Lined	33.9	18-48	2500-27000cfs					222.13	66.64	288.77	17,055	34	17,089
	Vertical Drops		3.0-6.5	700-4000 cfs	41				2.34	0.70	3.04	180		180
	Access Shafts		20		7				6.70	2.01	8.71	514		514
	Mined Reservoir			12000 MG	1				1065.00	319.50	1384.50	81,769	300	82,069
	Pumping Requirements													
	Mined Reservoir Eff.			640 MGD	1	103.0			4.60	1.38	5.98	353	1030	1,383
				(400 MGD)	(1)	(64.6)			(3.59)	(1.08)	(4.67)	(276)	(646)	(922)

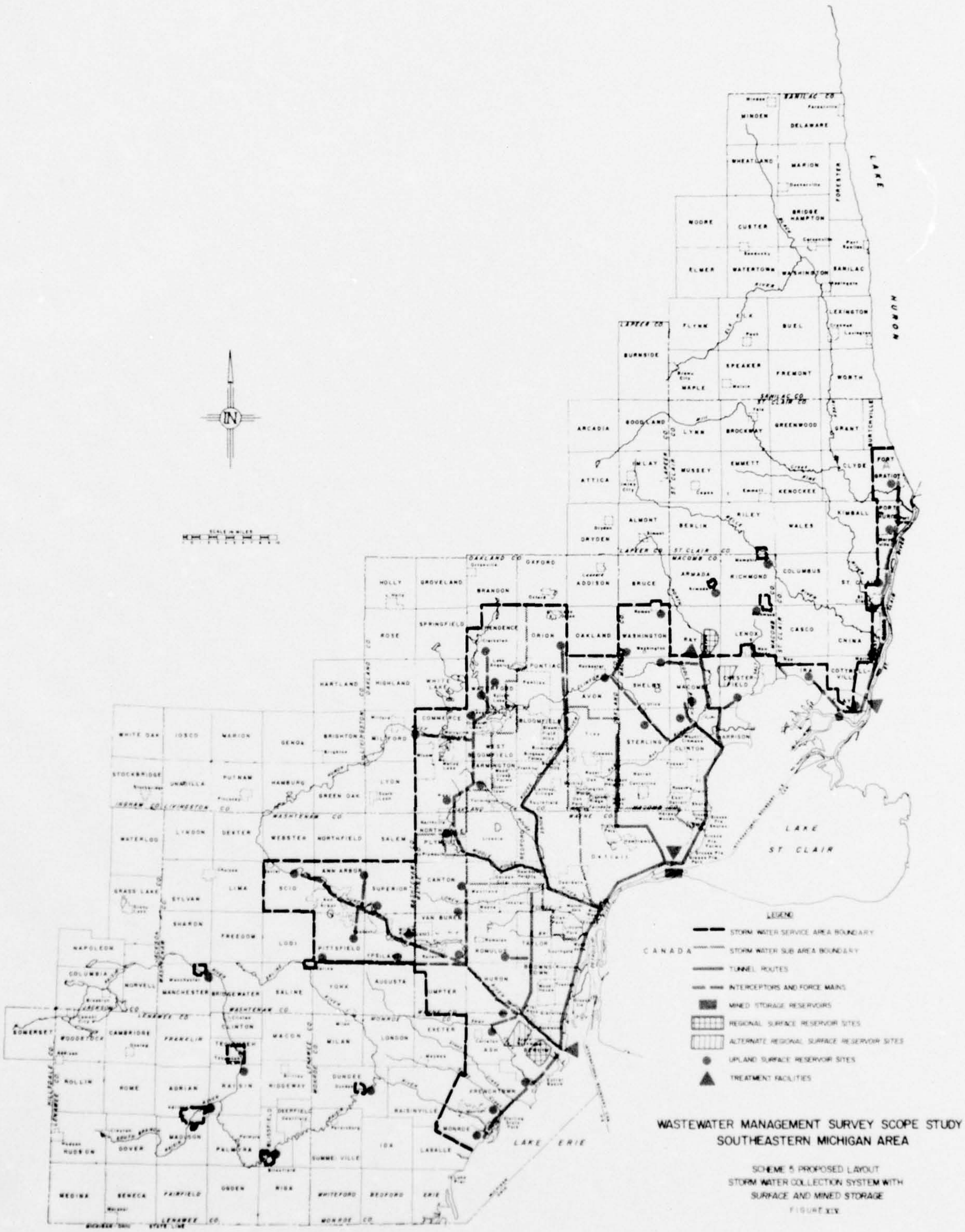
TABLE 6 (Cont'd)

DRAINAGE SUB-AREA	COMPONENT OF COLLECTION SYSTEM							COSTS[+]						
	Description	Length (miles)	Size (ft.)	Capacity	No. of Units	Power kwh x10^6	Land (acres)	Land x10^6	Component x10^6	Engin. Admin. Legal & Cont. x10^6	Total Capital x10^6	Annual Capital[++] x10^3	Annual O & M x10^3	Total Annual x10^3
D	Tunnels													
	Lined	24.3	20-46	3500-17000cfs					$174.56	$52.37	$226.93	$13,402	$ 24	$13,426
	Partially Lined	25.2	34-48	5500-27000cfs					182.24	54.67	236.91	13,992	25	14,017
	Vertical Drops		2.5-6.5	500-4000 cfs	46				1.93	0.58	2.51	148		148
	Access Shafts		20		10				10.28	3.08	13.36	787		787
	Upland Surface Reservoirs			970 MG	1		370	$ 1.85	5.75	1.73	9.33	551	60	611
	Force Mains	7.5	3						2.18	0.65	2.83	167		167
	Pumping Requirements													
	Upland Reservoir Eff.			26 MGD		1.4			0.05	0.02	0.07	4	14	18
E	Upland Surface Reservoirs			380-2010 MG	8		3345	16.74	53.59	16.08	86.41	5,103	480	5,583
	Force Mains	49.5	4-15						37.86	11.36	49.22	2,907		2,907
	Interceptors	9.5	5-7						6.43	1.93	8.36	494		494
	Pumping Requirements													
	Upland Reservoir Inf.			650-1520 MGD		4.3			13.81	4.14	17.95	1,060	43	1,103
	Upland Reservoir Eff.			10-54 MGD		11.7			0.29	0.09	0.38	22	117	139
F	Tunnels													
	Lined	5.7	30	6000 cfs					36.29	10.89	47.18	2,786	6	2,792
	Partially Lined	26.2	30-38	6000-17000 cfs					152.02	45.61	197.63	11,672	26	11,698
	Vertical Drops		2.0-6.5	300-4000 cfs	19				0.56	0.17	0.73	43		43
	Access Shafts		20-35		6				5.95	1.79	7.74	457		457
	Upland Surface Reservoirs			800-2480 MG	9		4640	23.21	75.49	22.65	121.35	7,167	540	7,707
	Interceptors	44.5	4-11						35.16	10.55	45.71	2,700		2,700
		(32.0)	(4-7)						(19.71)	(5.91)	(25.62)	(1,513)		(1,513)
	Force Mains	25.5	3-12						19.95	5.99	25.94	1,532		1,532
	Pumping Requirements													
	Regional Treatment Inf.			1000 MGD	1	161.8			6.25	1.88	8.13	480	1618	2,098
				(800 MGD)	(1)	(129.2)			(5.35)	(1.61)	(6.96)	(411)	(1292)	(1,703)
	Upland Reservoir Inf.			470-1066 MGD		16.6			14.65	4.40	19.05	1,125	166	1,291
	Upland Reservoir Eff.			21-66 MGD		12.6			0.44	0.13	0.57	34	126	160
G	Upland Surface Reservoirs			770-1620	7		2820	14.11	44.01	13.20	71.32	4,212	420	4,632
	Interceptors	50.0	3-8						21.99	6.60	28.59	1,689		1,689
	Force Mains	7.0	8-12						13.23	3.97	17.20	1,016		1,016
	Pumping Requirements													
	Upland Reservoir Inf.			375-1810 MGD		4.4			12.11	3.63	15.74	930	44	974
	Upland Reservoir Eff.			20-43 MGD		8.0			0.27	0.08	0.35	21	80	101

TABLE 6 (Cont'd)

DRAINAGE SUB-AREA	COMPONENT OF COLLECTION SYSTEM							COSTS +						
	Description	Length (miles)	Size (ft.)	Capacity	No. of Units	Power kwh x10^6	Land (acres)	Land x10^6	Component x10^6	Engin. Admin. Legal & Cont. x10^6	Total Capital x10^6	Annual Capital ++ x10^3	Annual O&M x10^3	Total Annual x10^3
Rural Communities +++	Upland Surface Reservoirs			30-140 MG	9		795	$ 4.00	$ 5.37	$ 1.61	$10.98	$649	$ 135	$ 784
	Force Mains	5.5	6-9						4.08	1.22	5.30	313		313
	Pumping Requirements													
	Upland Reservoir Inf.			220-590 MGD		0.7			5.51	1.65	7.16	423	7	430
	Upland Reservoir Eff.			1-4 MGD		0.3			0.04	0.01	0.05	3	3	6
TOTAL COSTS FOR STUDY AREA								$85.48 ($85.48)	$3510.89 ($3493.53)	$1053.31 ($1048.10)	$4649.68 ($4627.11)	$274,609 ($273,276)	$7,419 ($6,709)	$282,028 ($279,985)
ANNUAL CAPITAL COST @ 7% for 50 YR												$336,916 ($335,280)	$7,419 ($6,709)	$344,335 ($341,989)
ANNUAL CAPITAL COST @ 10% for 50 YR												$468,967 ($466,690)	$7,419 ($6,709)	$476,386 ($473,399)

NOTES: No.'s in parentheses are for Scheme Four only.
- \+ All costs are based on ENR of 1,960.
- ++ Annual capital cost is based on 5-1/2 percent interest rate and 50-year project life
- +++ Consists of communities not served by major storm water interceptors



WASTEWATER MANAGEMENT SURVEY SCOPE STUDY
SOUTHEASTERN MICHIGAN AREA

SCHEME 5 PROPOSED LAYOUT
STORM WATER COLLECTION SYSTEM WITH
SURFACE AND MINED STORAGE

FIGURE XIV

that fifty percent of the area is available for storage, approximately 2.3 square miles are required for the 12,000-MG storage reservoir and 2.1 square miles for the 11,000-MG storage reservoir.

Effluent pumping facilities are provided under Scheme Three and Scheme Four to pump out storm water from the tunnels and mined storage. These facilities have been sized according to the capacity of the treatment facilities which are summarized in Table 5.

SCHEME FIVE

Scheme Five consists of a combination of surface and mined storage for urbanized areas and surface storage for sparsely populated areas. The collection system, as well as the number and location of upland reservoirs, is the same as in Schemes One and Three. Scheme Five has been considered because of the high peak power requirements for influent pumping to regional surface reservoirs in Schemes One and Two and the high cost of mined storage in Schemes Three and Four. By providing a minimum of mined storage along with the surface storage, influent pumping requirements are considerably reduced.

The proposed storm water collection and storage system for Scheme Five is shown in Figure XIV. Treatment plants are located at Algonac, at each of the two surface reservoir sites and at the mined storage site.

Table 7 summarizes the major components of the proposed storm water collection and storage system for Scheme Five. A total of 23,000 MG of storage is provided in two regional surface reservoirs and one mined storage reservoirs. The rest of the storage is provided in tunnels and upland reservoirs. Mined storage with a capactiy of 5,000-MG is located beneath Lake St. Clair near the confluence of Conners Creek and the Detroit River. Two regional surface reservoirs of 8,500-MG each are located in Macomb and Monroe counties as in Schemes One and Two.

TABLE 7

SUMMARY OF VARIOUS COMPONENTS OF STORM WATER COLLECTION SYSTEM

SCHEME FIVE

DRAINAGE SUB-AREA	COMPONENTS OF COLLECTION SYSTEM							COSTS+						
	Description	Length (miles)	Size (ft.)	Capacity	No. of Units	Power kwh x10^6	Land (acres)	Land x10^6	Component x10^6	Engin. Admin. Legal & Cont. x10^6	Total Capital x10^6	Annual Capital++ x10^3	Annual O & M x10^3	Total Annual x10^3
A	Upland Surface Reservoir			320-980 MG	8		1965	$ 9.84	$ 27.69	$ 8.31	$ 45.84	$ 2,707	$ 480	$ 3,187
	Force Mains	59.5	2-12						30.91	9.27	40.18	2,373		2,373
	Pumping Requirements													
	Upland Reservoir Inf.			350-970 MGD		6.6			11.01	3.30	14.31	845	66	911
	Upland Reservoir Eff.			13-26 MGD		6.6			0.25	0.08	0.33	19	66	85
B	Tunnels													
	Lined	4.4	34	10000 cfs					31.23	9.37	40.60	2,398	5	2,403
	Partially Lined	27.1	48	27000 cfs					212.75	63.83	276.58	16,335	27	16,362
	Vertical Drops		2.5-6.5	500-4000 cfs	26				1.39	0.42	1.81	107		107
	Access Shafts		20-35		6				7.11	2.13	9.24	546		546
	Regional Surface Reservoir			8500 MG	1		2500	12.50	42.87	12.86	68.23	4,030	120	4,150
	Upland Surface Reservoirs			710-1500 MG	7		3145	15.73	49.23	14.77	79.73	4,709	420	5,129
	Interceptors	35.8	2-7						17.12	5.14	22.26	1,315		1,315
	Force Mains	3.5	6-11						3.85	1.16	5.01	296		296
	Pumping Requirements													
	Regional Reservoir Inf.			10200 MGD	1	132			72.13	21.64	93.77	5,538	1320	6,858
	Upland Reservoir Inf.			250-905 MGD		2.3			3.20	0.96	4.16	246	23	269
	Upland Reservoir Eff.			29-40 MGD		12.5			0.41	0.12	0.53	31	125	156
C	Tunnels													
	Partially Lined	33.9	18-48	2500-27000cfs					222.13	66.64	288.77	17,055	34	17,089
	Vertical Drops		3.0-6.5	700-4000 cfs	41				2.34	0.70	3.04	180		180
	Access Shafts		20		7				6.70	2.01	8.71	514		514
	Mined Reservoir			5000 MG	1				450.00	135.00	585.00	34,550	125	34,675
	Pumping Requirements													
	Mined Reservoir Eff.			400 MGD	1	64.6			3.59	1.08	4.67	276	646	922

TABLE 7 (Cont'd)

DRAINAGE SUB-AREA	COMPONENT OF COLLECTION SYSTEM							COSTS+						
	Description	Length (miles)	Size (ft.)	Capacity	No. of Units	Power kwh x10^6	Land* (acres)	Land x10^6	Component x10^6	Engin. Admin. Legal & Cont. x10^6	Total Capital x10^6	Annual Capital++ x10^3	Annual O & M x10^3	Total Annual x10^3
D	Tunnels													
	Lined	24.3	20-46	3500-17000cfs					$174.56	$52.37	$226.93	$13,402	$ 24	$13,426
	Partially Lined	25.2	34-48	5500-27000cfs					182.24	54.67	236.91	13,992	25	14,017
	Vertical Drops		2.5-6.5	500-4000 cfs	46				1.93	0.58	2.51	148		148
	Access Shafts		20		10				10.28	3.08	13.36	787		787
	Upland Surface Reservoirs			970 MG	1		370	$ 1.85	5.75	1.75	9.33	551	60	611
	Force Mains	7.5	3						2.18	0.65	2.83	167		167
	Pumping Requirements													
	Upland Reservoir Eff.			26 MGD		1.4			0.05	0.02	0.07	4	14	18
E	Upland Surface Reservoirs			380-2010 MG	8		3345	16.74	53.59	16.08	86.41	5,103	480	5,583
	Force Mains	49.5	4-15						37.86	11.36	49.22	2,907		2,907
	Interceptors	9.5	5-7						6.43	1.93	8.36	494		494
	Pumping Requirements													
	Upland Reservoir Inf.			650-1520 MGD		4.3			13.81	4.14	17.95	1,060	43	1,103
	Upland Reservoir Eff.			10-54 MGD		11.7			0.29	0.09	0.38	22	117	139
F	Tunnels													
	Lined	5.7	30	6000 cfs					36.29	10.89	47.18	2,786	6	2,792
	Partially Lined	26.2	30-38	6000-17000 cfs					152.02	45.61	197.63	11,672	26	11,698
	Vertical Drops		2.0-6.5	300-4000 cfs	19				0.56	0.17	0.73	43		43
	Access Shafts		20-35		6				5.95	1.79	7.74	457		457
	Regional Surface Reservoir			8500 MG	1		2500	12.50	37.76	11.33	61.59	3,638	120	3,758
	Upland Surface Reservoirs			800-2480 MG	9		4640	23.21	75.49	22.65	121.35	7,167	540	7,707
	Interceptors	44.5	4-11						35.16	10.55	45.71	2,700		2,700
	Force Mains	25.5	3-12						19.95	5.99	25.94	1,532		1,532
	Pumping Requirements													
	Regional Reservoir Inf.			5400 MGD	1	132			38.42	11.53	49.95	2,950	1320	4,270
	Upland Reservoir Inf.			470-1066 MGD		16.6			14.65	4.40	19.05	1,125	166	1,291
	Upland Reservoir Eff.			21-66 MGD		12.6			0.44	0.13	0.57	34	126	160
G	Upland Surface Reservoirs			770-1620	7		2820	14.11	44.01	13.20	71.32	4,212	420	4,632
	Interceptors	50.0	3-8						21.99	6.60	28.59	1,689		1,689
	Force Mains	7.0	8-12						13.23	3.97	17.20	1,016		1,016
	Pumping Requirements													
	Upland Reservoir Inf.			375-1810 MGD		4.4			12.11	3.63	15.74	930	44	974
	Upland Reservoir Eff.			20-43 MGD		8.0			0.27	0.08	0.35	21	80	101

TABLE 7 (Cont'd)

DRAINAGE SUB-AREA	COMPONENT OF COLLECTION SYSTEM							COSTS +						
	Description	Length (miles)	Size (ft.)	Capacity	No. of Units	Power kwh x10^6	Land (acres)	Land x10^6	Component x10^6	Engin. Admin. Legal & Cont. x10^6	Total Capital x10^6	Annual Capital ++ x10^3	Annual O&M x10^3	Total Annual x10^3
Rural Communities +++	Upland Surface Reservoirs			30-140 MG	9		795	$ 4.00	$ 5.37	$ 1.61	$10.98	$649	$ 135	$ 784
	Force Mains	5.5	6-9						4.08	1.22	5.30	313		313
	Pumping Requirements													
	Upland Reservoir Inf.			220-590 MGD		0.7			5.51	1.65	7.16	423	7	430
	Upland Reservoir Eff.			1-4 MGD		0.3			0.04	0.01	0.05	3	3	6
TOTAL COSTS FOR STUDY AREA								$110.48	$2208.18	$662.50	$2981.16	$176,067	$7,213	$183,280
ANNUAL CAPITAL COST @ 7% for 50 YR												$216,015	$7,213	$223,228
ANNUAL CAPITAL COST @ 10% for 50 YR												$300,680	$7,213	$307,893

NOTES:
- \+ All costs are based on ENR of 1,960.
- ++ Annual capital cost is based on 5-1/2 percent interest rate and 50-year project life.
- +++ Consists of communities not served by major storm water interceptors.

Mined storage for Scheme Five reduces the peak pumping requirements for the regional surface reservoirs. Influent pumping facilities for Macomb County regional reservoir are designed to handle 10,800 MGD, and the Monroe County regional reservoir pumping facilities are designed for 5,400 MGD. A 440-MGD pumping station is also provided for pumping storm water from tunnels and mined storage to the Conners Creek treatment plant.

Treatment rates for the various drainage sub-areas and the treatment facilities for Scheme Five are summarized in Table 5.

COST ESTIMATES FOR ALTERNATE SCHEMES

Cost estimates for Schemes One through Five are discussed in this section. A tabular summary including costs for land, construction, contingencies, and annual operation and maintenance is included for each scheme. Annual capital cost estimates are based on interest rates of 5-1/2 percent, 7 percent and 10 percent with a 50-year project life. Estimated unit prices for construction of the various components of the storm water collection and storage system are included in Supplement B.

Unit prices are based, wherever possible, on actual construction costs for similar projects. However, land costs vary widely within the study area making them difficult to estimate. In addition, land costs may escalate at proposed reservoir sites. Therefore, a uniform land cost of $5,000.00 per acre is used throughout the entire service area.

Annual operation and maintenance costs for the pumping facilities also include replacement cost. In estimating these replacement costs, it is assumed that effluent pumps and motors used with the upland reservoirs and for pumping storm water from the tunnels and the mined storage to the treatment facilities at the ground surface have a life of 25 years. These pumps and motors will be replaced once during the 50-year life of the project. Reservoir influent pumping facilities and screening facilities will not have to be replaced during the life of the project.

COMPONENT COSTS

Assumptions used in arriving at unit prices of construction and operation and maintenance for each component of the storm water collection and storage system are discussed herein:

Tunnels

Unit prices for construction of tunnels have been summarized in Table B-1. Unit prices have been arrived at based on bid prices of two tunneling projects in the Chicago area and on contacts with various equipment manufacturers. The following assumptions have been made:

1. Advance rate of 35 feet per day for tunnel construction (24 hour per day operation).

2. Excavated rock from the tunnels does not have any salvage value.

3. Equipment used on the project does not have any salvage value.

4. 12-inch concrete lining will be provided in areas of tunnel construction where necessary. Concrete cost for lining tunnels is $65 per cubic yard.

Vertical Drops

The unit price for construction of the vertical drops is assumed to be $45 per foot of diameter per foot of vertical drop. This represents an average price for 2 to 6.5 foot diameter drops. This price also includes costs for the construction of an expansion chamber and associated structures at the bottom of the drop.

Access Shafts

Unit prices for construction of the 20-35 foot diameter access shafts is assumed to be $200 per foot of diameter per foot of vertical drop. This includes the cost of providing an elevator and associated mechanisms for transportation of men and equipment.

Annual operation and maintenance costs for the above three components have been grouped together. These costs are based on cleaning tunnels once every year and periodic cleaning of expansion chambers in vertical drops. Cleaning operations will be performed using a modified street cleaning machine. The estimated unit price for operation and maintenance of the three components is $1,000 per mile of tunnel per year.

Force Mains and Interceptors

Force main and interceptor capital costs are shown in Table B-2. The interceptor costs are for Class IV reinforced concrete pipe, and the force main costs are for prestressed concrete embedded cylinder pipe. The costs shown are based on similar projects in the study area. For these larger sizes of pipe, the higher fabrication cost of the prestressed concrete embedded cylinder pipe approximately equals the higher installation cost usually associated with gravity interceptors. For estimating purposes the same unit costs were used for interceptors and force mains.

Mined Storage

Mined storage construction costs are presented in Table B-3. These are based on the following assumptions:

1. Unit price for excavation of smaller reservoirs (500 MG or less) is $20 per cubic yard and for larger reservoirs (10,000 MG or more) is $15 per cubic yard. The unit price varies linearly for reservoirs in between 500 MG and 10,000 MG storage capacity.

2. Floors of the reservoirs are concrete lined with 8-inch thick concrete.

3. Reservoirs are constructed using long room mining methods. Conventional blasting is used for construction of the rooms and boring machines for the crest portion of the rooms.

Annual operation and maintenance on the reservoirs include removal of the deposited solids and checking for any visual structural weaknesses in the rocks. A unit price of $25 per million gallon storage capacity of the reservoir is used for this purpose.

Surface Reservoirs

Surface reservoir construction costs are divided in two parts: (1) regional reservoirs and (2) upland reservoirs. Both costs have been based on the following unit prices:

Site preparation @ $1,000.00 per acre

Excavation (balanced cut and fill) @ $1.50 per cubic yard

Lining @ $0.24 per square yard

Fencing @ $4.50 per lineal foot

Landscaping @ $2,500 per acre

Concrete @ $125.00 per cubic yard

Compacted road gravel @ $1.45 per square yard for 8-inches of gravel thickness.

Table B-4 presents a summary of the construction costs for regional reservoirs in Schemes One, Two and Five. Construction costs for upland surface reservoirs with three different kinds of influent structures have been summarized in Tables B-5 through B-7.

Operation and maintance costs for upland storage reservoirs are estimated at $60,000 per year per storage facility. This estimate includes costs for grounds upkeep, general maintenance, cleaning and screenings removal. Operation and maintenance costs for regional storage reservoirs are included in Tables 2 and 7.

Underground Reservoirs

Underground reservoir costs are obtained using capital costs for site preparation, excavation, concrete, grit removal equipment, screening equipment, diversion gates, effluent pumps and superstructure as shown in B-8.

Pumping Facilities

Construction costs of various pumping facilities are presented in Tables B-6 and B-9 through B-11. Influent pumping facilities for upland reservoirs are summarized in Table B-6 and B-9. Effluent pumping costs for upland reservoirs are summarized in Table B-11.

Table B-10 summarizes costs of pumping stations used with regional surface and mined storage reservoirs in Schemes One through Five. Pumping stations used for pumping storm water into the surface reservoirs are summarized under influent pumping. Those used for pumping storm water to the treatment facilities are summarized under effluent pumping. In these cost estimates, it has been assumed that motors used with influent pumps are located at the ground level while those used with the effluent pumps are located adjacent to the wet wells in bed rock formations. The cost estimates show that it is slightly costlier to install motors at the ground level than in the bed rock for the same size of pumping station, but this offers a considerable advantage in operation and maintenance of motors, providing ease of accessibility.

Annual operation costs for the pumping facilities are based on power cost of 0.9 cent per killowatt -hour. Annual maintenance costs for the pumping facilities and related structures are based on 0.1 cent per killowatt-hour of power consumption.

COSTS FOR SCHEMES ONE AND TWO

Construction and operation and maintenance cost estimates for Schemes One and Two are presented in the Table 2. Scheme One has slightly higher total capital cost (2,581.71 vs 2,561.62 million dollars) because of the interceptors and force mains used for bringing flows from sub-areas E and G to the tunnels. The cost differential between local treatment plans and regional treatment plants for serving sub-areas E and G must be included in cost estimates for Schemes One and Two for a valid comparison of the two schemes. Annual operation and maintenance costs for Scheme One also are higher than for Scheme Two (7.14 vs 6.42 million dollars) because the total quantity of pumping required for Scheme One is higher than for Scheme Two.

The total annual cost for Scheme One is 159.619 million dollars and for Scheme Two is 157.712 million dollars based on an ammortization of capital cost at 5-1/2 percent for a 50 year project life. A comparative cost summary for all the five schemes is presented in Table 8. It should be noted that cost estimates for Schemes One and Two do not include any capital costs for additional generating facilities which may be required to supply power to the various pumping facilities. Since the power requirements under these two schemes are very substantial, further investigations regarding the power cost should be made.

COSTS FOR SCHEMES THREE AND FOUR

Table 6 summarizes construction and operation and maintenance costs for Schemes Three and Four. Scheme Three has slightly higher capital cost and annual operation and maintenance costs as compared to Scheme Four because of the regional treatment of storm water flows from sub-areas E and G. Total capital cost figures for Schemes Three and Four, like Schemes One and Two , do not include the cost differential associated with local and regional treatment plants for sub-areas E and G.

Total annual cost for Scheme Three is 282 million dollars and for Scheme Four is 280 million dollars based on ammortization of capital cost at 5-1/2 percent for a 50 year project life.

Table 8 shows that it costs approximately 122.5 million dollars more annually to provide mined storage as opposed to surface storage. However, evaluation of the desirability of mined storage versus surface storage should include assessment of the environmental impacts of the alternatives.

COSTS FOR SCHEME FIVE

Scheme Five cost estimates are summarized in Table 7. Total capital cost is 2,981.1 million dollars. Total annual cost including operation and maintenance is 183 million dollars based on an ammortization of capital cost at 5-1/2 percent for a 50 year project life.

In total annual cost, Scheme Five is about 99.0 million dollars less than Schemes Three and Four and 23.0 million dollars more than Schemes One and Two. The additional cost of Scheme 5 should be evaluated against the benefits derived from providing a combination of mined and surface storage. A detailed discussion of these benefits is included in the Recommendation Section.

TABLE 8
COMPARATIVE COST SUMMARY OF ALTERNATE SCHEMES
ALL COSTS IN 1000'S OF DOLLARS
ENR = 1,960

	SCHEME ONE	SCHEME TWO	SCHEME THREE	SCHEME FOUR	SCHEME FIVE
TOTAL CAPITAL COST	$2,581,710	$2,561,620	$4,649,680	$4,627,110	$2,981,160
Annual Capital Cost 50 YR@ 5-1/2%	152,477	151,290	274,609	273,276	176,067
Annual O & M	7,142	6,422	7,419	6,709	7,213
TOTAL ANNUAL COST	$ 159,619	$ 157,712	$ 282,028	$ 279,985	$ 183,280
Annual Capital Cost 50 YR @ 7%	187,071	185,615	336,916	335,280	216,015
Annual O & M	7,142	6,422	7,419	6,709	7,213
TOTAL ANNUAL COST	$ 194,213	$ 192,037	$ 344,335	$ 341,989	$ 223,228
Annual Capital Cost 50 YR @ 10%	260,391	258,365	468,967	466,690	300,680
Annual O & M	7,142	6,422	7,419	6,709	7,213
TOTAL ANNUAL COST	$ 267,533	$ 264,787	$ 476,386	$ 473,399	$ 307,893

RESOURCE REQUIREMENTS

Resource requirements of any proposed project are of increasing importance as more and more demands are imposed on the limited resources of an area. The following section describes the significant resource requirements of the storm water collection and storage systems discussed in this report.

LAND

Large tracts of land are required for surface storage facilities and will be committed for the life of the project. Typical upland reservoirs used in outlying townships require 300 to 400 acres of land per township. Large regional surface reservoirs serving urbanized areas require as much as 3210 acres per reservoir. Two such reservoirs are required to serve all urbanized areas with surface storage. The extensive use of underground or mined reservoirs can reduce land requirements, but their capital costs are significantly higher than that of the surface storage.

POWER

Very large power requirements (720 to 1,140 megawatts) are necessary for schemes involving the use of regional surface reservoirs. These power requirements are for pumping peak flows from the tunnel system to storage reservoirs and will only occur during design storm conditions for a very short period of time. This type of intermittent peak power demand is very costly to supply. The use of mined storage reduces excessive peak power demands because the only pumping associated with mined reservoirs is effluent pumping . This pumping is at a much smaller rate and for longer periods of time.

CONSTRUCTION EQUIPMENT

The boring machines required for the larger diameter tunnels have not been developed at the present time. The largest boring machine that has been used to this date (1972) is 36.0 feet in diameter. It is assumed that technological advancements will make larger diameter machines available in the near future. If these machines are not available when required, smaller parallel tunnels or conventional mining methods will have to be used in some areas. Some new machines also will have to be developed for the cleaning operation of tunnels and mined storage facilities.

LABOR

The simultaneous construction of many of these proposed facilities may impose a significant drain on construction and labor forces in the study area resulting in overall higher construction costs. The effects of this can be reduced through proper time phasing of construction.

FINANCING

Financing of the project under consideration forms a very important resource requirement. Since the financing of this project will have to be arranged through mutual cooperation of local, regional, state and federal governments, a considerable amount of planning is involved. This will affect financial planning of the various governments involved. A detailed analysis of costs and benefits of such a project is very essential and highly desirable.

CONSTRUCTION TIME PHASING

Maximum benefit from the proposed storm water collection and storage program will only be realized through a carefully planned construction sequence. The slow advance rates obtained in tunnel construction and mined reservoir construction along with the size of the proposed system make timing an important consideration.

The project requires approximately 72 billion gallons of storage which is provided by surface reservoirs or a combination of surface and mined reservoirs. In addition, the project involves approximately 134 miles of tunnels varying in diameter from eighteen feet to forty-eight feet, 132 vertical drops varying in diameter from two to six and one-half feet, 31 access shafts and 310 miles of interceptors and force mains. Also, modifications will have to be made to existing storm water collection systems in order to adapt them to the proposed system.

The project is to be constructed in three phases over a fifteen year period as directed by the U.S. Army Corps of Engineers. The first phase, 1975 to 1980, involves the construction of tunnels, storage and related structures to intercept storm water from the existing combined sewer overflows presently going into the Ecorse Creek, Detroit River, Red Run Drain and the Rouge River and its tributaries.

The second phase, 1980 to 1985, involves the construction of facilities required to collect and store storm water runoff from areas that have existing separate storm sewers. In general this means that the tunnels constructed in the first phase will be extended to cover the remaining urbanized areas and that a major portion of the upland reservoirs and associated interceptors will be constructed.

The third phase , 1985 to 1990, involves the facilities required for the control of storm water runoff from areas that are presently unsewered but projected to be sewered during the life of the project. This will involve the construction of additional upland reservoirs and connecting interceptors.

A more detailed discussion of the time phasing for the recommended scheme is presented in the Recommendations Section.

Although three construction phases as discussed above were assigned for this report, a more realistic time table may involve as much as ten years for each phase in order to avoid simultaneous construction of many of the facilities which may pose some planning and scheduling problems. For example, in order to construct the 134 miles of tunnels in a ten year period, a minimum of seven boring machines must be in full time operation for the ten year period (one boring machine may be expected to complete two miles of tunnel per year). Also, in order to allow time for detailed design and system optimization, a more realistic starting construction date may be in the late 1970's or early 1980's, as against 1975 assigned for this report.

RECOMMENDATIONS

This section deals with the recommended scheme of storm water collection and storage and discusses the areas that should be studied further in the future phases of storm water planning and control for southeastern Michigan. The recommended scheme also should be evaluated in the light of the total storm water pollution abatement program for the study area.

RECOMMENDED SCHEME

Scheme Five is the recommended scheme for the various advantages it offers over the other four schemes. It provides a combination of surface and mined storage reservoirs for the highly urbanized areas and multiple surface storage reservoirs in the less urbanized outlying areas.

The estimated construction cost of Scheme Five as shown in Table 8 is considerably less than Schemes Three and Four but more than Schemes One and Two. The major cost difference between the various schemes is due to the type of regional storage (mined or surface) that is used for the urbanized areas. Schemes Three and Four are based on total mined storage for these areas while Schemes One and Two are based on total surface storage. The cost of providing mined storage is considerably more than that of the surface storage which accounts for the higher costs of Schemes Three and Four. For the same reason Scheme Five is approximately 400 million dollars costlier in capital cost than Scheme One. This cost difference is slightly misleading without including the impact of the proposed schemes on the available sources of electrical power supply in the area. It is highly probable that new power plants will have to be constructed in order to meet the power demands of the proposed facilities.

Scheme One has very high peak power requirements for pumping peak storm water flows from the tunnel system to the surface reservoir. This requires very large amounts of power to be available on a stand-by basis. Since this type of power is not available for other uses, the capital cost of producing this power should be included in cost estimates in order to realistically compare the Schemes. By including mined storage in Scheme Five, the peak power requirements of Scheme One are reduced by approximately forty percent. This may reduce the capital cost difference between Schemes One and Five by as much as 50 percent.

Scheme Five offers several advantages which make it more desirable than Scheme One in spite of the higher capital costs. These are discussed as follows:

1. The proposed system under Scheme Five is well suited with respect to the immediate service needs of the study area. The existing combined sewer systems that cause overflows of raw sewage and storm water into the Ecorse Creek, the Rouge River and the Detroit River need immediate relief in order to reduce the potential health hazards associated with these overflows. The mined storage in scheme five is located at the confluence of Conners Creek with the Detroit River and it becomes quite feasible to construct tunnels to collect overflows from most of the combined sewered areas and construct a mined reservoir to store these flows in the first phase of construction. Storm water treatment will be provided at the Conners Creek regional plant which will also be constructed during this phase. In order to accomplish the same degree of storm water control under scheme one approximately 30 additional miles of tunnels are required in the first phase of construction to bring storm water runoff to a regional surface reservoir. Since only a limited number of miles of tunnels can be constructed in any period of time due to the practical limits on the number of boring machines that can efficiently operate in an area, this additional 30 miles of tunnel construction in scheme one will delay the implementation of the first phase of the storm water control program. Any such delay will prolong adverse effects on the public health and welfare caused by the present combined sewer overflows.

2. The inclusion of mined storage and a treatment plant near Conners Creek in scheme five will provide operational

flexibility. For example, it may be possible to operate the Conners Creek treatment plant on a continuous basis with other regional plants operated only as required. This mode of operation should reduce the annual operation costs for treatment facilities.

3. Scheme five requires approximately twenty percent less land than scheme one for regional surface reservoirs, thereby making an important natural resources available for other purposes.

4. The proposed system under scheme five will not require the purchasing of any land for storage reservoirs in the first phase of the project. The process of acquiring land from the private owners will be very time consuming and may involve relocating several families. Scheme five will provide more time to accomplish this.

RECOMMENDATIONS FOR FUTURE STUDIES

During the course of this study it was recognized that some areas will need further investigations for designing and implementing the proposed storm water collection and storage scheme. These areas are discussed in the following sections.

Hydrologic Studies

Hydrologic considerations form the backbone of a storm water collection and storage system design. Peak flow rates and volume of storm water runoff are two such important considerations. The unit hydrograph- infiltration capacity approach used in the report for estimating peak flow rates should be further modified using computer aids for evaluating the effect of the direction and movement of the storms.

Geologic Studies

In order to determine suitable rock formations for locating tunnel routes, mined storage and pumping facilities, detailed geologic investigations are necessary. Test boring, geologic mapping, studies of existing well logs, and proven geophysical techniques are some of the conventional underground exploration methods which can be employed. The more recent techniques for investigating underground conditions employ remote sensing devices, seismic holography, electromagnetic pulse sounding, and optical scanning for structural features. These various methods should be studied in preparing a program for geologic investigations.

Optimazation of Design

Before detailed design is performed for the various components utilized for storm *water collection and storage*, the overall system must be optimized. Hydraulic analysis of the tunnels using computer assistance is required in order to determine the effects of slope, lining, surcharge and various storm patterns on the required sizes of tunnels. Flood routing procedures can be used to minimize the required storage without sacrificing the integrity of the program. As more detailed power costs become available, it will be possible to optimize the amount of storage that should be provided in the regional surface vs. mined reservoirs.

Aeration Studies

The need of providing aeration in storm water collection and storage systems was considered during the study program. It was concluded that aeration will not be required because of the very rare circumstances under which anaerobic conditions will occur in the system. The very slow rate of oxygen consumption by the storm water was a primary reason for arriving at this conclusion. It is recommended that pilot plant investigations incorporating the proposed methods of operations of storage facilities should be undertaken in order to establish the validity of the above assumption. Studies should be conducted on both separate storm sewer and combined storm sewer overflows. These same studies may be used to investigate the amount of solids accumulation that may be expected in the facilities, which will decide the operation and maintenance necessary for the proposed storage reservoirs.

LIST OF REFERENCES CITED

1. "Alternatives for Storm Water Runoff Control in Southeastern Michigan", Preliminary Report prepared by Ayres, Lewis, Norris and May, Inc., June, 1972.

2. ASCE Committee on Hydrology of the Hydraulics Division, "Hydrology Handbook", Manual of Engineering Practice No. 28.

3. Brater, E.F., and Sherrill, J.D., "Prediction of the Magnitudes and Frequencies of Floods in Michigan", August 1971, University of Michigan, Ann Arbor, Michigan.

4. "Standard Project Flood Determination", Civil Engineering Bulletin No. 52-8, Department of the U.S. Army.

5. Mozola, Andrew J., "Geology for Land and Ground-Water Development in Wayne County, Michigan", Published by State of Michigan, Department of Natural Resources, 1969.

6. Mozola, Andrew J., "Geology for Land and Ground-Water Development in Monroe County, Michigan", Published by State of Michigan, Department of Natrual Resources, 1969.

7. Carstens, J.P., Davison, W.R., "Heat-Assisted Tunnel Boring Machines". Prepared by United Aircraft Research Laboratories, East Hartford, Connecticut, September 1970.

8. Huval, Carl J., "Hydraulic Design of Unlined Rock Tunnels", Journal of the Hydraulics Division, Proceedings of the American Society of Civil Engineers, Vol. 95, No. HY4, July 1969.

9. Environmental Protection Agency, "Hydraulics of Long Vertical Conduits and Assocaited Cavitation", Water Pollution Control Research Series, 11034 FLU 06/71.

10. Environmental Protection Agency, "Combined Sewer Overflow Abatement Alternatives", Water Pollution Control Research Series, 11024 EXF 08/70.

11. Environmental Protection Agency, "Retention Basin Control of Combined Sewer Overflows," Water Pollution Control Research Series, 11023 08/70.

SUPPLEMENT A
REPORTS ON GEOLOGY OF THE STUDY AREA

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SUBJECT: Storm Water Tunnel Project -- Preliminary Geologic Considerations.

TO : Mr. Robert Gregory, Chief Basin Planning Section, U. S. Army Engineer District, Detroit, P. O. Box 1027, Detroit, Michigan, 48231

DATE : June 2, 1972

Introduction

Michigan is a structural basin in which the sedimentary rocks of Paleozoic age dip inwardly from all directions toward the central area of the Southern Peninsula. The project area is situated along the southeast rim of this basin and, hence, the sedimentary strata have a general northeast-southwest strike with a gentle regional dip to the northwest. Except where local rock structures are involved, the regional dip is usually less than 40 feet per mile. The rock surface is dissected by numerous valleys of which some may exceed 200 feet in depth. The soil overburden will vary in thickness from less than 10 feet to more than 400 feet. Thickest overburden is usually found in those areas where morainic ridges cross or coincide with bedrock valleys.

Stratigraphy and Lithology

A review of the proposed storm water tunnels with respect to the geology of the southeastern Michigan area indicates that the following rock units will be encountered in the course of tunnel construction:

Coldwater Formation (youngest)	shale, some sandstone
Sunbury Formation	shale, dark brown to black
Berea Formation	sandstone, shale
Bedford Formation	shale
Antrim Formation	shale, dark brown to black
Traverse Group	shales, limestone, dolomite
Dundee Formation	limestone, some dolomite
Detroit River Group	
Anderdon Formation	limestone
Lucas Formation	dolomite
Amherstberg Formation	dolomite
Sylvania Formation	sandstone, dolomitic sandstone
Bois Blanc Formation	dolomite
Bass Islands Group	
Raisin River Formation	dolomite
Put-in-Bay Formation	dolomite
Salina Group (upper portion)	dolomite, shaly dolomite, shale.

With the exception of the Sylvania sandstone formation, it is to be noted that a carbonate lithology, with some shale horizons, dominates the

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sequence from the upper Salina upwardly through the Dundee formation. Carbonate rocks (limestones, dolomites as well as their shaly counterparts) are considered as being soluble and thus prone to solution by ground-water circulation particularly along bedding planes, joints, and fractures. Where solution has led to the development of subterranean caverns then sink hole features may occur on the bedrock surface.

The Traverse Group consists of a shale-carbonate lithology. This rock unit is usually not subdivided into distinct and separate formations in the subsurface of southeastern Michigan. The carbonate rocks can be thinly or massively bedded and, on occasion, rich in chert. The shale hori zons are generally blue-gray in color and may contain thin calcareous or dolomitic beds or lenses. The ratio of carbonate rock to shale within the total section of the Traverse Group can vary considerable from one area to another within the limits of the project area. Changes in ratio from place to place are usually gradual rather than abrupt.

Above the Traverse Group the remaining rock units constitute a clastic lithology principally shales, some sandstones (Berea Fm) with occasional lenses or layers of carbonate rock appearing in the sequence.

Potential Problems and Hazards

1. Solution enlarged joints, fractures, and bedding planes (subterranean passageways) in the carbonate rock sequence can function as conduits for ground-water movement. Hence, unexpected and copious volumes of ground-water may be encountered in the event these passageways are intersected in the course of tunneling. Should wells be required for dewatering purposes then another problem is generated in that the temporary lowering of the piezometric water level along the project route can result in the failure of nearby domestic wells. Continuous pumping to relieve the water problem during tunneling can bring about a change in the quality of the ground-water resulting in additional complaints from local residents. The occurrence of these subterranean passageways in the carbonate rock is difficult to predict without recourse to a program of closely spaced borings which may be prohibitive in terms of both time and cost. Rather than attempt to predict their presence perhaps provisions should be made to have the necessary equipment available to counter any excessive ground water discharge.

2. Hydrogen sulphide gas in association with ground-water is not unusual in the southeastern Michigan area. It is toxic and represents a hazard to personnel working in tight quarters such as narrow trenches, caissons, and tunnels without adequate ventilation.

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3. As a general rule, ground-water discharge from the clastic rock sequence should not present any serious problems with respect to quantity except for highly weathered or fractured zones. However, the Antrim shale formation is known for its methane gas. This gas has also been detected in the soil overburden; its frequency of detection being greatest where the overburden rests directly over the outcrop area of the Antrim formation. With respect to the soil overburden the methane gas may be encountered (1) at any depth from the surface to the bedrock floor, (2) in any of the lithologies present in the soil overburden, (3) as free gas or mixed with ground-water, and (5) may occur as a slow unnoticeable seepage or as gas pockets with pressures reported as high as 37 pounds per square inch. In the Port Huron area methane gas encountered in the Antrim Formation had pressures up to 75 pounds per square inch.

Preliminary Comments Relating to the Proposed Tunnel Routes.

1. Port Huron to Algonac (St. Clair County): Soil overburden thickness 90 to 218 feet; bedrock surface elevations range from 375 to 525 feet above sea level (150+ feet relief); bedrock formations encountered predominantly clastic; methane gas in rock and soil overburden; artificial brine operations in the Marysville-Port Huron area.

2. Clinton River to Jefferson and thence along Jefferson to Monroe City: Soil overburden thickness 80-120 feet in Macomb County segment, 20-150 feet in Wayne County, 10-30 feet in Monroe County. Along this route the bedrock surface elevations range from 425 to 580 feet above sea level (155+ feet relief); bedrock formations -- mainly a carbonate lithology from the City of Monroe northward to Belle Isle in the City of Detroit, giving way to a shale-carbonate lithology (Traverse Group) for a short distance, and finally to a clastic lithology in northeast Wayne County and southeast Macomb County. Solution enlarged openings in the carbonate sequence are possible, particularly that portion of the proposed route in Macomb County. Methane gas also a hazard. Detroit Mine of the International Salt Company is located in the vicinity of the Rouge River and I-75 Freeway (depth 1100 ft); subsidence craters recently developed at northernmost end of Grosse Isle and presumably the result of brining operations; strong shows of ground water from wells penetrating Sylvania Formation in vicinity of Grosse Isle; possible artesian flowing well area in the City of Monroe and vicinity. Buried sink holes, brecciated rock possible along southernmost segment of this tunnel route.

3. Upper Rouge River -- Telegraph Road: Soil overburden 10-120 feet thick along Wayne County segment, 100-250 feet along Oakland County segment. Bedrock surface elevations range from 475 to 700 feet above sea level (225+ feet relief). Bedrock formations -- largely a carbonate lithology along southern one-third of proposed route, clastic lithology for remainder particularly in Oakland County. Methane gas can be expected in both

bedrock and soil overburden; solution enlarged openings in the carbonate section possible.

4. Six Mile Conner Creek Tunnel: Soil overburden 60-120 thick. Bedrock elevations range from 425 to 550 feet above sea level (125+ feet relief). Bedrock formations along route are largely clastics. The Antrim shale outcrops beneath the overburden along most of this route. Methane gas can be expected to be present.

5. River Rouge Tunnel: Soil overburden thickness from 50-150 feet. Bedrock eleveations 475-575 feet above sea level (100+ feet relief). In terms of bedrock units a clastic lithology prevails for the upper portion of the route and a carbonate lithology for the lower. Methane gas is to be expected.

Test Boring Program

1. Inasmuch as the bedrock surface is a hidden feature beneath the glacial overburden there is no assurrance that the existing data (logs of oil and gas wells, water wells, and soil borings) include the highest and lowest possible bedrock elevations along each of the proposed tunnel routes. Hence, the indicated relief shown along each of the routes cannot be considered as maximum. Test boring program should include (1) detailed logging and sampling of both overburden and bedrock (slit spoon samples and cores, (2) geophysical logging of each hole for delineating water-bearing horizons, depth of rock weathering, and (3) testing for methane gas and hydrogen sulphide. To detect slow seepage of methane gas, it is recommended that each test hole, upon completion, should be capped for a period of 24-48 hours and then checked with an explosimeter.

2. Depending on the spacing and results of the test borings it may be advisable to complete the bedrock profile by geophysical survey methods.

3. Geological cross sections, based on existing data, along each of the proposed tunnel routes are currently under preparation.

Sincerely yours,

Andrew J. Mozola
2471 Mulberry Road
Bloomfield Hills, Michigan 48013

Tel: 335-6388

cc: Mr. Carr W. Baldwin, Ayres, Lewis, Norris, and May, Inc., Ann Arbor, Mich.

ANDREW J. MOZOLA, PH.D.

Consulting Geologist

SUBJECT: Storm Water Tunnel Project -- Bedrock Surface Profile and Geologic Structure Sections Along Proposed Routes.

TO : Mr. Robert Gregory, Chief Basin Planning Section
U. S. Army Engineer District, Detroit, P. O. Box 1027
Detroit, Michigan 48231

DATE : July 29, 1972

1. Submitted herewith are the bedrock profiles and schematic geologic structures sections that have been added to the project drawings furnished by Ayres, Lewis, Norris and May, Inc.

2. The bedrock profile, bedrock topography and geologic cross sections are based on existing oil, gas and water well records and, to some extent, on soil test borings that have reached or penetrated bedrock. Of these various records only oil and gas logs provide usable information relative to bedrock lithology but unfortunately such records, except for St. Clair County, are sporadic in terms of areal distribution. From the drawings it will be evident that the density and distribution of control points for subsurface interpretation along the proposed routes leaves much to be desired.

3. Bedrock elevations and contours have been shown on both sides of the proposed routes for some distance in order to portray the configuration of the rock surface in terms of bedrock valleys and divides. Straight or gently curving contour lines imply a poor density and distribution of bedrock elevations; a higher density where they appear irregular in form. Contour interval is 25 feet except for that segment of the Jefferson Route in Monroe County.

4. The formation contacts shown in the structure cross sections are highly inferred and should not be used in determining the depth of any formation top or bottom along the proposed routes. As will be noted very few oil and gas records, when plotted, fell along the routes. As a general rule the various rock units increase in thickness to the northwest, i.e., in the direction of dip towards the center of the Michigan Basin. The variation in thickness of the rock units along the proposed routes is attributed to a combination of several factors namely (1) increase in thickness of the individual units towards the northwest, (2) effect of local rock structures, (3) local thickening of the units, (4) the direction of the route in relation to the regional strike and dip of the sedimentary strata and (5) the inherent difficulty in recognizing formation tops and bottoms in the subsurface. The dip of the strata along the proposed routes will vary depending upon the direction of the route in relation to the regional strike and dip and the presence of local structures. In any event, the strata are not as steeply inclined as shown since the cross sections represent a vertical exaggeration of 50x.

ANDREW J. MOZOLA, PH.D.

Consulting Geologist

5. Inasmuch as many of the rock units in this area have oil and gas producing horizons elsewhere in the State, occasional shows of oil and/or gas might be encountered in the course of tunneling, and hence the methane gas hazard is not restricted solely to the Antrim Shale.

6. Brief lithologic descriptions of the rock units and some unconfined compression test data of upper Traverse beds in the W 1/2, Sec. 26, T-1S, R-10E have been appended to this report. The latter represent tests on samples obtained from borings located one-half mile south of the intersection of Evergreen and Schoolcraft Roads where I-96 (Jeffries Freeway) crosses the C. and O. Railroad and Yard.

In the event there are some aspects of this report, or the prior report of June 2, 1972, that need further elucidation kindly do not hesitate to call upon me to do so.

Sincerely yours,

Andrew J. Mozola
2471 Mulberry Road
Bloomfield Hills, Michigan 48013

Tel: (313) 335-6388

encl's: Lithologic descriptions
Unconfined compression test data

STRATIGRAPHIC SECTION IN SOUTHEASTERN MICHIGAN

Coldwater Formation

Youngest (uppermost stratigraphically) of the Paleozoic sedimentary strata to be encountered along the northernmost segment of the Upper Rouge River - Telegraph proposed tunnel. The total thickness of the Coldwater Formation in southeastern Michigan is approximately 850 feet. In all probability the proposed tunnel will penetrate the lower one-third to one-half of the total Coldwater section.

The formation is dominantly a blue, blue-gray to greenish gray, micaceous shale becoming more sandy and reddish in color in the upper part of the section. Some reddish, greenish, and purplish colored shale, though not of widespread extent, may be present near the base. Limestone, dolomite, sandstone, or siltstone as lenses, or as thin beds which are not continuous over large areas, may be interspersed with the shale. In some areas alternating shale and sandstone sequences appear but again subsurface records suggest that these are not of widespread areal occurrence. Clay-ironstone nodules are distinctive of the Coldwater. The nodules are small to fairly large concretionary masses characterized by an indurated clay, or silty clay, center and in turn surrounded by concentric limonitic shells. Both ball and pillow shaped clay-ironstones have been described from a Coldwater shale exposure in Branch County, Michigan. The former are usually spherical and average six inches in diameter; the latter are flattish and round with the largest one found measuring 42 inches in diameter.

The lower contact of the Coldwater Formation is easily recognized by the definite appearance of the dark brown to black shales of the underlying Sunbury Formation.

Some salt water and natural gas are known to be present in this formation as reported on the records of wells drilled in Holly and Independence townships in the northwestern and northern parts of Oakland County respectively. Reported yields of water wells completed in the Coldwater Formation ranged from 10 to 70 GPM depending on the depth of the well and, hence, the number of joints, fractures and bedding planes intersected (secondary permeability), or the number of sandstone and carbonate rock layers encountered. Some of the wells were flowing.

Sunbury Formation

A hard, dark brown, dark gray to black bituminous shale with traces of dolomite. Lithologically, it is similar in appearance to the Antrim Shale appearing lower in the stratigraphic sequence but lacking the abundance of fossil plant spore cases. Depending on geographic position the thickness of the Sunbury ranges from 20 to more than 50 feet. It appears that the formation thickens in the direction of dip. Presence of some natural gas in this unit is a distinct possibility.

The lower contact of this formation is usually place at first consistent appearance of the light-gray to blue shales, or the light-gray, fine-grained sandstones of the underlying Berea Formation.

Berea-Bedford Formations

Owing to the fact that the Berea-Bedford contact is difficult to recognize in the subsurface, the two formations are usually shown as a single unit on many geologic maps.

Berea Lithology: Fine-grained, white, gray to light drab to brown, micaceous sandstone in beds of varying thickness from 25 to 40 feet and nearly everywhere separated by beds of light-gray to blue gray shale having sporadic zones of calcareous or dolomitic material. The sandstone beds are usually well cemented but some friable zones, which are waterbearing, appear in the section. Thickness between 55 and 235 feet except where it outcrops beneath the soil overburden.

Bedford Lithology: Dominantly shale,in part calcareous and sandy. Generally light-gray in color with sporadic dark gray horizons. Occasional beds of micaceous sandstone, shaly dolomite, or limestone may appear in the section. Thickness 65 to 155 feet except in outcrop areas beneath the soil overburden.

The lower contact of the Bedford is usually placed at the first persistent appearance of the underlying dark brown to black Antrim Formation.

Natural gas is known to be present in the formation in other parts of the state. Gas show reported in exploratory oil and gas well in Independence Twp., Oakland County. Water wells penetrating the Berea have yields ranging from 5 to 30 GPM. Salt water is generally encountered in this formation where it is overlain by Sunbury and younger formations; potable water where the Berea occurs in outcrop beneath the soil overburden. Bedford formation not important as aquifer.

Antrim Formation

Predominantly a dark brown to black bituminous shale that is finely laminated and fissile so that the formation is frequently described by water well drillers as "black slate". Some gray shale may appear near the base. Pyrite and/or marcasite nodules present throughout the entire section. The lower portion is characterized by hard, black to dark brown, crystalline and nearly spherical concretions which are composed of the mineral "anthraconite", a petroliferous variety of calcium carbonate. These concretions often exceed 3 to 4 feet in diameter and may be mistakenly logged as limestone beds during drilling. An excellent outcrop revealing these nearly spherical concretions may be seen at Kettle Point, Ontario. Also characteristic of the Antrim Formation is the abundance of very small, but visible, disc-like resinous structures that are reddish-brown in color. These have been identified as fossil spore cases of floating fossil plants. Thickness in the southeastern Michigan area varies from 0 to nearly 200 feet.

The lower contact of the Antrim is uncertain because the basal gray shales, where present, resemble the blue-gray shales of the underlying Traverse Group.

Except for local areas where the formation is highly weathered, fractured, and overlain by the soil overburden, the Antrim is not important as an aquifer. The Antrim does contain methane gas and the formation, along with the overlying soil overburden, does constitute a hazard to construction projects.

Traverse Group

This group consists of limestones, shales and dolomites which are not subdivided into separate formations in the southeastern Michigan area. The shales are largely blue-gray to gray, occasionally brown, in color and may or may not contain thin calcareous or dolomitic beds or stringers. The carbonate rocks (limestone and dolomite) can be thinly or massively bedded and, in instances, are cherty. Generally the limestone beds are light gray, gray, or gray brown, fine to coarsely grained in texture and often high in calcium carbonate as to render them useful in Portland Cement making. At times, the limestone beds can be richly fossiliferous as to be called "shelly limestone" by drillers. The dolomite beds and their shaly counterparts are normally gray or buff in color, again thinly to massively bedded but somewhat more coarsely crystalline in texture. In the total section represented by the Traverse Group, the ratio or carbonate rocks to shale varies considerably from one area to another. Some logs of wells show a dominance of shale over carbonate materials; others the opposite situation. Pyrite is noted throughout the section. Thickness 0 to 300 feet.

The Traverse-Dundee contact is difficult to place in those areas where limestone beds of the Traverse Group rest directly on the Dundee limestone.

Occasional oil shows indicated on oil and gas logs. Limestone beds, if characterized by solution enlarged joints and fractures, can result in copious amounts of ground water. Hydrogen sulfide gas usually associated with the ground water.

It is to be noted that formations above the Traverse represent essentially a clastic sequence (shales-sandstones); below the Traverse, essentially a non-clastic, or carbonate, sequence (limestones-dolomites).

The base of the Traverse can be considered as marking the beginning of the carbonate rock sequence except for the Sylvania sandstone occurring lower in the section. Much of this carbonate sequence is represented along the proposed tunnel routes where it outcrops beneath the glacial soil overburden. From the Detroit area the thickness of the overburden decreases downriver towards Monroe, Michigan. The presence of solution enlarged openings in the carbonate sequence beneath the soil overburden should be expected and with it the probability of copious amounts of ground-water under artesian conditions, usually mineralized but potable, and characterized by an odor of hydrogen sulfide. Vintage geologic reports make reference to flowing and non-flowing wells of high yield in the Rouge River Flats in Dearborn, in downtown Detroit and downriver towards Monroe, Michigan. Formations producing these high yields include the Dundee, Lucas, and Sylvania sandstones. The Swan Well (elevation of mouth, 597 feet A.S.L.) near the south end of Grosse Ile has been reported (1916) as having a depth of 2375 feet and flowing strongly (3000 GPM) since 1903. Strongest flows were encountered at depths of 420 feet (177 feet A.S.L.) and 450 feet (147 feet A.S.L.). Large springs were also reported to be common along the lower Huron River and Detroit River areas; specifically along the Huron River and also northward toward Gibralter and southward along the shore of Lake Erie in Monroe County. In fairly recent years strong flows of ground water occurred during caisson construction at the Northeast Water Filtration Plant (8 Mile Rd. and Van Dyke) and again at the site of New Quarry (Martin-Marietta) located in the southeasternmost extremity of Washtenaw County. The yield and quality of ground water (hydrogen sulfide) forced abandonment of quarry.

Dundee Formation

The formation consists of gray, bluish-gray, light buff to brown limestones, dolomitic limestones, and dolomites. The strata are thinly to massively bedded, finely to coarsely crystalline in texture, and containing cherty and/or siliceous horizons. Some shale horizons occasionally may be present in the section. The type locality of this formation is the old Christiancy Quarry at Dundee where it is a high-calcium limestone suitable for cement and lime. Although the Dundee is normally a limestone it is also a dolomitic limestone or dolomitic elsewhere within its outcrop area. Carbonaceous partings between limestone beds and cavities containing hydrocarbons are common. Grains of frosted quartz sand appear abundant in the basal beds. Thickness 0 to 160 feet.

The lower contact of the Dundee is difficult to place in the subsurface in that the underlying Detroit River Group consists of limestones and dolomites.

Detroit River Group

This group where exposed in quarries in Monroe County and northwestern Ohio has been subdivided, in descending order, into the Anderdon (24 feet), Lucas (84 feet), Amherstburg (19 feet), and Sylvania (50 feet) formations. These increase in thickness towards the north and northwest. The uppermost three formations consist predominantly of a carbonate lithology that is difficult to differentiate, in terms of their contacts, in the subsurface. The Sylvania Formation is a quartz rich sandstone and easily recognized. For this reason the Detroit River Group is shown on geologic maps as two separate units--a non-clastic unit designated as the Detroit River Dolomites (Anderdon, Lucas, Amherstburg) and the clastic unit as the Sylvania Sandstone.

Detroit River Dolomite Lithology

The Anderdon, uppermost of the group, consists of a high calcium limestone which makes it difficult to distinguish from the overlying Dundee Limestone. Dolomite beds, however can be expected within the Anderdon in some areas. The remaining (Lucas, Amherstburg) are nominally dolomites with some limestone beds, occasionally cherty and/or argillaceous. These dolomites vary in color--gray, buff, light brown, light gray to white and have textures ranging from finely crystalline to granular. Irregular cavities (vugs) are common and frequently lined with calcite crystals measuring 3-4 inches in length in a form known as "dog-tooth spar". Occasional masses and crystals of native sulfur are not uncommon. Anhydrite ($CaSO_4$) can be present, particularly in the Lucas Formation, as thin beds of limited areal extent or as lenses. As the basal beds of the Amherstburg are approached there is an increase in the amount of frosted quartz sand grains similar in appearance to the quartz sand which makes up the underlying Sylvania Sandstone.

The lower contact of the Detroit River Group is usually placed at the first persistent appearance of sandstone of the underlying Sylvania Formation

Sylvania Formation Lithology

A white to light gray, fine to medium grained, high-purity quartz sandstone. Individual grains are frosted in appearance, subangular to rounded in shape. The sandstone is poorly cemented and becomes extremely friable upon exposure to weathering. When crushed, screened and washed the sand resembles granular sugar; terms such as "sugar sand" and "silica sand" are common notations in driller's records. Where the Sylvania has been exposed to weathering, a dull gray appearance predominates in contrast to a nearly pure white color when freshly quarried. Paper thin seams of carbonaceous materials are very apparent on fresh cuts and occur at varying intervals. Geodes (cavities) lined with calcite and/or celestite crystals are common; on rare occasions native sulfur may be found. Near the base of the formation 15 to 20 feet of sandy dolomite is usually encountered which is light to dark gray in color and containing some zones of chert nodules and dolomite pebbles. In Monroe County the basal beds of this formation rest unconformably (prior erosion surface) on the Bois Blanc Formation or the Bass Islands Group. In Ohio, pebbles derived from the upper Bass Islands beds have been incorporated in the basal Sylvania beds. The Sylvania thickens to the west and north. Thickness in southeast Michigan is 0 to 288 feet.

Lower contact may rest on Bois Blanc Formation or the Bass Islands Group of dolomites.

Good aquifer. Many domestic wells are completed in the Sylvania sandstone in its outcrop area in Monroe County. If project requires dewatering in the course of tunneling in Monroe County then domestic well failures, or decreased well performance, may be expected.

Though the quartz sand grains are highly abrasive, the Sylvania sandstone is considered to be poorly cemented. Low unconfined compressive strengths may be characteristic of this sandstone.

Bois Blanc Formation

Not shown as a rock unit on geologic maps of the southeastern Michigan area because of the difficulty in recognizing its boundaries and correlating between areas due to scarcity of records. Both the upper and lower contacts of the Bois Blanc are marked by erosional unconformities and, therefore, its thickness can vary considerably from place to place. Though reported as eroded in southern Michigan and northern Ohio, its removal was not necessarily complete everywhere in the region. Remnants of the Bois Blanc in the project area beneath the drift are possible and, if recognized, are most likely to occur on the bedrock surface highs.

Lithology: The Bois Blanc Formation has a lithology dominated by dolomites though in some areas limestones may prevail. The dolomites are light gray to gray-brown, tan to light brown or medium brown in color, and characterized by fine to medium-grained textures. Chert is abundant throughout the section and, perhaps, represents a useful criterion for the recognition of the Bois Blanc in the subsurface. Some horizons have been reported as chert-rich (up to 20 percent) which may imply weathering particularly if the chert itself shows signs of decomposition and staining by iron oxides. The chert is highly variable; it can be hard (unweathered) or soft (weathered), smooth, occasionally vitreous, and frequently features conchoidal fractures. Color may be white, light to dark gray, brownish-gray, or bluish-gray. Siliceous zones or cherty streaks within dolomite and limestone beds are also present.

Thickness of the Bois Blanc varies from 0 to 125 feet and is highly variable within short distances laterally.

Bass Islands Group

Lithology: Includes the Raisin River and Put-In Bay dolomites which are usually not dubdivided in the subsurface. The group consists largely of light gray, tan, buff, brown, or dark brown, dense to finely crystalline dolomites and shaly dolomites. In some areas dense to finely crystalline limestone may prevail. Vugs, tiny fractures, and highly porous zones may be locally characteristic. Gypsum and anhydrite in thin beds, as nodules or stringers, as well as clear selenite occur more commonly in the Bass Islands than in the overlying rock units.

Thickness 0 to 302 feet. Lower contact not easily recognized.

Salina Group

In the Monroe County area the Salina Group consists largely of dolomites and shaly dolomites with appreciable amounts of dolomitic shale,

AD-A041 122 AYRES LEWIS NORRIS AND MAY INC ANN ARBOR MICH F/G 13/2
ALTERNATIVES FOR STORMWATER RUNOFF CONTROL IN SOUTHEASTERN MICH--ETC(U)
FEB 73 DACW35-72-C-0027
UNCLASSIFIED NL

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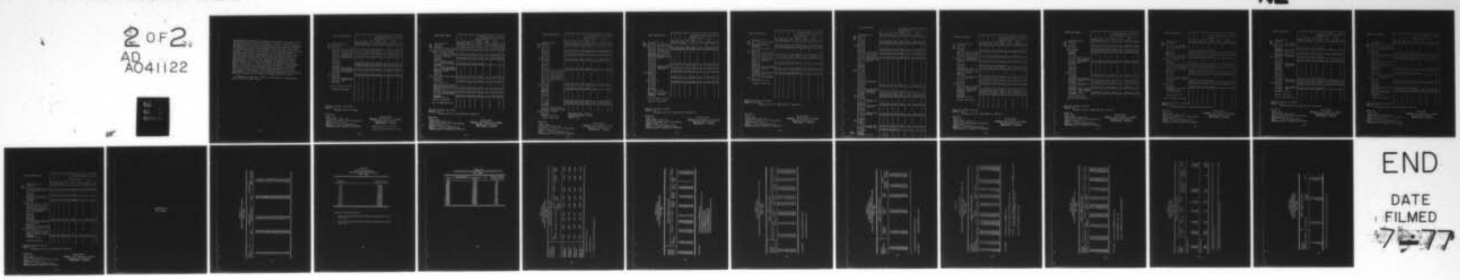

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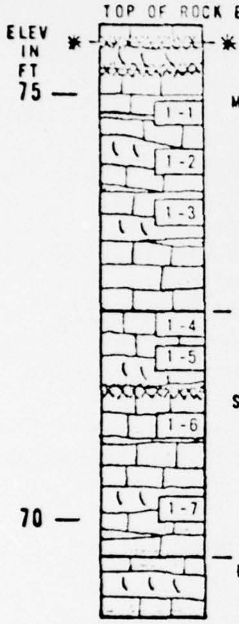
and alternating shale-dolomite sequences, particularly in the upper portion. The dolomites are gray, buff, light brown, or brown in color, dense to finely crystalline in texture but occasionally coarse. Anhydrite and gypsum are commonly associated with the dolomite but salt beds are rarely present. The dolomites are further characterized by stylolitic seams, black shale or carbonaceous partings, vugs, crevices, porous zones and, in some instances, cavernous. Hydrocarbons (often as black oil in pores), petroliferous odors and shows of gas are not unusual. The shale beds are usually gray, but green, greenish-gray, and minor amounts of red may be present. The shale beds may contain dolomitic beds or stringers, gypsum, anhydrite, and occasional oil and gas shows. Anhydrite may appear in the section as distinct beds 5 to 15 feet with stringers, or inclusions, of shale and/or dolomitic shale. Within the total Salina Section gypsum is usually massive, white, and in thin beds, stringers, and nodules. Selenite and satin spar varieties of gypsum, though minor in amount, are frequently noted in oil and gas logs. The most distinctive characteristic of the Salina Group in Monroe County is the apparent absence of salt beds (only one instance of a 5 foot bed) which is in marked contrast to the considerable aggregate thickness of salt (730 feet) in Wayne County to the north.

Thickness 0 to 820 feet. Oldest of the rock units to be encountered along the proposed tunnel routes.

LOG OF ROCK PROFILE

TOP OF ROCK ELEV. 75.8'



MEDIUM GRAY DOLOMITE WITH MINOR BEDDING ZONES OF ARGILLACEOUS CARBONATES - CHERT INCLUSIONS SCATTERED THROUGHOUT THE INTERVAL, OCCASIONAL VUGS

SAME AS ABOVE WITH MINOR EVIDENCE OF VERTICAL FRACTURES, MORE CARBONATES

INTERBEDDED MEDIUM GRAY DOLOMITE AND CHERT

E.O.B. 68.8'

—— Water return loss

xxxxxxxx Fracture Zone

SAMPLE NO.	ELEV IN FEET	DRY BULK SP GRAV	POROSITY %	UNCONFINED COMPRESSION TEST DATA: UNCONFINED COMPRESSIVE STRENGTH, PSI	DEFORMATION AT FAILURE, %	TANGENT MODULUS AT 50% ULTIMATE STRENGTH, PSI	$\frac{L}{D}$ RATIO
1-1	74.7	2.80	1.26	25,280	.41	5.88×10^6	2.07
1-2	74.1	2.78	1.92	23,940	.63	4.30×10^6	1.92
1-3	73.5	2.71	4.46	9,110	.47	2.05×10^6	2.05
1-4	72.2	2.63	5.32	7,430	.53	1.12×10^6	2.05
1-5	71.8	2.76	2.53	11,330	.29	3.86×10^6	2.09
1-6	71.0	2.75	2.07	18,690	.52	3.86×10^6	2.10
1-7	70.0	2.72	3.73	17,300	.41	4.98×10^6	2.10

WATER LEVEL IN CASING: Not recorded
RECOVERY: 100%
39% based on cores 4" or longer

BORING DATA:

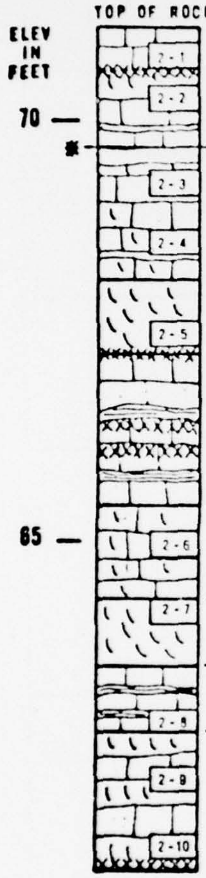
NUMBER: RCB-1
DATE OF BORING: October, 1971
LOCATION: Sta 238+00, 134'Rt of Construction ℄
GROUND ELEVATION: 146.3 ft
MADE BY: J. P. McGuire, Geophysical Unit
GEOLOGICAL LOGS BY: Geophysical Unit Geologists

Project 82122
PROPOSED I-96 (JEFFRIES FWY) THROUGH
OAK YARD, CITY OF DETROIT
WAYNE COUNTY, MICHIGAN

W½, Sec 26, T-1S-R10E
I-96 over C&O RR (OAK YD)

LOG OF ROCK PROFILE

TOP OF ROCK ELEV 71.1



MEDIUM GRAY DOLOMITE WITH MINOR BEDDING ZONES OF ARGILLACEOUS CARBONATES - CHERT INCLUSIONS SCATTERED THROUGHOUT THE INTERVAL, OCCASIONAL VUGS

GRAY BANDED CHERT - SOME EVIDENCE OF VERTICAL FRACTURES

MEDIUM GRAY DOLOMITE WITH SHALE PARTINGS, VERY MINOR VERTICAL FRACTURES

GRAY CHERTY DOLOMITE

GRAY CHERT

PETROLIFEROUS MEDIUM GRAY DOLOMITE WITH SHALY ZONES, SOME PARTINGS - SOME VUGS IN DOLOMITE

INTERBEDDED GRAY AND WHITE CHERTS AND MEDIUM GRAY DOLOMITE

E.O.B. 61.1

xxxxxxxx Fracture Zone

—— Water return loss

SAMPLE NO.	ELEV IN FEET	DRY BULK SP GRAV	POROSITY %	UNCONFINED COMPRESSION TEST DATA: UNCONFINED COMPRESSIVE STRENGTH, PSI	DEFORMATION AT FAILURE, %	TANGENT MODULUS AT 50% ULTIMATE STRENGTH, PSI	L/D RATIO
2-1	70.8	2.75	3.02	13,180	.41	3.29×10^6	2.05
2-2	70.2	2.77	1.93	15,610	.48	3.90×10^6	2.04
2-3	69.2	2.63	6.64	9,760	.30	3.60×10^6	2.02
2-4	68.5	2.77	2.20	19,160	.36	8.08×10^6	2.02
2-5	67.4	2.59	0.64	NO TEST			
2-6	64.9	2.80	1.94	12,560	.42	2.84×10^6	2.02
2-7	64.1	2.71	2.91	16,900	.48	4.67×10^6	2.02
2-8	62.8	2.66	6.05	5,960	.36	1.78×10^6	1.36
2-9	62.1	2.66	4.77	17,990	.30	8.01×10^6	2.01
2-10	61.3	2.28	15.66	3,500	.18	1.67×10^6	2.00

WATER LEVEL IN CASING: Not recorded
RECOVERY: 100%
47% based on cores 4" or longer (52% 1st 5', 42% 2nd 5')

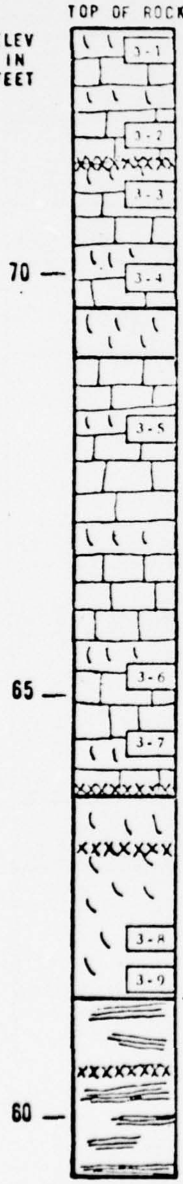
BORING DATA:

NUMBER: RCB-2
DATE OF BORING: October, 1971
LOCATION: Sta 239+40, 177'Lt of Construction ℄
GROUND ELEVATION: 146.7 ft
MADE BY: J. P. McGuire, Geophysical Unit
GEOLOGICAL LOGS BY: Geophysical Unit Geologists

Project 82122
PROPOSED I-96 (JEFFRIES FWY) THROUGH
OAK YARD, CITY OF DETROIT
WAYNE COUNTY, MICHIGAN

LOG OF ROCK PROFILE

TOP OF ROCK ELEV 72.9



MEDIUM GRAY PETROLIFEROUS VUGGY DOLOMITE WITH MANY CHERT ZONES - SOLID CHERT ZONES FROM 69.6' to 69.0' and 63.8' to 61.4'

BUFF ARGILLACEOUS SILTSTONE AND SHALES INTERBEDDED

E.O.B. 59.3'

xxxxxxxx Fracture Zone

SAMPLE NO.	ELEV IN FEET	DRY BULK SP GRAV	POROSITY %	UNCONFINED COMPRESSION TEST DATA			
				UNCONFINED COMPRESSIVE STRENGTH, PSI	DEFORMATION AT FAILURE, %	TANGENT MODULUS AT 50% ULTIMATE STRENGTH, PSI	L/D RATIO
3-1	72.6	2.79	1.54	18,820	.23	3.63×10^6	2.09
3-2	71.6	2.75	1.85	18,250	.63	2.71×10^6	2.13
3-3	70.9	2.66	5.90	8,290	.28	3.21×10^6	2.15
3-4	69.9	2.57	3.28	10,430	.28	3.23×10^6	2.16
3-5	68.1	2.72	2.76	15,880	.62	--	2.18
3-6	65.2	2.44	7.36	14,080	.52	4.81×10^6	2.09
3-7	64.4	2.72	3.90	10,180	.06	--	1.91
3-8	62.1	2.57	9.09	7,540	.18	2.18×10^6	2.09
3-9	61.6	2.56	8.90	7,910	.34	3.03×10^6	2.16

WATER RETURN LOSS: Intermittent
WATER LEVEL IN CASING: Elev 98.9'
RECOVERY: 92%

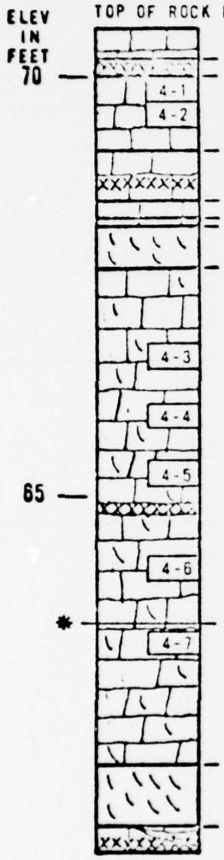
BORING DATA:

NUMBER: RCB-3
DATE OF BORING: October, 1971
LOCATION: Sta 241+35, 120'Rt of Construction ℄
GROUND ELEVATION: 146.4 ft
MADE BY: J. P. McGuire, Geophysical Unit
GEOLOGICAL LOGS BY: Geophysical Unit Geologists

Project 82122
PROPOSED I-96 (JEFFRIES FWY) THRC
OAK YARD, CITY OF DETROIT
WAYNE COUNTY, MICHIGAN

LOG OF ROCK PROFILE

TOP OF ROCK ELEV. 70.5'



- MEDIUM GRAY DOLOMITE
- BASAL TILL AND BLOCKY DOLOMITE FRAGS AND CLAY
- MEDIUM GRAY DOLOMITE. MANY HOLES, HONEY-COMB STRUCTURE
- GRAY TO BUFF DOLOMITE
- SAME AS 70.0 TO 70.9'
- GRAY DOLOMITE
- GRAY AND WHITE BANDED CHERT
- DOLOMITE - SOME CHERT AND SOFT MINERAL BLEBS, SEAMY
- GRAY CHERT
- DOLOMITE AND SILT-STONE SEAMS

E.O.B. 60.8'

—— Water return loss

XXXXXXXX Fracture Zone

SAMPLE NO.	ELEV IN FEET	DRY BULK SP GRAV	POROSITY %	UNCONFINED COMPRESSION TEST DATA: UNCONFINED COMPRESSIVE STRENGTH, PSI	DEFORMATION AT FAILURE, %	TANGENT MODULUS AT 50% ULTIMATE STRENGTH, PSI	L/D RATIO
4-1	69.9	2.52	10.78	8,270	.30	4.14×10^6	1.64
4-2	69.5	2.52	11.01	10,930	.28	3.59×10^6	2.10
4-3	66.7	2.74	3.25	7,570	.17	3.75×10^6	2.10
4-4	66.0	2.71	3.97	2,900	.15	1.68×10^6	2.07
4-5	65.3	2.73	3.81	12,990	.46	2.99×10^6	2.11
4-6	64.1	2.79	1.41	19,910	.29	5.87×10^6	2.10
4-7	63.3	2.75	2.77	13,500	.47	3.64×10^6	2.08

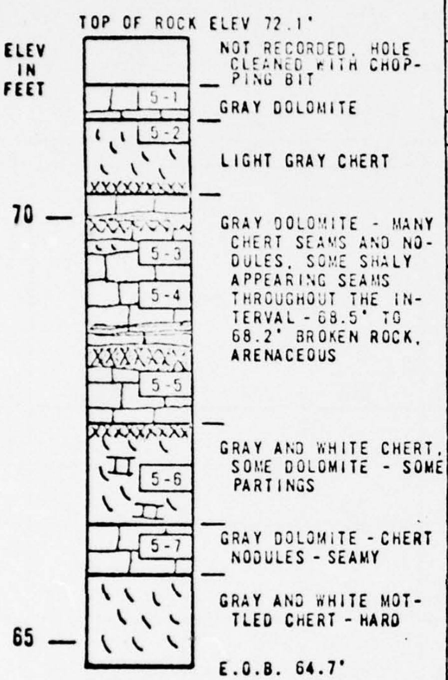
WATER LEVEL IN CASING: Elev 98.5'
RECOVERY: 97%
33% based on cores 4" or longer (27% 1st 5', 40% 2nd 4.7')

BORING DATA:

NUMBER: RCB-4
DATE OF BORING: October, 1971
LOCATION: Sta 243+00, 166'Lt of Construction ℄
GROUND ELEVATION: 144.5 ft
MADE BY: J. P. McGuire, Geophysical Unit
GEOLOGICAL LOGS BY: Geophysical Unit Geologists

Project 82122
PROPOSED I-96 (JEFFRIES FWY) THROUGH OAK YARD, CITY OF DETROIT WAYNE COUNTY, MICHIGAN

LOG OF ROCK PROFILE



XXXXXXXX Fracture Zone

SAMPLE NO.	ELEV IN FEET	DRY BULK SP GRAV	POROSITY %	UNCONFINED COMPRESSION TEST DATA			
				UNCONFINED COMPRESSIVE STRENGTH, PSI	DEFORMATION AT FAILURE, %	TANGENT MODULUS AT 50% ULTIMATE STRENGTH, PSI	L/D RATIO
5-1	71.4	2.74	3.27	16,840	.50	3.58×10^6	1.81
5-2	71.0	2.56	3.30	3,930	.18	--	2.04
5-3	69.6	2.76	1.86	16,260	.30	4.85×10^6	2.03
5-4	69.1	2.73	2.83	13,210	.45	4.13×10^6	1.87
5-5	68.0	2.75	2.39	10,140	.17	--	2.03
5-6	67.0	2.61	3.88	13,080	.35	4.14×10^6	2.08
5-7	66.1	2.78	2.25	NO TEST		--	--

WATER LEVEL IN CASING: Not recorded
RECOVERY: Nearly 100%
30% based on cores 4" or longer (32% 1st 5', 24% 2nd 1.8')

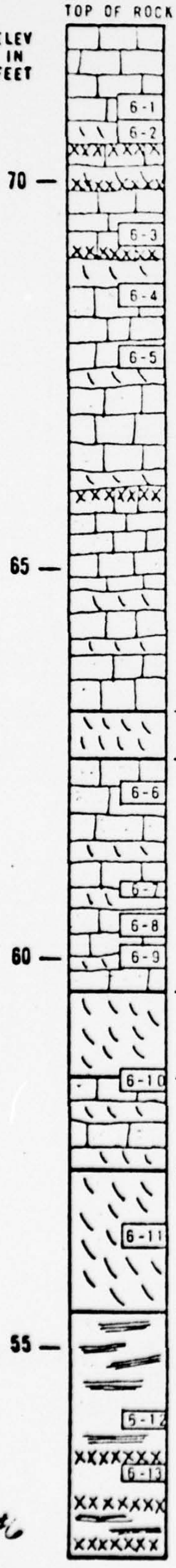
BORING DATA:
NUMBER: RCB-5
DATE OF BORING: October, 1971
LOCATION: Sta 245+00, 124'Rt of Construction ℄
GROUND ELEVATION: 145.6 ft
MADE BY: J. P. McGuire, Geophysical Unit
GEOLOGICAL LOGS BY: Geophysical Unit Geologists

Project 82122
PROPOSED I-96 (JEFFRIES FWY) THROUGH
OAK YARD, CITY OF DETROIT
WAYNE COUNTY, MICHIGAN

LOG OF ROCK PROFILE

TOP OF ROCK ELEV 72.0'

ELEV IN FEET



MEDIUM GRAY DOLOMITE WITH MINOR BEDDING ZONES OF ARGILLACEOUS CARBONATES - CHERT INCLUSIONS SCATTERED THROUGHOUT THE INTERVAL - OCCASIONAL VUGS

GRAY BANDED CHERT

MEDIUM GRAY DOLOMITE WITH MANY CHERT ZONES SIMILAR TO 72.0' TO 63.2'

GRAY AND WHITE MOTTLED CHERT

LIKE 72.0' TO 63.2', HIGHLY VUGGY

GRAY AND WHITE MOTTLED CHERT

BUFF ARGILLACEOUS SILTSTONE - SHALY

E.O.B. 52.3'

				UNCONFINED COMPRESSION TEST DATA			
SAMPLE NO.	ELEV IN FEET	DRY BULK SP GRAV	POROSITY %	UNCONFINED COMPRESSIVE STRENGTH, PSI	DEFORMATION AT FAILURE, %	TANGENT MODULUS AT 50% ULTIMATE STRENGTH, PSI	L/D RATIO
6-1	70.9	2.59	8.68	13,410	.23	6.03×10^6	2.06
6-2	70.6	2.52	10.62	11,470	.24	4.73×10^6	2.05
6-3	69.3	2.67	3.49	18,560	.58	5.12×10^6	1.48
6-4	68.5	2.77	2.18	9,860	.11	9.35×10^6	2.12
6-5	67.7	2.77	2.07	11,120	.45	1.59×10^6	1.63
6-6	62.1	2.78	0.29	26,040	.53	5.29×10^6	1.83
6-7	60.9	2.62	6.66	3,730	.12	--	1.97
6-8	60.4	2.74	2.54	6,770	.30	2.35×10^6	2.04
6-9	60.0	2.78	1.85	10,930	.31	3.33×10^6	1.97
6-10	58.4	2.41	8.04	7,430	.29	2.56×10^6	2.08
6-11	56.4	2.40	8.78	21,780	.59	3.74×10^6	2.05
6-12	54.2	2.08	22.18	5,690	.43	1.39×10^6	1.42
6-13	53.5	1.80	33.45	--	--	--	--

LOG OF ROCK PROFILE

TOP OF ROCK ELEV 77.5'

ELEV IN FEET

75 —

70 —

LIGHT GRAY TO BLACK DOLOMITE, MANY SOLUTION CAVITIES AND FILLINGS, STYLOLITIC STRUCTURES AND PARTINGS, CHERT ZONES THROUGHOUT THE ENTIRE INTERVAL

WHITE AND GRAY MOTTLED CHERT

LIGHT GRAY TO BLACK DOLOMITE

WHITE AND GRAY MOTTLED CHERT

DOLOMITE - SILTSTONE - MINOR VUGS AND SHALYLIKE STRUCTURES THROUGHOUT INTERVAL

E.O.B. 67.5'

xxxxxxxx Fracture Zone

SAMPLE NO.	ELEV IN FEET	DRY BULK SP GRAV	POROSITY %	UNCONFINED COMPRESSION TEST DATA			
				UNCONFINED COMPRESSIVE STRENGTH, PSI	DEFORMATION AT FAILURE, %	TANGENT MODULUS AT 50% ULTIMATE STRENGTH, PSI	$\frac{L}{U}$ RATIO
7-1	76.4	2.73	1.53	14,550	.47	8.45×10^8	1.67
7-2	75.4	2.62	5.65	4,760	.45	9.35×10^5	1.90
7-3	74.5	2.77	1.97	9,240	.29	3.69×10^6	2.13
7-4	73.5	2.75	0.80	NO TEST	--	--	--
7-5	73.0	2.48	6.20	10,650	.29	3.82×10^6	2.12
7-6	71.5	2.27	12.92	15,240	.44	5.52×10^6	1.91
7-7	70.9	2.35	10.07	10,980	.24	2.82×10^6	2.02
7-8	70.3	2.11	19.75	2,940	.28	9.27×10^5	2.15
7-9	69.2	2.65	6.19	2,340	.22	7.85×10^5	2.18
7-10	68.6	2.22	19.35	1,860	.19	1.12×10^6	1.94
7-11	68.1	1.91	28.84	1,700	.28	5.71×10^5	1.73

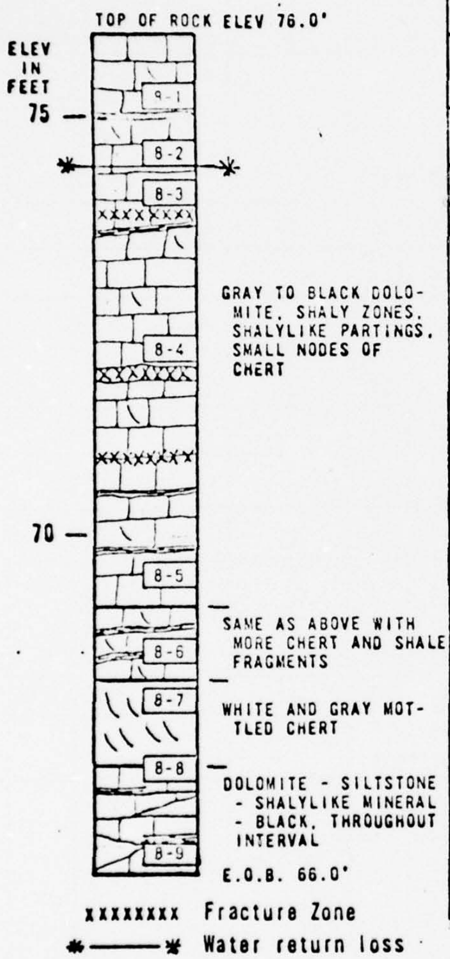
WATER LEVEL IN CASING: Elev 103.3'
RECOVERY: 100%
39% based on cores 4" or longer (32% 1st 5', 46% 2nd 5')

BORING DATA:

NUMBER: RCB-7
DATE OF BORING: November, 1971
LOCATION: Sta 249+00, 124'Rt of Construction ℄
GROUND ELEVATION: 144.3 ft
MADE BY: J. P. McGuire, Geophysical Unit
GEOLOGICAL LOGS BY: Geophysical Unit Geologists

Project 82122
PROPOSED I-96 (JEFFRIES FWY) THROUGH
OAK YARD, CITY OF DETROIT
WAYNE COUNTY, MICHIGAN

LOG OF ROCK PROFILE



SAMPLE NO.	ELEV IN FEET	DRY BULK SP GRAV	POROSITY %	UNCONFINED COMPRESSION TEST DATA: UNCONFINED COMPRESSIVE STRENGTH, PSI	DEFORMATION AT FAILURE, %	TANGENT MODULUS AT 50% ULTIMATE STRENGTH, PSI	L/D RATIO
8-1	75.2	2.75	2.33	17,110	.28	4.95×10^6	2.19
8-2	74.5	2.66	5.79	4,070	.18	1.24×10^6	2.03
8-3	74.0	2.69	5.20	4,490	.29	1.86×10^6	2.12
8-4	72.2	2.81	0.33	21,310	.28	5.11×10^6	2.18
8-5	69.5	2.83	0.41	23,040	.52	5.23×10^6	2.21
8-6	68.6	2.42	11.69	5,640	.12	3.21×10^6	2.08
8-7	68.0	2.32	11.25	21,450	.50	3.46×10^6	2.16
8-8	67.2	2.41	8.16	28,040	.73	3.60×10^6	2.15
8-9	66.2	1.86	28.33	3,320	.22	9.95×10^6	2.20

WATER LEVEL IN CASING: Elev 99.9'
RECOVERY: 100%
38% based on cores 4" or longer (33% 1st 5', 43% 2nd 5')

BORING DATA:

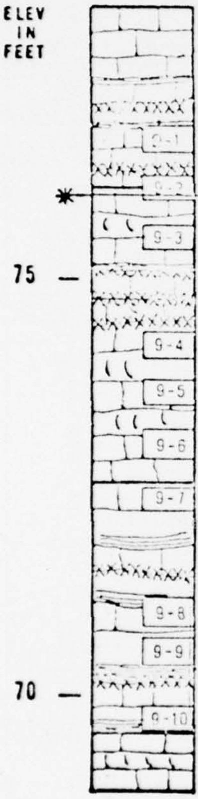
NUMBER: RCB-8
DATE OF BORING: November, 1971
LOCATION: Sta 251+00, 126'Lt of Construction ℄
GROUND ELEVATION: 144.4 ft
MADE BY: J. P. McGuire, Geophysical Unit
GEOLOGICAL LOGS BY: Geophysical Unit Geologists

Project 82122
PROPOSED I-96 (JEFFRIES FWY) THROUGH
OAK YARD, CITY OF DETROIT
WAYNE COUNTY, MICHIGAN

LOG OF ROCK PROFILE

TOP OF ROCK ELEV 78.3'

ELEV IN FEET



LIGHT GRAY DOLOMITE, VUGS, SOME SHALE PARTINGS

LIGHT GRAY DOLOMITE, VUGS, SOME SHALE PARTINGS, CHERT LAYERS

LIGHT GRAY DOLOMITE, VUGS, INTERBEDDED AND INTERMIXED WITH CHERT, MANY ZONES WITH CHERT NODULES

SILTSTONE, SHALES AND DOLOMITE - INTERBEDDED

DOLOMITE AND CHERT INTERBEDDED

E.O.B. 68.9'

xxxxxxxx Fracture Zone

✱ ——— ✱ Water return loss

SAMPLE NO.	ELEV IN FEET	DRY BULK SP GRAV	POROSITY %	UNCONFINED COMPRESSION TEST DATA			
				UNCONFINED COMPRESSIVE STRENGTH, PSI	DEFORMATION AT FAILURE, %	TANGENT MODULUS AT 50% ULTIMATE STRENGTH, PSI	L/D RATIO
9-1	76.7	2.77	2.08	NO TEST			
9-2	76.1	2.77	1.61	11,210	.29	4.55×10^6	2.05
9-3	75.5	2.48	6.27	NO TEST			
9-4	74.2	2.35	14.06	6,100	.33	2.16×10^6	1.82
9-5	73.7	2.20	16.27	NO TEST			
9-6	73.1	2.67	4.94	NO TEST			
9-7	72.4	1.92	28.00	2,790	.29	1.04×10^6	1.69
9-8	71.0	1.84	30.63	NO TEST			
9-9	70.6	1.74	34.74	1,100	.34	3.45×10^5	1.79
9-10	69.7	2.51	8.36	NO TEST			

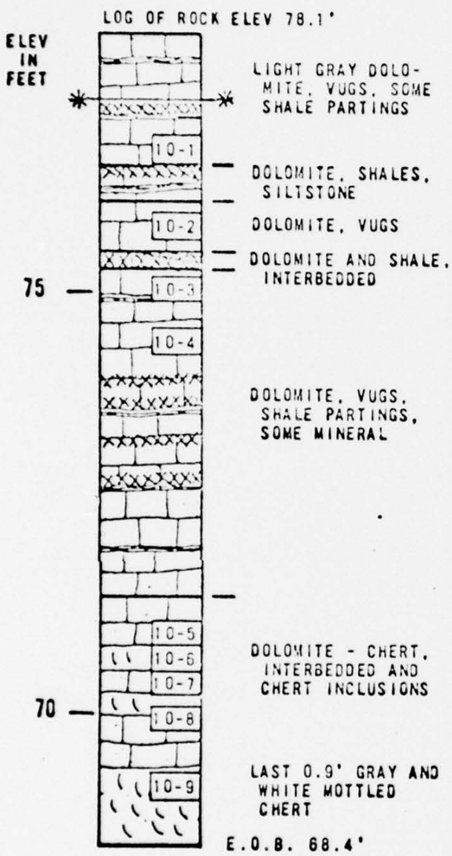
WATER LEVEL IN CASING: Elev 106.9'
RECOVERY: 97%
33% based on cores 4" or longer (32% 1st 5', 34% 2nd 4.4')

BORING DATA:

NUMBER: RCB-9
DATE OF BORING: October, 1971
LOCATION: Sta 253+00, 110'Rt of Construction ℄
GROUND ELEVATION: 143.4 ft
MADE BY: J. P. McGuire, Geophysical Unit
GEOLOGICAL LOGS BY: Geophysical Unit Geologists

Project 82122
PROPOSED I-96 (JEFFRIES FWY) THROUGH OAK YARD, CITY OF DETROIT WAYNE COUNTY, MICHIGAN

LOG OF ROCK PROFILE



xxxxxxxx Fracture Zone

—— Water return loss

SAMPLE NO.	ELEV IN FEET	DRY BULK SP GRAV	POROSITY %	UNCONFINED COMPRESSION TEST DATA: UNCONFINED COMPRESSIVE STRENGTH, PSI	DEFORMATION AT FAILURE, %	TANGENT MODULUS AT 50% ULTIMATE STRENGTH, PSI	L/D RATIO
10-1	76.7	2.74	2.63	NO TEST			
10-2	75.8	2.75	3.38	9,630	.34	2.63×10^6	1.78
10-3	75.1	2.66	0.51	NO TEST			
10-4	74.5	2.80	0.25	9,480	.46	2.44×10^6	2.11
10-5	71.0	2.74	2.46	NO TEST			
10-6	70.7	2.30	10.68	8,640	.45	2.28×10^6	2.17
10-7	70.4	2.39	8.51	NO TEST			
10-8	70.0	2.60	5.51	6,540	.28	2.21×10^6	2.18
10-9	69.2	2.38	12.89	NO TEST			

WATER LEVEL IN CASING: Not recorded
RECOVERY: 100%
33% based on cores 4" or longer (27% 1st 5', 40% 2nd 4.7')

BORING DATA:

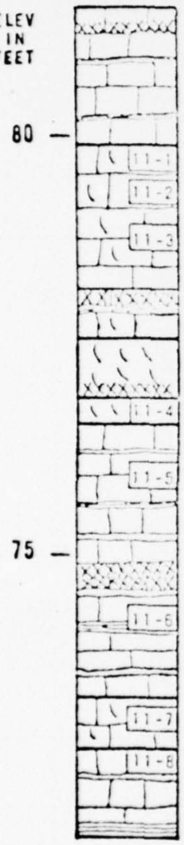
NUMBER: RCB-10
DATE OF BORING: December, 1971
LOCATION: Sta 255+00, 126'Lt of Construction ℄
GROUND ELEVATION: 144.3 ft
MADE BY: J. P. McGuire, Geophysical Unit
GEOLOGICAL LOGS BY: Geophysical Unit Geologists

Project 82122
PROPOSED I-96 (JEFFRIES FWY) THROUGH
OAK YARD, CITY OF DETROIT
WAYNE COUNTY, MICHIGAN

LOG OF ROCK PROFILE

TOP OF ROCK ELEV 81.6'

ELEV IN FEET



LIGHT GRAY DOLOMITE, VUGS AND CAVITY FILLINGS, SOME SHALE PARTINGS (FOSSIL AT 84.8')

LIGHT GRAY DOLOMITE, VUGS, CHERT INCLUSIONS

SAME AS NEXT ABOVE, SHALE

GRAY AND WHITE MOTTLED CHERT

CHERT

DOLOMITE, SHALES AND SILTSTONE ALTERNATING THROUGHOUT INTERVAL

DOLOMITE, GRAY AND WHITE CHERTS, VUGS

GRAY DOLOMITE WITH SHALE PARTINGS

E.O.B. 71.8'

xxxxxxxx Fracture Zone

SAMPLE NO.	ELEV IN FEET	DRY BULK SP GRAV	POROSITY %	UNCONFINED COMPRESSION TEST DATA			
				UNCONFINED COMPRESSIVE STRENGTH, PSI	DEFORMATION AT FAILURE, %	TANGENT MODULUS AT 50% ULTIMATE STRENGTH, PSI	L/D RATIO
11-1	79.7	2.58	6.05	NO TEST			
11-2	79.4	2.39	8.51	11,120	.23	3.93×10^6	2.12
11-3	78.8	2.48	5.80	NO TEST			
11-4	76.7	2.44	7.33	5,000	.36	1.69×10^6	2.00
11-5	76.0	2.33	14.53	NO TEST			
11-6	74.2	1.84	28.87	1,800	.79	2.83×10^5	1.84
11-7	73.0	2.36	9.85	NO TEST			
11-8	72.5	2.73	2.41	22,230	.52	4.63×10^6	1.88

WATER LEVEL IN CASING: Elev 105.6'
RECOVERY: 100%
27% based on cores 4" or longer (22% 1st 5', 32% 2nd 5')

BORING DATA:

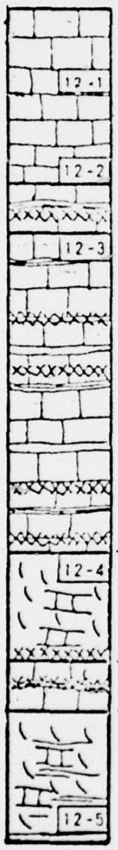
NUMBER: RCB-11
DATE OF BORING: December, 1971
LOCATION: Sta 257+00, 126'Rt of Construction ℄
GROUND ELEVATION: 144.6 ft
MADE BY: J. P. McGuire, Geophysical Unit
GEOLOGICAL LOGS BY: Geophysical Unit Geologists

Project 82122
PROPOSED I-96 (JEFFRIES FWY) THROUGH
OAK YARD, CITY OF DETROIT
WAYNE COUNTY, MICHIGAN

LOG OF ROCK PROFILE

TOP OF ROCK ELEV 78.8'

ELEV IN FEET: 75, 70



LIGHT GRAY FINE-GRAINED DOLOMITE, SOME VUGS AND CAVITY FILLINGS

LIGHT GRAY FINE-GRAINED DOLOMITE WITH SHALE PARTINGS - SILTSTONE

LIGHT GRAY FINE-GRAINED DOLOMITE, SHALE PARTINGS, VUGS, CAVITY FILLINGS, SOFT SILTSTONE ZONES AND PUNKY PARTINGS THROUGHOUT THE INTERVAL

GRAY AND WHITE CHERT AND DOLOMITE, INTERBEDDED - SOME VUGS

LIGHT GRAY DOLOMITE, SHALE PARTINGS, VUGS, SOME FOSSIL EVIDENCE, CHERT INCLUSIONS

LIGHT GRAY DOLOMITE AND CHERTS, SOME VERTICAL FRACTURES, SILTSTONE LAST 0.1' OF INTERVAL

E.O.B. 68.6'

xxxxxxxx Fracture Zone

SAMPLE NO.	ELEV IN FEET	DRY BULK SP GRAV	POROSITY %	UNCONFINED COMPRESSION TEST DATA: UNCONFINED COMPRESSIVE STRENGTH, PSI	DEFORMATION AT FAILURE, %	TANGENT MODULUS AT 50% ULTIMATE STRENGTH, PSI	L/D RATIO
12-1	77.7	2.74	2.31	12,060	.41	3.90×10^6	2.05
12-2	76.6	2.67	5.20	NO TEST			
12-3	75.7	2.80	0.65	NO TEST			
12-4	71.9	2.51	5.31	15,190	.23	4.67×10^6	2.12
12-5	68.9	2.39	12.49	4,110	.24	2.34×10^6	2.02

WATER LEVEL IN CASING: Elev 99.4'

RECOVERY: 100%

24% based on cores 4" or longer (26% 1st 5', 22% 2nd 5')

BORING DATA:

NUMBER: RCB-12

DATE OF BORING: December, 1971

LOCATION: Sta 259+00, 125'Lt of Construction ℄

GROUND ELEVATION: 141.9 ft

MADE BY: J. P. McGuire, Geophysical Unit

GEOLOGICAL LOGS BY: Geophysical Unit Geologists

Project 82122

PROPOSED I-96 (JEFFRIES FWY) THROUGH OAK YARD, CITY OF DETROIT WAYNE COUNTY, MICHIGAN

SUPPLEMENT B
COST TABLES

TABLE B-1
CONSTRUCTION COSTS FOR TUNNELS
ENR = 1960

Tunnel Diameter (ft.)	Unlined Tunnels		Lined Tunnels	
	$/LF	$/Mile (in Millions)	$/LF	$/Mile (in Millions)
14	450	2.37	590	3.11
16	500	2.64	660	3.48
18	560	2.96	740	3.91
20	620	3.27	820	4.33
22	680	3.59	900	4.75
24	740	3.91	980	5.17
26	800	4.22	1060	5.59
28	860	4.54	1140	6.02
30	910	4.80	1210	6.39
32	960	5.07	1280	6.76
34	1020	5.39	1360	7.18
36	1080	5.70	1440	7.60
38	1140	6.02	1520	8.02
40	1200	6.34	1600	8.45
42	1260	6.65	1680	8.87
44	1310	6.92	1750	9.24
46	1360	7.18	1820	9.61
48	1420	7.50	1900	10.03
50	1480	7.80	1980	10.45

TABLE B-2

CONSTRUCTION COSTS
FORCE MAINS AND INTERCEPTORS*
ENR = 1,960

DIAMETER	COST PER FOOT
3'-0"	$ 55.00
4'-0"	75.00
5'-0"	95.00
6'-0"	115.00
7'-0"	140.00
8'-0"	165.00
9'-0"	190.00
10'-0"	220.00
11'-0"	245.00
12'-0"	270.00
13'-0"	300.00
14'-0"	325.00

* Costs are for installed pipe, assuming:

a. Force main is prestressed concrete embedded cylinder pipe with minimum 5 foot cover.

b. Gravity interceptor sewer is Class IV reinforced concrete pipe with average 12 foot cover.

TABLE B-3
CONSTRUCTION COSTS FOR MINED STORAGE RESERVOIRS
ENR = 1,960

Storage Capacity		Construction Costs (in Million Dollars)
MG	ACRE-FT.	
500	1540	58
1000	3075	95
2000	6150	190
3000	9230	280
4000	12310	360
5000	15380	450
6000	18460	545
7000	21540	630
8000	24610	715
9000	27690	805
10000	30750	890
11000	33850	975
12000	36920	1065

TABLE B-4
CONSTRUCTION COSTS
REGIONAL SURFACE RESERVOIRS
ENR = 1,960

Location and Storage Capacity of the reservoir	COSTS IN 1000'S OF DOLLARS								
	Site Preparation	Excavation	Lining	Fencing	Concrete for Effluent Conduits	Influent Force Mains	Landscaping	Underground Tunnel+++	TOTAL COST
MaComb County+ (22,000 MG)	3,210	14,035	2350	330	13,510	11,620	8,025	17,200	70,280
Monroe County+ (22,000 MG)	3,210	14,035	2350	330	13,510	8,260	8,025	13,780	63,500
MaComb County++ (8,500 MG)	2,500	1,084	1820	270	8,900	9,150	6,250	12,900	42,874
Monroe County++ (8,500 MG)	2,500	1,084	1820	270	8,900	6,600	6,250	10,340	37,764

\+ Used in Schemes One and Two

++ Used in Shceme Five

+++ Underground tunnel below the surface reservoirs.

TABLE B-5
CONSTRUCTION COSTS
UPLAND LINED SURFACE RESERVOIRS
ENR = 1,960

Storage Volume (Million Gallon)	COSTS IN 1000'S OF DOLLARS								
	Site Preparation	Excavation	Lining	Fencing	Overflow Structure	Effluent Wet Well	Land-scaping	Access Road	TOTAL
200	110	425	400	40	100	34	178	5	1292
400	190	850	800	54	200	68	280	5	2447
600	250	1275	1200	61	300	102	332	5	3525
800	315	1700	1600	67	400	136	388	5	4611
1000	375	2125	2000	73	500	170	438	5	5686
1200	435	2550	2400	79	600	204	490	5	6763
1400	490	2975	2800	86	700	238	525	5	7819
1600	560	3400	3200	92	800	272	600	5	8929

UNIT COSTS:

Site Preparation @ $1000.00 per acre
Excavation (balanced cut and fill) @ $1.50 per cubic yard
Lining @ $0.25 per square yard
Fencing @ $4.50 per linear foot
Concrete @ $125.00 per cubic yard
Landscaping @ $2500.00 per acre
Compacted Road Gravel @ $1.45 per square yard

TABLE B-6
CONSTRUCTION COSTS
UPLAND SURFACE RESERVOIR INFLUENT STRUCTURE UTILIZING
SCREW PUMPS
ENR = 1,960

Pumping Capacity (Million Gallon per day)	COSTS IN 1000'S OF DOLLARS							
	Superstructure	Motor Ventilation	Motors & Pumps	Trash Rack	Diversion Gates	Structural Concrete	Overhead Crane	TOTAL
288	25.0	2.5	320.0	40.9	37.0	82.0	13.0	520.4
432	37.0	3.0	480.0	43.4	42.0	122.0	13.0	740.4
576	50.0	4.0	640.0	46.4	50.0	163.0	13.0	966.4
720	62.0	4.5	800.0	48.9	57.0	204.0	13.0	1189.4
864	74.0	6.0	960.0	51.8	84.0	244.0	13.0	1432.8
1008	88.0	7.0	1120.0	54.3	100.0	285.0	13.0	1667.3
1152	99.0	8.0	1280.0	56.8	112.0	326.0	13.0	1894.8
1296	111.0	9.0	1440.0	59.3	125.0	366.0	13.0	2123.3
1440	122.0	10.0	1600.0	61.8	137.0	407.0	13.0	2350.8
1584	133.0	11.0	1760.0	64.3	150.0	448.0	13.0	2579.3

UNIT COSTS: Superstructure @ $25.00 per square ft.

Concrete @ $125.00 per cubic yard

TABLE B-7
CONSTRUCTION COST
UPLAND SURFACE RESERVOIR
GRAVITY AND DIVERSION INFLUENT STRUCTURES
ENR = 1,960

Capacity (Million Gallon Per day)	COSTS IN 1000'S OF DOLLARS				
	Structural Concrete	Diversion Gates	Trash Rack*	TOTAL	
				Diversion Structure	Gravity Structure
200	9.5	18.0	35.0	27.5	62.5
400	14.4	28.0	40.0	42.4	82.4
600	18.6	38.0	45.0	56.6	101.6
800	22.8	48.0	50.0	70.8	120.8
1000	27.0	58.0	55.0	85.0	140.0
1200	31.2	68.0	60.0	99.2	159.2
1400	35.4	78.0	65.0	113.4	178.4
1600	39.6	88.0	70.0	127.6	197.6
1800	43.8	98.0	75.0	141.8	216.8
2000	48.0	108.0	80.0	156.0	236.0

* Required for Gravity Influent Structure Only

UNIT COSTS: Concrete @ $125.00 per cubic yard

TABLE B-8

CONSTRUCTION COSTS
UNDERGROUND RESERVOIRS WITH GRAVITY INFLUENT AND
PUMPED EFFLUENT
ENR = 1,960

Storage Volume (Million Gallon)	COSTS IN 1000'S OF DOLLARS								
	Site Preparation	Excavation	Concrete	Grit Removal Equipment	Screening	Diversion Gates	Effluent Pumps	Superstructure	TOTAL
10	2.4	243.0	751.0	70.0	37.0	22.0	6.0	116.0	1247.4
20	4.7	482.0	1414.0	140.0	38.0	32.0	6.0	144.0	2260.7
30	6.9	706.0	2056.0	210.0	38.5	42.0	6.5	172.0	3237.9
40	9.3	937.0	2685.0	280.0	39.0	50.0	6.5	200.0	4206.8
50	11.6	1241.0	3529.0	350.0	39.5	53.0	7.0	228.0	5459.1
60	13.8	1409.0	3936.0	420.0	40.0	57.0	7.5	257.0	6190.3
80	18.3	1875.0	5436.0	490.0	41.0	73.0	8.0	285.0	8226.3
100	22.8	2409.0	6838.0	560.0	42.0	90.0	10.0	312.5	10284.3
200	40.8	4800.0	13361.0	630.0	47.0	105.0	15.0	350.0	19348.8
300	55.2	7203.0	19813.0	700.0	52.0	120.0	20.0	397.0	28360.2
400	75.0	9634.0	26368.0	770.0	57.0	135.0	25.0	444.0	37508.0

UNIT COSTS

Site Preparation @ $1000.00 per acre

Excavation (includes backfilling) @ $3.00 per cubic yard

Concrete: slab on grade @ $75.00 per cubic yard, slab above grade @ $150.00 per cubic yard, walls and columns @ $130.00 per cubic yard

Superstructure @ $25.00 per square foot

TABLE B-9
CONSTRUCTION COSTS
UPLAND TURBINE PUMPING STATION
ENR = 1,960

Pumping Capacity Million Gallon Per Day	COSTS IN 1000'S OF DOLLARS							
	Superstructure	Motor Ventilation	Concrete	Pumps & Motors	Overhead Crane	Screening	Ventilation	TOTAL
300	141.0	8.5	290.0	440.0	13.0	5.5	90.0	988.0
400	167.0	10.5	333.0	575.0	13.0	7.5	104.0	1210.0
500	193.0	15.0	376.0	710.0	13.0	9.0	120.0	1436.0
800	271.0	24.0	507.0	1115.0	13.0	14.5	168.0	2112.5
1000	323.0	29.5	593.0	1385.0	13.0	18.0	200.0	2561.5
1200	375.0	32.5	690.0	1655.0	13.0	21.5	220.0	3007.0
1400	428.0	35.5	786.0	1925.0	13.0	25.0	243.0	3455.5
1600	480.0	38.5	876.0	2195.0	13.0	28.5	270.0	3901.0
1800	532.0	41.5	966.0	2465.0	13.0	32.0	297.0	4346.5
2000	584.0	44.5	1055.0	2735.0	13.0	35.5	324.0	4791.0

UNIT COTS: Superstructure @ $25.00 per square foot

Concrete @ $125.00 per cubic yard

Excavation @ $3.00 per cubic yard (includes dewatering)

TABLE B-10
CONSTRUCTION COSTS
PUMPING STATIONS
ENR = 1,960

Pumping Capacity (MGD)	COSTS IN 1000'S OF DOLLARS						
	Pumps & Motors	Rock Excavation	Concrete Lining	Ventilation	Vertical Shafts for force mains or pump casings	Foundation for Motors on the ground	TOTAL COST
Effluent Pumping+							
400	1650	331	128	110	1368		3,587
600	2310	425	170	110	1420		4,435
800	2970	539	222	140	1480		5,351
1000	3630	634	266	140	1580		6,250
Influent Pumping++							
800	3585	162	55	100	1575	57	5,534
1000	4460	207	91	100	1925	70	6,853

\+ Used in schemes 3, 4 and 5 for pumping storm water from the tunnels to the treatment facilities. Both pumps and motors are located in bed rock formations.

++ Used in schemes 1, 2 and 5 for pumping storm water from the tunnels to the regional surface reservoirs. Pumps are located in a Wet Well near the tunnel and motors are located on the ground.

TABLE B-11
CONSTRUCTION COSTS
UPLAND SURFACE RESERVOIR
EFFLUENT PUMPING STATION [+]
ENR = 1,960

Pumping Capacity (Million Gallon Per Day)	COSTS IN 1000'S OF DOLLARS		
	Superstructure	Pumps & Motors	TOTAL
2	4.0	6.5	10.5
4	4.5	7.5	12.0
10	5.0	13.5	18.5
20	5.5	32.5	38.0
30	6.0	48.5	54.5
40	6.5	64.5	71.0
50	7.0	80.5	87.5

[+] Wet Well structure cost included in Surface Reservoir costs. (See Table B-5).