GROUND-WATER INVESTIGATIVE PROGRAM

AT WOODBURY, MINNESOTA

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ILLUSTRATIONS

Figure 1. Location Map - Woodbury Site

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INTRODUCTION

A study of the ground-water conditions in the vicinity of The 3M Company Woodbury waste disposal site was undertaken in the summer and fall of 1966 to determine: (1) If a residential well water pollution problem in this area was a result of contamination from the disposal site; (2) The extent of the migration of water containing chemical contaminants from the waste disposal pit, if any; and (3) To outline a program, if necessary, to prevent uncontrolled migration of water from the disposal area.

In conjunction with this study a 12 inch diameter test well was drilled on The 3M Company property. See Figure 1, Location Map. The well site was located on the basis of a geophysical survey of a portion of The 3M Company property. The well was drilled to a depth of 370 feet. Six separate carefully controlled and monitored water quality pumping tests were conducted at different depths as the test well was constructed. Water samples were obtained during each individual test and subsequently analyzed for chemical constituents by the gas chromatographic technique. All water analyses were conducted by 3M Company personnel.

During the period September - December, 1966, water samples were also obtained for chemical analysis from observation wells on The 3M Company Woodbury property. In addition, water samples were obtained from 20 private wells in the vicinity of the Woodbury disposal site and the Cheney well on The 3M Company property. Two of the private wells are being utilized as control wells and are approximately four miles from the disposal site.

Water samples from the private wells were also independently collected and analyzed by the Minnesota State Board of Health.

Water samples for analysis by The 3M Company were obtained from the well on the Schussler property on an approximate two week schedule from September to December, 1966.

The 3M Company discontinued use of the waste disposal site on April 28, 1966, and the disposal pits have since been filled.

PUMPING TESTS

The primary objective in drilling test well No. 1 was to determine the water quality in each geologic formation at the site.

Test Well 1 is located on 3M Company property between the waste disposal pits and the Schussler private well. The specific well location was chosen on the basis of results of an electrical resistivity survey conducted in August of 1966. The resistivity survey indicated that at the site of Test Well 1 the glacial drift consisted of clean sand and gravel.

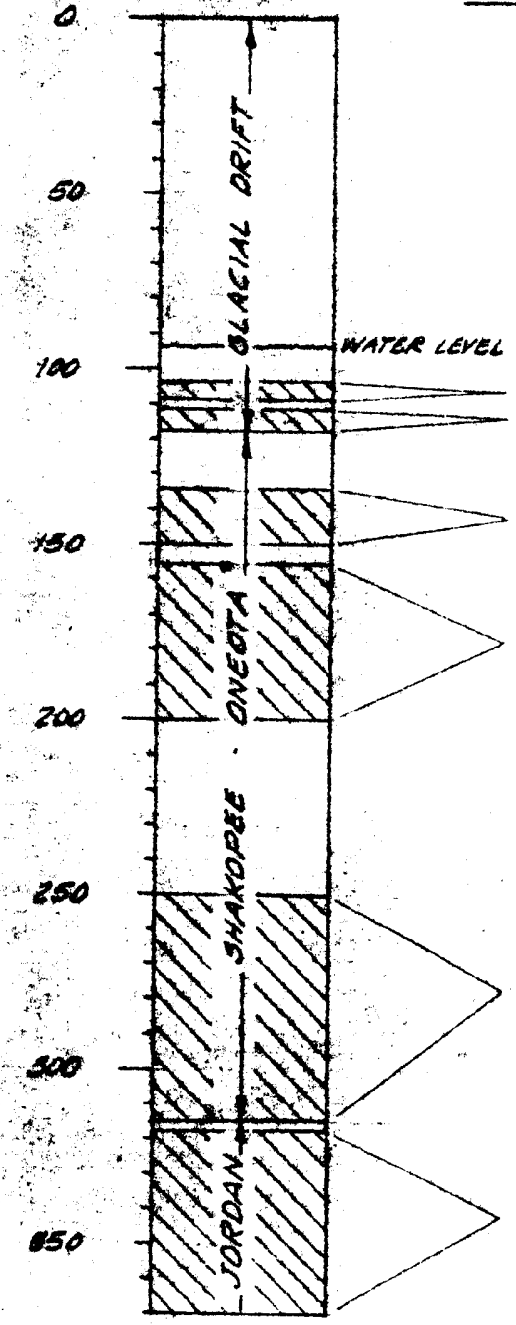
The resistivity survey indicated that the method is applicable to the problem of determining the relative vertical and lateral variation of the glacial drift deposits in the Woodbury area.

The resistivity anomalies or highs appear to trend in a general east-west direction in the area of investigation. The trend of the deposits is important as the permeability of the glacial drift is expected to initially exert some control on the direction and rate of migration of liquids from the waste disposal pits.

Six separate water quality pumping tests were conducted as Test Well 1 was being constructed. In the glacial drift the aquifer above the section tested was blanked off with the 12-inch casing. During each test in the Shakopee and Jordan formations, the aquifers above the section being tested were sealed by means of a mechanical packer placed in the test hole. The packer was placed to assure that the water samples obtained were representative of the aquifer section tested. The packer arrangement was effective in isolating the section of aquifer being tested as evidenced by the observed substantial differences in water level above and below the packer during each test. Table 1 is a log of Test Well 1 showing the geologic formations and each aquifer section tested.

TABLE I

WELL LOG - TEST WELL 1



TEST NO.	DATE	YIELD
1	OCT 10	10 GPM
2	OCT 18	37 GPM
3	OCT 25	10 GPM
4	NOV 1	60 GPM START 40 GPM END
5	DEC 2	37 GPM - 2 HRS. 350 GPM - FINISH
6	DEC 14	37 GPM - 2 HRS. 400 GPM - FINISH

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Each individual pumping test was approximately 8 hours long. The pumping rate was 10 to 60 gallons per minute (gpm) during the first four tests. The pumping rate during tests 5 and 6 was approximately 37 gallons per minute (gpm) for the first two hours of the test.

It was anticipated that at the low pumping rate only the water in the immediate vicinity of the pumped section would move into the well. It is believed that the analysis of the water samples obtained at the low pumping rate is truly indicative of the water composition which exists under non-pumping conditions at the depth tested.

During Test No. 5 of the Shakopee geologic formation and Test No. 6 of the Jordan geologic formation, the pumping rates were increased to 350 and 400 gpm, respectively, at the end of each test. Rates were chosen which would reflect the water quality to be expected under sustained pumping at the site of Test Well 1.

Drawdown measurements were made in Test Well 1 during all tests to determine the relative permeability of each aquifer. This information was subsequently utilized in the determination of locations for future test wells.

Observation Wells 1 and 2 on The 3M Company property were also pump tested during October 1966. These wells have multiple screens, and each geologic section screened, glacial drift and St. Peter sandstone, was independently tested by a packer arrangement which isolated the section being tested.

The water samples from private wells and the Schussler well were obtained utilizing the existing pumping equipment. Data

regarding the depth, geologic formation penetrated and well construction details of many of the private wells is not available at the present time.

GROUND-WATER QUALITY

In order to identify the type and direction of migration of the chemical constituents in the aquifers underlying the waste disposal site, gas chromatograph analytical techniques were utilized. Individual samples were obtained and analyzed by the 3M Company analytical laboratories on the day collected.

The analytical results have been expressed as arbitrary chromatographic units. In the case of isopropyl ether the arbitrary units were converted to parts per million (ppm) by comparison with a sample of known concentration of isopropyl ether.

Isopropyl ether or a compound similar to it was identified in Test Well 1. The concentration decreased with depth. The water produced at Test Well 1 in the glacial drift and St. Peter formations had a noticeable sweet, antiseptic chemical odor. The water also created a noticeable foam which was not persistent and rapidly disappeared. With depth the odor became less noticeable and the water did not foam as readily.

The migration of the chemicals has been differential in both a horizontal and vertical direction away from the waste disposal pits. The migration varies with the type and structure of the chemical as some chemical elements are clearly leading or migrating faster than others as indicated by detailed review of the analysis of water samples from the Schussler well.

In part this differential movement can be attributed to the water from the waste pits following preferred paths of flow through the most permeable sections of the glacial drift and then through fracture zones in the Shakopee formation. The fracture zones could provide direct paths for migration of relatively undiluted chemical

constituents in any direction from the waste pits controlled only by the effective artesian pressure or water table gradient present.

The Cheney well and observation wells 1 and 2 did not show a significant concentration of those chemical compounds for which they were tested. Additional analysis of water from these wells will be required to determine if chemical contaminants are moving toward these wells.

Concentrations of isopropyl ether of more than 1.0 ppm are objectionable and detectable by a characteristic taste and odor. It was at a concentration of less than 1.0 ppm of isopropyl ether that the chemical was first noticed at the Schussler residence.

As the ground-water investigation proceeds, it will be important to positively identify the chemical compounds present and their individual concentrations. To date concentrations of individual chemicals have been expressed by arbitrary gas chromatograph units. The detailed laboratory work which will be involved is necessary as trace amounts of a few of the compounds present in water samples from the Woodbury site have been found in both private wells and in control water sampling wells outside of the Woodbury area. These compounds are believed to be naturally occurring ones.

The Schussler well has shown a progressive increase in isopropyl ether concentrations since April of 1966. There has also been a water quality change observed in the routine chemical analysis. The chemical oxygen demand, chlorides, sulfate and fluoride present in the water have all progressively increased. Under continuous pumping over a period of 4 to 8 hours, there is a slight improvement of water quality. If a similar pattern of increase in the common chemical constituents is associated with the increase in isopropyl ether

at other observation wells it will provide a rapid, economical system for routine analysis to trace the movement of the ground-water of the area.

Analysis of 18 private wells in the area by both The 3M Company and the Minnesota State Department of Health determined that eleven private wells had excessively high concentrations of nitrates. These concentrations were in excess of that recommended for domestic use by the United States Public Health Service. The high nitrate concentrations indicated probable local pollution at the individual well sites. It is understood that the Minnesota Health Department has notified the parties concerned.

GROUND-WATER CONTROL PROGRAM

The 3M Company Woodbury waste disposal site was completely closed in April 1966 and no further liquid or other wastes disposed of in the area. The disposal pits were subsequently backfilled. Local residents are continuing to use the site for refuse disposal.

The investigative work undertaken in the past eight months indicates that chemicals similar to those placed in the pits have been identified approximately 3/4 of a mile in a westerly direction from the waste pits at the Schussler well. The liquor has also moved vertically downward and is present in the glacial drift, and to a much lesser degree in the Shakopee formation and possibly in trace concentrations in the Jordan geological formation.

The glacial drift and Shakopee formations are primarily utilized for domestic wells in the Woodbury area. The Jordan geologic formation is the principle aquifer in the Minneapolis-St. Paul metropolitan area and is widely utilized for domestic, industrial and municipal water supplies.

In evaluating means of controlling the migration of chemicals from the waste discharge pits the material contained in the acid waste pits has been considered to be a separate problem. It may be possible to recover the chemical wastes in the acid pit area before they penetrate to the Shakopee and Jordan geologic formations. An independent program to control the ground-water in the vicinity of the acid waste pit is believed to be justified.

The measures which appear most promising in controlling the movement of chemicals in the ground-water aquifers beneath the wet scrap disposal pits are:

1. Initiation of a pumping barrier to prevent further lateral and downward migration of contaminated water from the disposal pits.
2. Construction of removal wells to pump contaminated water out of the ground within the area of highest concentration before it has an opportunity for migration and dilution.

The pumping barrier would consist of widely spaced pumping wells of moderate yields. The wells would be pumped continuously with the purpose of reversing the natural ground-water gradient, which is away from the Woodbury site, and thereby cause ground-water to move toward the disposal site. At the same time an attempt would be made to reverse the differential head which now exists between the Shakopee and Jordan aquifers causing movement of water and chemicals from the Shakopee to the Jordan formation.

It is extremely important to prevent further dispersion of any contaminated ground-water. As the chemicals become dispersed ever larger quantities of water must be pumped to recover even small amounts of chemicals. It must be emphasized that concentrations of less than 1.0 ppm of isopropyl ether has been found to be objectionable for domestic use.

In order to assure that the proposed pumping barrier would be effective additional test wells and pumping tests will be necessary, both to determine the extent of migration of the chemical contaminants from the waste pits and to establish the exact number, construction and placement of barrier and removal wells.

A 5 well barrier system consisting of Test Well 1 and 4 additional wells is believed to be the minimum number of wells necessary based upon the hydrologic information available at the present time.

The pumping barrier wells would be finished in the Shakopee formation and designed to pump 700 gpm.

A minimum of two and possibly three removal wells will be required and should be constructed in the vicinity of the wet scrap pits. These wells should be constructed in the Shakopee geologic formation and designed to yield from 1000 - 1200 gpm.

The specific locations for these wells would be dependent on the results of additional test drilling and pumping tests. It should be noted that individual test wells may be utilized not only to determine the geologic conditions and hydrologic coefficients of each aquifer, but also to positively outline the extent of migration of chemical wastes.

When water is withdrawn from a well, the water level in the ground-water reservoir is drawn down in the vicinity of the well, forming a cone of depression in the ground-water surface. The drawdown is greatest in the well and diminishes as the distance from the well increases. As a result, pumping causes ground-water to move radially through the underground reservoir toward the well. With continuous pumping, the cone of depression is steadily enlarged until the reservoir is exhausted or until the cone of depression reaches a source of recharge large enough to sustain the yield of the well and thus stop further water level declines.

The rate of growth and lateral extent of the cone of depression are independent of the rate of pumping. However, the pumping rate causes a proportional variation in the depth of the cone of depression. If a well were to be pumped at twice a given rate, the cone of depression would be twice as deep at any point, but it would not have an appreciably greater lateral extent.

Table 2 represents theoretical pumping water levels from a combination of five barrier and two removal wells. The design of individual wells should be flexible and guided by the results obtained from the first wells constructed. See Table 2.

It is not possible at this time to predict the period for which pumping of the barrier and removal wells will be necessary.

At the acid waste disposal pit it is anticipated that the chemical wastes have not yet penetrated the Glenwood shale and thereby contaminated the underlying St. Peter, Shakopee and Jordan formations.

Test drilling will be necessary to determine the extent of the lateral and vertical migration of chemicals from the pit. If the chemicals have not penetrated the Glenwood shale and are actually migrating laterally above it, it may be possible to intercept the chemicals with a system of shallow low capacity wells in the immediate vicinity of the acid pit. Much more detailed test work will be necessary in this area and provision for this testing has been made in the overall cost estimates.

TABLE 2

THEORETICAL PUMPING WATER LEVELS

After 100 Days Continuous Pumping

	WELL NO.						
	Removal Well		Barrier Well				
	1	2	1	3	4	5	6
Yield gpm	1000	1000	700	700	700	700	700
Specific Capacity gpm/ft/dd	27	27	27	27	27	27	27
Static Water Level	70.0	70.0	95.0	72.0	155.0	95.0	92.0
Dynamic Drawdown	37.0	37.0	26.0	26.0	26.0	26.0	26.0
Interference Effects	56.5	56.5	58.5	50.5	49.0	50.5	49.0
Theoretical pumping water level - below ground level	163.5	163.5	179.5	148.5	230.0	171.5	167.0

NOTE: Specific Capacity estimated from data obtained at Test Well 1.

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WASTE WATER DISPOSAL

The disposal of the water produced from operation of the ground water control program will cause substantial problems. The chemical compounds in the ground-water are anticipated to be complex and their concentrations too dilute for disposal by burning and quite expensive to treat by filtration. At the same time, it is quite possible that the concentrations would be sufficiently high as to be unfit for human consumption.

A preliminary study of possible transmission line sites has been made and the preliminary cost estimates prepared are based on property or right-of-way being available along the most direct route. It is anticipated that a twenty foot right-of-way will be required. The transmission main would be concrete pipe approximately 18 inches in diameter. (See section on cost estimates.)

Preliminary testing by the 3M Engineering Department of water from the Schussler well indicates that the organic chemical compounds present are removed by filtration through an activated carbon filter. Further study of the feasibility of utilizing this technique to treat large volumes of water on a continuous basis should be undertaken. If the technique proves capable of removing all of the organic chemicals the treated water could be utilized in creating and maintaining artificial lakes in the area of the Woodbury disposal site.

Preliminary examination of the Woodbury area indicates several potential lake sites. The most logical sites are those along the natural drainage from the Woodbury site to the Mississippi River. These sites are in Sec. 2 and Sec. 11, T 27 N, R 2 W. Potential sites also exist to the northwest of the Woodbury site in Sec. 27, T 28 N, R 21 W.

The suitability of these areas for lake development requires further hydrologic investigation. A determination of the availability of acquiring land for flooding and flowage easements should also be made.

Many desirable considerations are associated with utilization of the ground-water to create and maintain artificial lakes. The most obvious ones are conservation of the natural water resource by creating usable recreational lakes which will also recharge the underground aquifers. If recharge is accomplished potential adverse interference effects on industrial and municipal wells caused by pumpage from the Woodbury site over extended periods of time can be held to a minimum.

There should be an economic advantage in utilizing the reclaimed water to create lakes as relatively low-cost farm lands could be converted to desirable lakeshore, park or industrial property. The reclaimed water would also be suitable for most industrial uses.

The expense of land acquisition for lake construction, water treatment facilities and water control structures are anticipated to approximate the expense of a transmission line to carry waste water from the Woodbury site to the Mississippi River.

COST ESTIMATES

The ground-water control program outlined is one of continuing investigation and is felt to be realistic in view of the nature of the problem.

The amount of time during which barrier or removal wells will be required will be governed by the extent of the area contaminated and the number of wells utilized to control or remove the contaminated ground-water. As the program progresses and more hydrologic information becomes available, it may be possible by careful management procedures to substantially reduce the quantity of water which has to be pumped.

Listed below are typical types of wells which will be required and cost estimates for each type. As the program progresses it may be possible to combine the functions of some wells. An example would be utilizing water quality test wells as barrier pumping wells.

Full consideration has been given to all available hydrologic information during the preparation of the cost estimates for the proposed ground-water control program.

Typical Glacial Drift or Plattville Limestone Observation Well

Six-inch diameter - 100 foot average depth
Ten foot well screen - 6 inch nominal diameter
Estimated cost per well to include materials,
construction and development..... $1,700.00

Typical St. Peter-Shakopee Formation Observation Well

Eight-inch casing average 125' depth
Eight-inch open hole 200'
Estimated cost per well to include materials,
construction, grouting and development..... $4,500.00

Typical Jordan Sandstone Observation Well

Eight-inch casing driven to Jordan formation - 430 feet
Six-inch casing - 200 feet and grouted
Four-inch casing 230 feet and grouted
Thirty feet open hole, 8 inch diameter
Estimated cost to include materials, construction, grouting and development..... $5,800.00

Typical Hinckley Formation Observation Well

Twelve-inch casing driven to 430 feet
Eight-inch casing - 200 feet
Six-inch casing - 230 feet
Six-inch open hole - 30 feet
Estimated expense to include materials, construction, grouting and development..... $6,400.00

Typical Barrier Well - Shakopee Formation

Twelve-inch diameter casing 125 feet		
Twelve-inch diameter open hole 200 feet	$6,100.00	
Seven hundred gallon per minute vertical turbine pump, 200 foot T.H.		
Fifty h.p. motor and part winding starter	$5,500.00	
Electrical wiring, discharge piping, concrete pump pad, fencing	$1,600.00	
		$13,200.00

Typical Removal Well - Shakopee Formation

Twenty-inch diameter casing 125'		
Twenty-inch open hole 200'	$7,600.00	
One thousand gpm vertical turbine pump with 210 foot T.H.		
Seventy-five h.p. motor and part winding electric starter	$6,500.00	
Electrical wiring, discharge piping, concrete pump pad, fencing	$1,600.00	
		$15,700.00

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Quantitative Test Pumping and Hydrologic Studies

Quantitative pumping tests include test pump installation and removal and 72 hour tests. See Notes 1 and 2.		
Six @ $2,600.00	$15,600.00	
Geophysical Survey 3M Woodbury property	$ 2,800.00	
Construction of an Analog model of the Woodbury site, to include electronic equipment rental and report preparation	$ 4,400.00	
Consulting Hydrologic Services including regional ground-water survey; supervision of pumping tests; design and supervision of construction of observation, barrier and removal wells	$ 8,200.00	
		$31,000.00

Note (1) No provision has been made for the expense of water analysis or services of engineering services of 3M Company personnel.

(2) Provision has been made for test pumping for water quality analyses of each aquifer, as well as quantitative pumping tests. It is anticipated that this work would be done under the supervision of the Consulting Hydrologist.

Wells and Pumping Equipment Requirements

Glacial drift and Platteville limestone observation wells		
Five @ $1,700.00	$ 8,500.00	
St. Peter-Shakopee observation well		
One @ $4,500.00	$ 4,500.00	
Jordan observation well		
Two @ $5,800.00	$11,600.00	
Hinckley observation well - one	$ 6,400.00	
Barrier production well - Shakopee formation with pump and controls		
Four @ $13,200.00	$52,800.00	
Barrier production well - electrical motor, pump and related equipment (Test Well 1)	$ 7,000.00	
Removal production well - Shakopee formation with pump and controls		
Two @ $15,700.00	$31,400.00	
Property acquisition for well sites		
Six acres @ $1,000.00 per acre	$ 6,000.00	
		$128,200.00

Water Disposal System - Alternate 1

Transmission of all water untreated to the Mississippi River		
Water collection system on 3M property 6,000 ft. @ $15.00	$ 90,000.00	
Water transmission line 30,000 ft. @ $15.00	$450,000.00	
Property acquisition for transmission line right-of-way	$ 20,000.00	
Transmission main, manholes 100 @ $400.00	$ 40,000.00	
Contingencies	$ 70,000.00	
		$670,000.00

Water Disposal System - Alternate 2

Treatment and utilization of all water pumped		
Water collection system on 3M property 6,000 ft. @ $15.00	$ 90,000.00	
Treatment of waste water by activated carbon filtration	$650,000.00 - $800,000.00	
Hydrologic investigations and lake site property acquisitions	$100,000.00	
	$840,000.00 - $990,000.00	

Operation and Maintenance Expenses - Wells and Related Equipment

Five wells @ 50 h.p.	250 h.p.	
Two wells @ 75 h.p.	150 h.p.	
Total h.p. requirement	400 h.p.	
Power costs (annual)	$ 32,000.00	
Maintenance and repair parts $1,500.00 per month	$ 18,000.00	
Operator - full time	$ 12,000.00	
Depreciation	$ 7,000.00	
Contingencies	$ 13,600.00	
Annual Expense		$ 82,600.00

Operation and maintenance of the water treatment plant

The operating expenses of an activated carbon filter plant of 5,000 - 6,000 gpm capacity would vary considerably dependent on the final design and efficiency of the installation. It is reasonable to expect the annual expenses to be of the order of:		
Annual Expense	$120,000.00 - $130,000.00	

SUMMARY - INVESTIGATIVE PROGRAM, WELL CONSTRUCTION AND WASTE WATER DISPOSAL

Hydrologic investigations and quantitative pumping tests	$ 31,000.00		
Wells and Pumping Equipment	128,200.00		
		$159,200.00	
Alternate 1 - Water Disposal Direct discharge to river		$670,000.00	
Grand Total (with Alternate 1).....			$ 829,200.00
Alternate 2 - Water Disposal Treatment and subsequent utilization of all water pumped		$840,000.00 to $990,000.00	
Grand Total (with Alternate 2).....			$ 999,200.00 to $1,149,200.00

NOTE: If the Alternate 2 means of water disposal is utilized, the total cost would be reduced by the increase in value of the land adjoining the lake or by sale or re-use of the treated ground-water for municipal, industrial or other uses.

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CONCLUSIONS

(1) The chemical wastes placed in the wet scrap disposal pits at the Woodbury site have penetrated to the Glacial Drift, St. Peter and Shakopee formations, and possibly in trace concentrations in the Jordan geologic formation at the site of Test Well 1 on the 3M Company property.

(2) The observed movement of the contaminated ground-water is westerly in the direction of private, municipal and industrial wells in the South St. Paul, Newport and St. Paul Park areas.

(3) The chemically contaminated ground-water is objectionable and may be a health hazard. Concentrations of less than 1.0 ppm of isopropyl ether, one of the compounds placed in the waste pits, can be detected by private well owners.

(4) In order to prevent uncontrolled migration of the contaminated ground-water a program to prohibit further dilution and migration of the chemical wastes is required.

(5) The most promising means of recovering the contaminated water and controlling its migration is by a system of removal wells in the area of high concentration and barrier wells around the perimeter of the contaminated area. While technical operational problems are to be expected, they are not considered to be prohibitive to the successful operation of such a control system.

(6) The ground-water control program should be considered one of continuing investigation. The extent of the contamination has been explored in only one direction. The specific hydrologic coefficients of each aquifer affected should be determined.

(7) Disposal of the water produced by the barrier and removal wells will be a major problem. It is anticipated that permission could be obtained from the proper authorities to discharge the untreated waste water to the Mississippi River if a water transmission main is constructed.

(8) Preliminary testing indicates that filtration of the contaminated water recovered by an activated carbon process will produce a high quality water free of organic chemicals. If the water is treated it could be used for industrial purposes or to create a recreational lake. Use of the water to create a lake is dependent on the availability of a suitable site.

(9) Should other private wells become contaminated by chemical wastes it may be possible to supply the home owners with water for domestic use from shallow low capacity wells. Water production would be from above the zone of contaminated water.

RECOMMENDATIONS

(1) A ground-water control program to prevent further dilution and migration of the chemical wastes should be initiated immediately.

(2) The following studies should start immediately:

(A) Conduct a regional well inventory and water quality survey. A water quality monitoring program on a regular basis at selected private wells should also be initiated.

(B) Install a water level recorder at Test Well 1.

(C) Drill Shakopee or Jordan formation observation wells at Test Sites indicated. (See Fig. 1.) The depth drilled to be dependent on the water analysis of the Shakopee formation at each site.

(D) Upon completion of each test well, conduct a 72-hour quantitative pumping test utilizing all available test wells as observation wells.

(3) Drill a minimum of two shallow observation wells at the acid waste disposal site. Dependent upon the results of the test wells, conduct a carefully controlled pumping test at the site. This should be done prior to drilling the barrier well at this site.

(4) Conduct an electrical resistivity survey of the areas surrounding the test pits on the 3M Company property. This survey to be undertaken in April or as soon as the frost has left the ground.

(5) An investigation should be undertaken at the earliest possible time to identify and determine exactly the amount of each chemical constituent present in water samples at Test Well 1.

(6) The potential health hazards associated with the contaminated water should be fully determined. If possible, toxic limits

should be established for each chemical identified in water samples from the Woodbury site.

(7) Preliminary design studies for a transmission line from the Woodbury site to the Mississippi River should be initiated.

(8) An investigation of property availability for transmission line and lake development use including flowage easements should be initiated. Permits for testing at observation well sites not on 3M Company property should be obtained immediately.

(9) Property acquisitions should be confidential and completed as soon as possible. The potential economic advantage of the lake site development program is largely dependent on obtaining land at a reasonable price.

(10) If lake sites are available, a hydrologic study of each one, including soil borings should be undertaken after options for the site are obtained.

(11) The economic and engineering feasibility of utilizing activated carbon filters to treat the waste water should be investigated. Consideration should be given to installing a pilot unit at Test Well 1 where the chemical concentrations in the ground-water are significantly higher than at the Schussler Well.

(12) If waste water treatment is determined to be economically and technically feasible, a study should also be undertaken to determine the economics of injection wells as an alternative means of disposing of the treated water. The injection wells would conserve the water resource, decrease interference with other

water users and, at the same time, decrease the pumping rate required at barrier wells.

Respectfully submitted,

EUGENE A. HICKOK & ASSOCIATES
Consulting Hydrologists
Minneapolis, Minnesota

January, 1967

I hereby certify that this plan, specification, or report was prepared by me or under my direct supervision and that I am a duly Registered Professional Engineer under the laws of the State of Minnesota.

Date 2-67 Reg. No. 7147

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