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TECHNICAL RECORD

SEWRPC

VOL. 4 NO. 1

MARCH 1978

* * * * * IN THIS ISSUE * * * * *

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TECHNICAL RECORD

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1978

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Inside Region $1.00
Outside Region $2.00

A BACKWARD GLANCE

MILWAUKEE'S WATER STORY

Text and Illustrations Courtesy of Milwaukee Water Works

THE BEGINNING YEARS

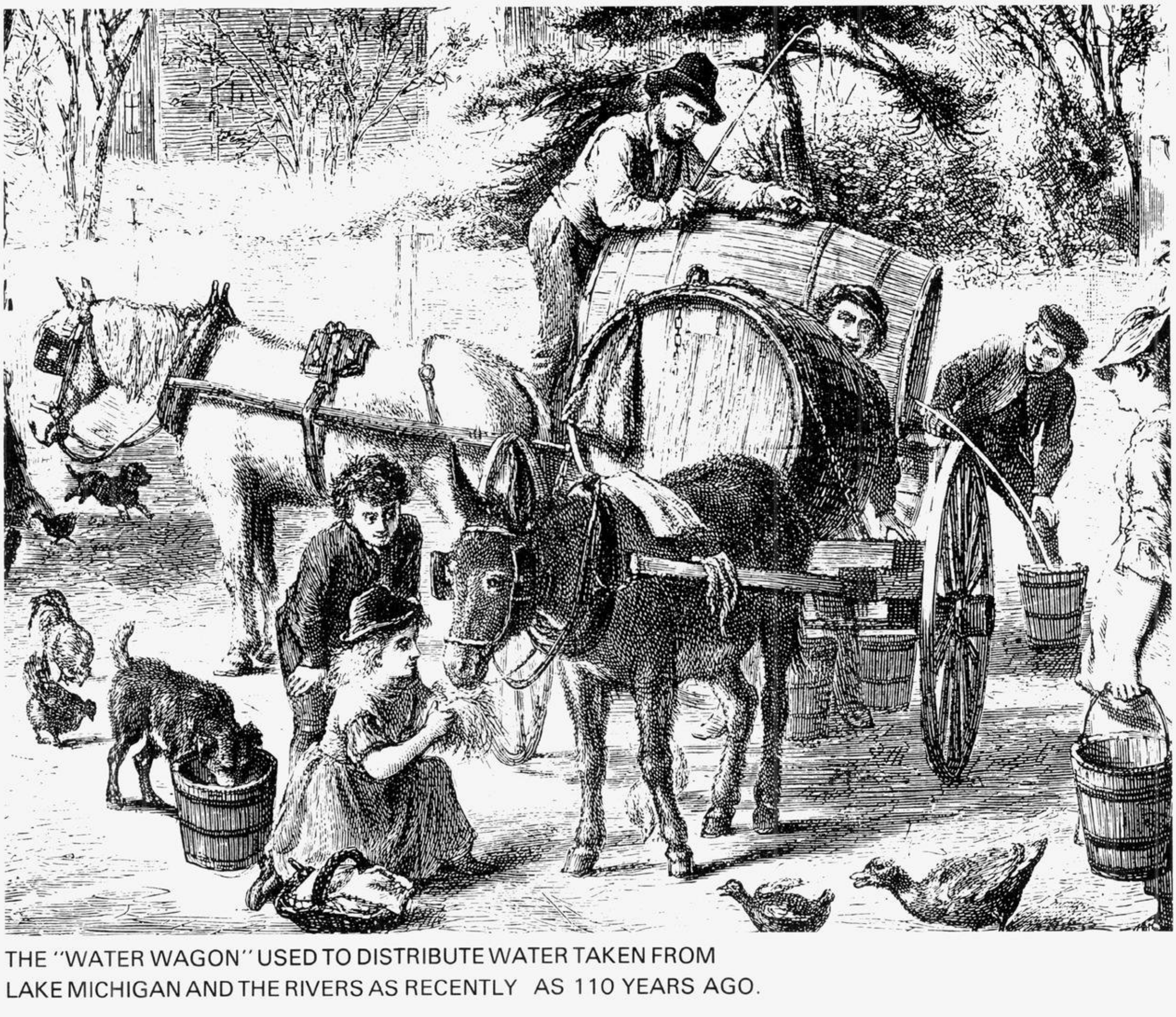
The story of water parallels the story of civilization, for men must build their homes and cities along the sources of water supply — the rivers, lakes, the great watersheds which feed the source of fresh water.

In respect to water supply, Milwaukee is ideally located, with Lake Michigan at its very doorstep. During the first forty years of the community's existence, however, the lake's chief usefulness was as an avenue for travel and trade, especially in pre-railroad days.

Up to 1873, the City of Milwaukee had no public water supply; its citizens were dependent entirely upon wells, springs, and vendors (such as the one pictured on this page) to procure water for household and industrial purposes. The fire protection afforded the city was equally primitive. The three rivers passing through Milwaukee, together with cisterns and ponds, supplied water for fire extinguishing purposes.

The first real steps in connection with Milwaukee's present water works were taken in 1868, twenty-two years after Milwaukee was incorporated as a city. The Common Council secured the services of Civil Engineer E. S. Chesbrough to make a survey, and prepare plans, specifications and estimates for the construction of a waterworks system for the City of Milwaukee.

On March 24th, 1871, the State Legislature gave Milwaukee the authority "to construct waterworks and to carry on and manage same" and "to create a Board of Water Commissioners to construct and complete the work." The Board of Water Commissioners, under whose direction the original construction work of the waterworks was performed, consisted of seven of the leading citizens of Milwaukee, Alexander Mitchell, John Plankinton, Frederick Pabst, Edward O'Neil, Guido Pfister, E. H. Broadhead, and George Burnham. The official date of organization of the Milwaukee Water Works was the date of the first meeting of the water commissioners, April 15th, 1871.



THE "WATER WAGON" USED TO DISTRIBUTE WATER TAKEN FROM LAKE MICHIGAN AND THE RIVERS AS RECENTLY AS 110 YEARS AGO.

The original construction began in 1872, under the direction of Civil Engineer Moses Lane, aided by City Engineer Theodore D. Brown, Esq. The first waterworks consisted of a pumping station on the lake shore (North Point) containing two steam pumping engines of 8-million gallons per day capacity each, a raw water intake, a standpipe (North Point Tower), a reservoir (Kilbourn Reservoir), and 50 miles of water distribution mains ranging in size from six to thirty-six inches in diameter.

Due to the fact that the Kilbourn Reservoir was completed before the North Point pumping station was operational, a temporary pumping station was erected on the west bank of the Milwaukee River, just north of the present North Avenue bridge. This station pumped river water into the reservoir. On November 3rd, 1873, the first untreated water from the reservoir was turned into the distribution system for delivery to the consumer.

On September 14th, 1874, the pumps at the North Point pumping station commenced pumping untreated lake water into the distribution system; the temporary plant at the river was abandoned. In the early years when consumption was low, the pumps at North Point pumped intermittently, depending upon the height of the water in the reservoir.

The total cost of the original waterworks under the Board of Water Commissioners, up to 1875, was $1.9 million. This cost was financed by a bond issue of $1.6 million bearing seven percent interest.

In accordance with a charter provision, the control and management of the waterworks was relinquished to the Board of Public Works on July 1, 1875. The members of the Board of Public Works at that time were Moses Lane, Jacob Velten, Francis S. Blodgett and Winslow A. Nowell.

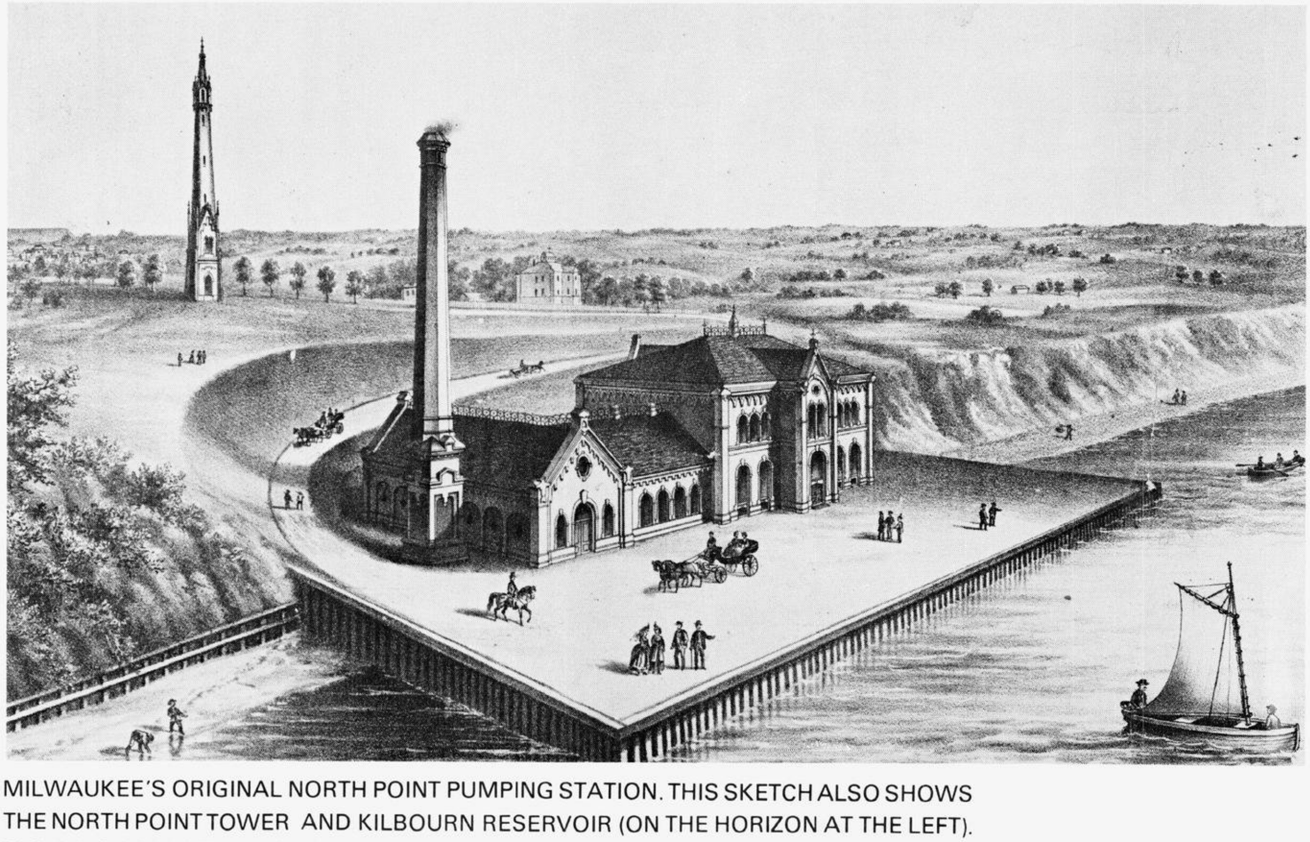
From 1875 until 1912, the utility was under the direction of the City Engineer. By 1912, however, the waterworks had grown to such size that a reorganization was made, and the position of Superintendent of Water Works was created. The Superintendent was placed in complete charge of the operation of the department under the direction of the Commissioner of Public Works, and the City Engineer was placed in charge of the design and construction of the waterworks. The following Superintendents and City Engineers have guided the Utility through more than a century of development:

SUPERINTENDENTS

Henry P. Bohmann	1912-1941
Herbert H. Brown	1941-1949
Edward F. Tanghe	1949-1956
Arthur Rynders	1956-1964
Elmer W. Becker	1964-1972
Nathan E. Miller	1972-

CITY ENGINEERS

Theodore D. Brown	1869-1875
Moses Lane	1875-1878, and 1881-1882
Heliodore J. Hilbert	1878-1881
George H. Benzenberg	1882-1899
Charles F. Poetsch	1899-1911
Joseph A. Mesiroff	1911-1914
George F. Staal	1914-1923
Joseph P. Schwada	1923-1951
Lloyd D. Knapp	1951-1956
Eugene A. Schmidt	1956-1962
Herbert A. Goetsch	1962-1963
Herbert D. McCullough	1963-1972
Edwin J. Laszewski	1972-



MILWAUKEE'S ORIGINAL NORTH POINT PUMPING STATION. THIS SKETCH ALSO SHOWS THE NORTH POINT TOWER AND KILBOURN RESERVOIR (ON THE HORIZON AT THE LEFT). PUMPING CAPACITY WAS 16 MILLION GALLONS PER DAY.

INTAKES — EARLY YEARS

The first water intake, built in 1873, consisted of a 36-inch cast iron pipe extending into the lake a distance of 2,100 feet where the depth of water was 18 feet. At the far-end of the intake, the pipe was turned upward and held in place by a hexagonal (six-sided) crib anchored with piling and stone fill. A protection pier was built immediately over the full length of the intake.

As the depth of the water at the inlet of the intake was only 18 feet, during the cold winter months a great deal of trouble was experienced in keeping the intake clear of ice. At times, great difficulty was encountered in getting tugs to break their way through the ice in the rivers and bay in time to thaw out the intake. At one time during 1885, there was only two hours' supply of water on hand when the difficulty was overcome. A boiler was therefore placed on the outer end of the pier, immediately over the intake inlet, and steam was forced down into the intake when icy conditions prevailed.

When it became apparent that the original intake could not supply the increasing demand for water, it was decided that a larger intake should be constructed. Engineers were appointed by the mayor to prepare plans for a new, larger intake. North Point was selected as the most desirable location for this intake.

An auxiliary intake, to supplement the original intake until the new intake was completed, was built in 1888. This auxiliary intake consisted of a 30-inch pipe extending into the lake a distance of 500 feet to a crib submerged in ten feet of water. This intake was abandoned when the new North Point intake was completed.

Work on the North Point water intake was begun in 1890 and was not completed until 1895. This intake was constructed under extraordinary difficulties, so much so that the contractor abandoned the job and it was completed by Milwaukee's City Engineer, George H. Benzenberg, Esq.

There were twenty lives lost during construction. Fourteen men were drowned on April 20th, 1893, when the crib house was washed away during a heavy storm; only one man was saved from the crib. Three men went adrift in the lake and were never found. Two men died of the "bends", and one man was killed when he fell into the shore shaft.

The North Point intake taken out of service in 1918 but kept on standby service until 1964, consisted of a brick-lined tunnel, seven and one-half feet in diameter, extending over 3,100 feet into the lake to an exposed concrete crib. From this crib, two parallel lines of cast iron pipe, each five feet in diameter, were entrenched in the lake bottom extending another 5,000 feet farther out into the lake, terminating in 60 feet of water. The outer ends of the upturned pipes were secured by submerged cribs. The maximum capacity of this intake was 95 million gallons per day.

INTAKES — AT PRESENT

<u>North (Linnwood)</u>

The Linnwood water intake was completed in 1918. It consists of a concrete tunnel, 12 feet in diameter, which extends from the lake shore into the lake a distance of 6,565 feet, where the water is 67 feet deep. At the shore end of the tunnel, there is a vertical circular shaft, 15 feet in diameter, which connects with the lake

TUNNELING FOR NORTH POINT INTAKE, AROUND 1891. THIS WORK, HAZARDOUS EVEN NOW, WAS EXTREMELY DANGEROUS IN THOSE DAYS. NOTE PRIMITIVE EQUIPMENT.

intake tunnel at a point 81 feet below lake level. The outer end of the tunnel is 150 feet below lake level and terminates in a submerged crib. The crib rests over the top of a vertical lake shaft. The eight-sided crib is 80 feet wide and 12 feet high.

The Linnwood intake crib is located about five miles from the mouth of the Milwaukee harbor. The capacity of the timber intake crib is approximately 370 MGD (million gallons per day) at a velocity of five feet per second. The intake is presently supplying raw water to the Linnwood Avenue Purification Plant, but is designed to supply raw water to the North Point and Riverside pumping stations in an emergency.

A shore tunnel, nine feet in diameter and approximately twenty feet below lake level, extends from the shore shaft up to each pumping station (North Point and Riverside). Through these tunnels, either raw or filtered water can be delivered to the pumping stations. From these supply tunnels branches lead to the pump wells located in the basement of each station.

South (Texas)

After World War II, it became apparent that the upward surge of local industries, as well as of population itself, was placing a severe strain on Milwaukee's existing water supply facilities. By 1955, the demand for water began to surpass the available supply capacity. Consulting engineers were contracted to make a complete study of the situation and to prepare plans for launching a vast waterworks project, the initial phase of which would add 100 MGD to the existing 275 MGD capacity of the city's system. The primary step in this improvement program was the construction of an additional raw water intake.

Milwaukee's Southside was chosen as the logical area for a complete water treatment facility. Construction of a nine-feet-in-diameter concrete water intake line was begun in June of 1959 and completed in September of 1960. This intake, the Texas Avenue Intake, extends into Lake Michigan a distance of 7,600 feet, beyond any contaminated waters which might exist near the shore, where it terminates in a submerged steel crib fifty feet under water. The intake and crib design provides for a capacity of 300 million gallons daily.

Due to the three and one-half mile distance between the lake and the southside treatment facility, a pumping station is required to transmit the lake water to the Howard Avenue Purification Plant. Construction of this station (Texas Avenue Raw Water Pumping Station) was started in November of 1959. This blast-resistant station draws lake water through the intake pipeline, adds chlorine, and pumps the chlorinated water through a conduit to the treatment plant.

The raw water pumping station is equipped with seven electrically driven centrifugal pumps, four rated at 1,250 horsepower each, and three rated at 2,000 horsepower each. The combined capacity of the seven pumps is 305 MGD. Texas Station is unmanned, with pumping operations being remotely controlled from the Howard Purification Plant "load center." Texas Station was placed into service in June of 1962.

The chlorinated lake water is conveyed to the treatment plant through an 80-inch prestressed concrete conduit. The conduit route, 18,300 feet long, is shown in the diagram on this page. At various points along the route, the depth of the conduit reaches nearly 30 feet. The cost of this raw water conduit was over $3.8 million, or roughly $200 per foot.

TREATMENT — BEFORE 1939

Originally, Lake Michigan water was of the highest quality, and could be pumped untreated into the water mains for consumption. By the early 1900's, however, bacteria from Milwaukee's polluted harbor began to reach the raw water intake when winds and currents were adverse. In 1910, during a high incidence of typhoid fever, immediate steps were taken to sterilize the raw water. Three wooden tanks were erected at North Point Station above the intake pipe, and hypochlorite of lime (bleaching powder) was mixed in the tanks and added to the water. By 1913, a permanent sterilization facility was constructed along with a laboratory, and more accurate chlorination by mechanical means was effected. After 1910, by the way, the typhoid fever death rate began to drop, and for many years now, the disease has been almost non-existent.

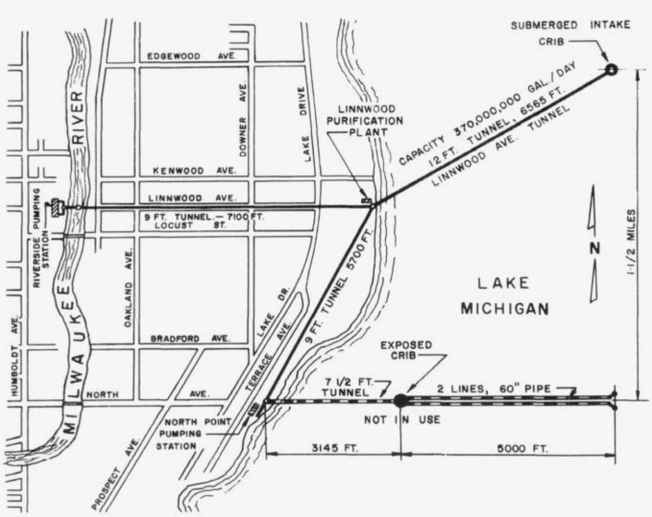
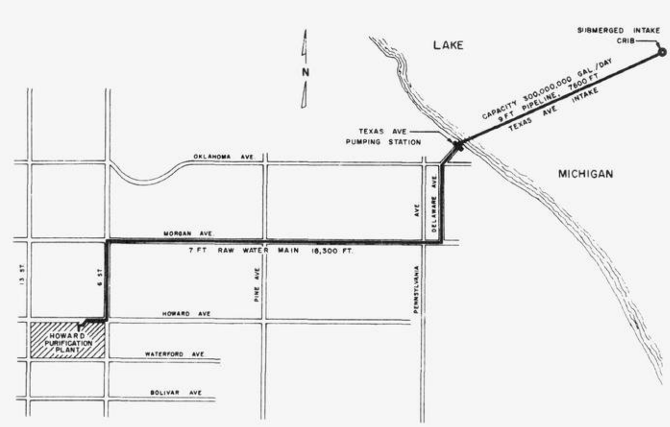


DIAGRAM SHOWING THE NORTH POINT AND LINNWOOD INTAKES, COMPLETED IN 1895 AND 1918 RESPECTIVELY. WATER SUPPLY TUNNELS TO NORTH POINT AND RIVERSIDE STATIONS ARE ALSO SHOWN.



TEXAS AVE. INTAKE WITH CONDUIT TO HOWARD PURIFICATION PLANT.

FIRST WATER TREATMENT EQUIPMENT, 1910.

Occasional turbidity and objectionable water tastes could not be controlled merely by adding chlorine, and the need for a filtration plant was gradually recognized. Construction of the Linnwood Purification Plant was authorized in 1933, and completed in 1939, ushering in a new era of Water Works operations.

TREATMENT — PRESENT FACILITIES

Linnwood (North Side)
The Linnwood plant is an imposing structure of modernized Gothic design, located on a twenty-four acre man-made site at the shore of Lake Michigan (3000 N. Lincoln Memorial Drive). It contains six raw water pumps, with a total capacity of 375 million gallons per day, 2 coagulation basins, each 300′ x 375′ x 28′, 32 filters, each 38′ x 57′, and 3 filtered water reservoirs with a combined capacity of 30 million gallons.

Although now nearly 40 years old, the Linnwood plant is still an up-to-date facility, due to an extensive renewal program which began in the 1960's. Chemical feed, electrical and filter control systems were replaced and filter operations placed under remote control.

The Linnwood plant's capacity is rated at 275 million gallons per day (MGD), although it has been operated at higher rates for brief periods. The highest day's production occurred in 1961 and was 267 million gallons. In the following year, the Howard Avenue water treatment plant was placed into service, and so the Linnwood plant has never since equalled its 1961 record.

Howard (South Side)
The Howard Avenue Purification Plant, located at South 6th Street and West Howard Avenue, has a present filtering capacity of 100 million gallons of pure water daily. This modern plant contains eight filters, each filter bed being approximately 42 feet by 69 feet, with a capacity of twelve and one-half MGD, at a filtration rate of three gallons per square foot per minute. Filtration operations at the Howard plant are semi-automatic, with most filtering operations being controlled from the Howard "load center." Washing of the beds is done by manual valve operation. The Howard Plant contains two clearwells for storage of filtered water, with a combined capacity of 35 million gallons, and one 500,000 gallon wash water tank.

Construction of this filtration facility was started in 1960 and took two years to complete. This plant can ultimately be expanded to a capacity of 300 million gallons per day.

THE TREATMENT PROCESS

Although the Linnwood and Howard Purification Plants differ in size and specific operational designs, the methods of water treatment are basically the same. The rapid-sand method of filtration is used to purify the water used in Milwaukee.

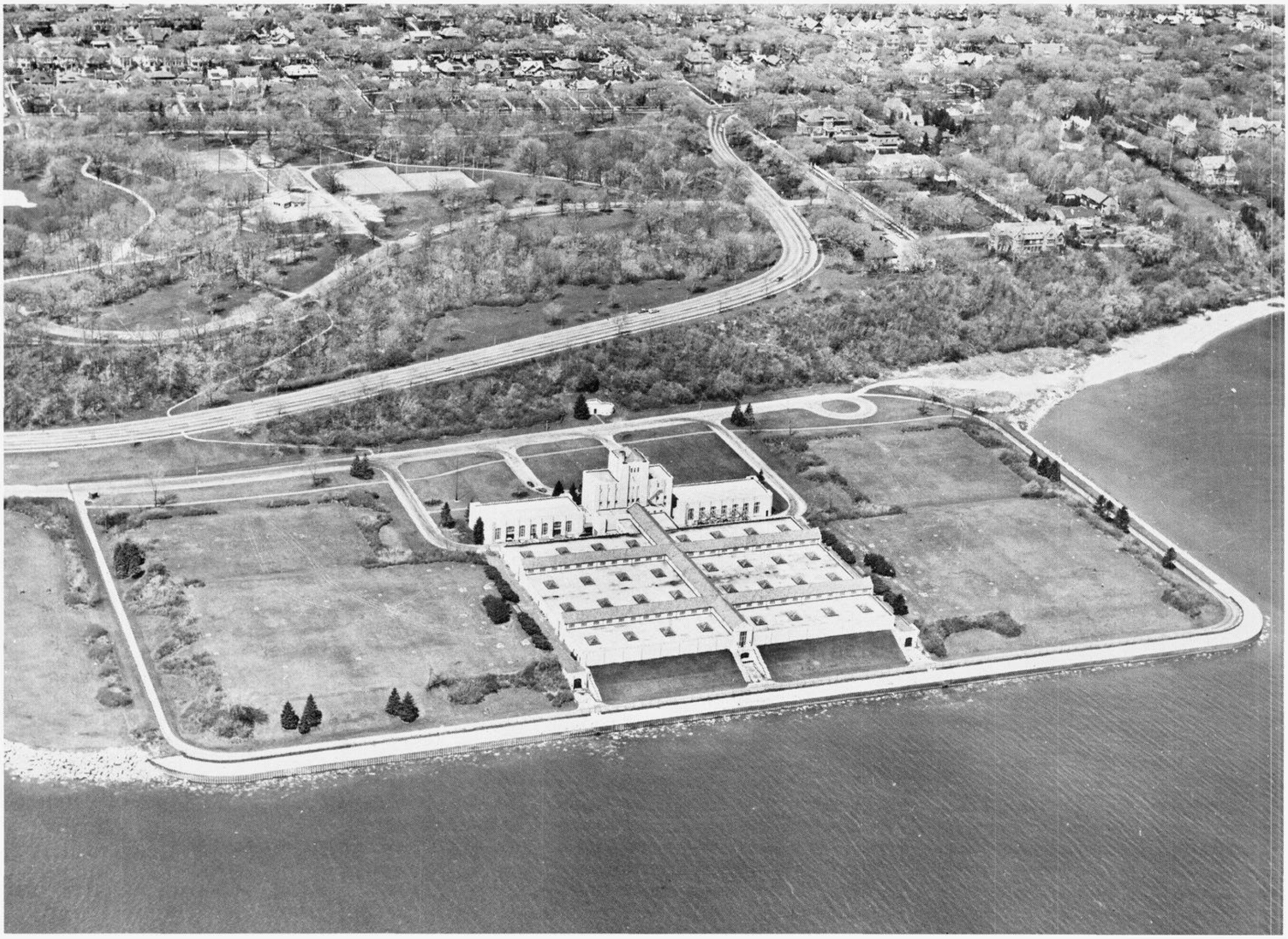
Raw water is taken from Lake Michigan, by methods previously described, and pumped to the mixing basins in the purification plants. Here the water receives all chemicals of treatment; chlorine, alum, activated carbon, and ammonia. Hydrofluosilicic acid is added to the filtered water. This chemical, for the prevention of tooth decay, was added to the Milwaukee water supply for the first time on July 22nd, 1953.

After the mixing process, a chemical reaction (coagulation) between the alum and the natural alkalinity in the water produces a white, insoluble, snow-flake-like substance called "floc." The complete mixing and coagulation process takes approximately one hour.

The coagulated water passes slowly through the sedimentation basin. During its passage through this basin, which requires about four hours, the "floc", being heavier than water, tends to settle to the bottom of the basin, taking with it a large percentage of the bacteria and suspended matter present in the water. This prevents the filters from becoming unduly loaded, and also lengthens the time between the washing of filters.

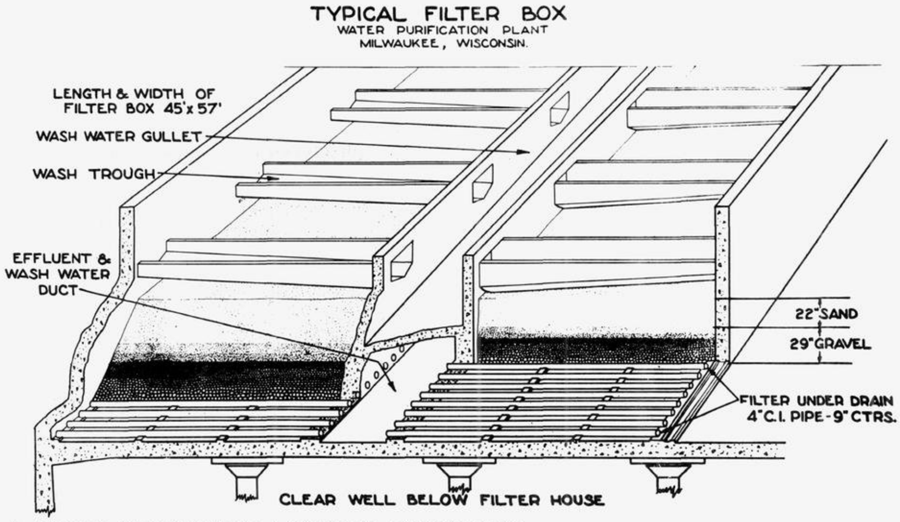
During certain seasons of the year, activated carbon is added to the raw water pipeline to help eliminate tastes and odors produced by microscopic plants (algae) and animals (protozoa), called plankton; also tastes and odors due to industrial wastes. If desired, potassium permanganate can also be added to the South Side raw water pipeline, to eliminate musty tastes caused by adverse winds carrying harbor water toward the intake.

From the settling basin, the water passes on to the filters, which are composed of layers of sand and gravel. The sand and gravel in each filter bed at both filter plants totals 51 inches in depth. A

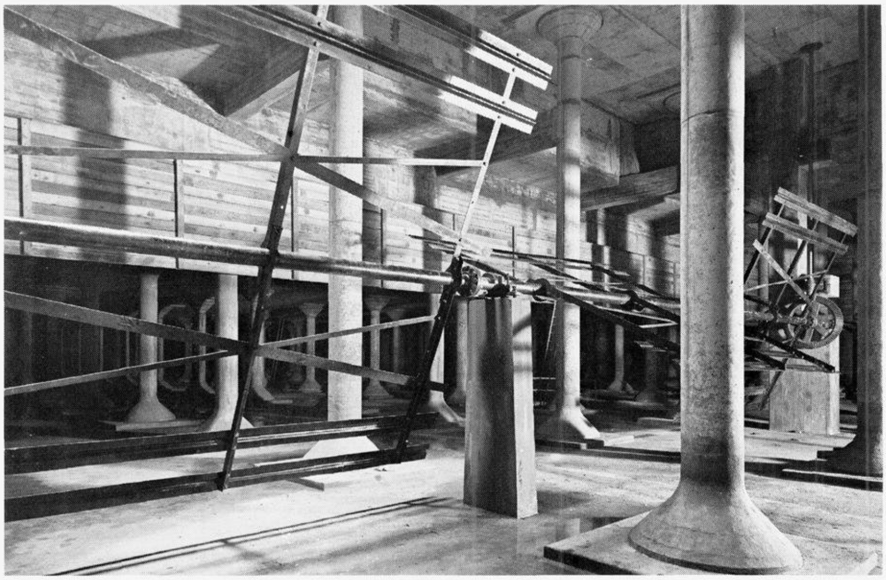


LINNWOOD PURIFICATION PLANT

HOWARD AVENUE PURIFICATION PLANT



A CROSS-SECTION OF A TYPICAL FILTER BED.



THE MIXING CHAMBER AND PADDLES OF ONE OF THE TWO COAGULATION BASINS AT LINNWOOD. THE MIXING PROCESS TAKES ABOUT ONE HOUR.

very important feature of the filter process is the gelatinous "mat" which is formed on top of the sand. This "mat" consists of the unsettled "floc", bacteria and other suspended matter that is carried on to the filter with the applied water. In forming this "mat", the voids between the sand grains are filled with this material to a depth of about one inch from the top of the filter bed.

The gelatinous "mat" is the actual filtering medium in the removal of the "floc", bacteria and other suspended matter, as the water trickles through the filter beds into a system of underdrains, from where it is conducted to the filtered water reservoirs. A small additional dose of chlorine, together with anhydrous ammonia and hydrofluosilicic acid, is applied to the filtered water. The purpose of anhydrous ammonia is to prevent chlorinous tastes. When combined with chlorine it forms chloramine, which is a more stable sterilizing agent than chlorine alone.

Treated water is accumulated in the filtered water reservoirs, from where it flows to the pumping stations for transmission to the water consumer; of whom there are nearly 900,000 served by the Milwaukee Water Works at present.

CHEMICALS

The application of the various chemicals in the water treatment process is carefully inspected and regulated to conform to the varying conditions of the raw water. These chemicals, with the exception of fluorine and a small chlorine residual as required by the Wisconsin State Board of Health, are entirely eliminated from the treated water before it leaves the treatment plants. Each chemical is carefully applied to serve a particular purpose, and is filtered out after this purpose is accomplished.

The average chemical doses amount to:

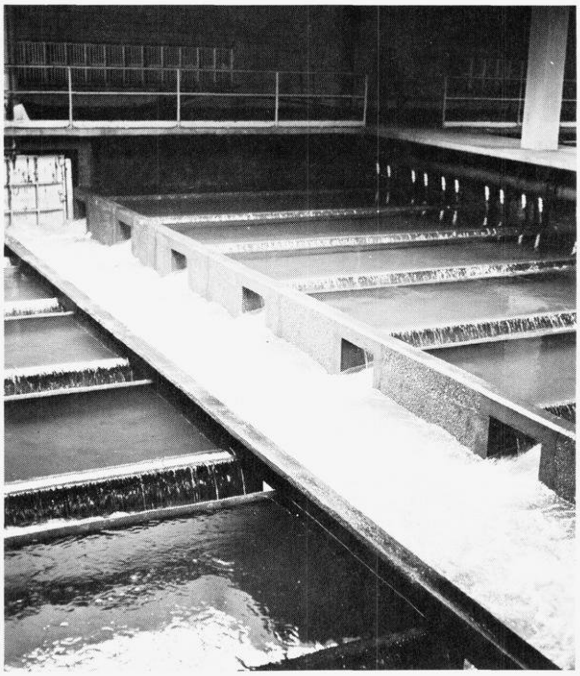
	POUNDS PER MG*
Aluminum Sulfate	110
Activated Carbon (when used)**	10 to 100
Anhydrous Ammonia	2
Hydrofluosilicic Acid	34
Chlorina — Pre.	15
Post	1

*one million gallons
**varies greatly with the condition of the raw water

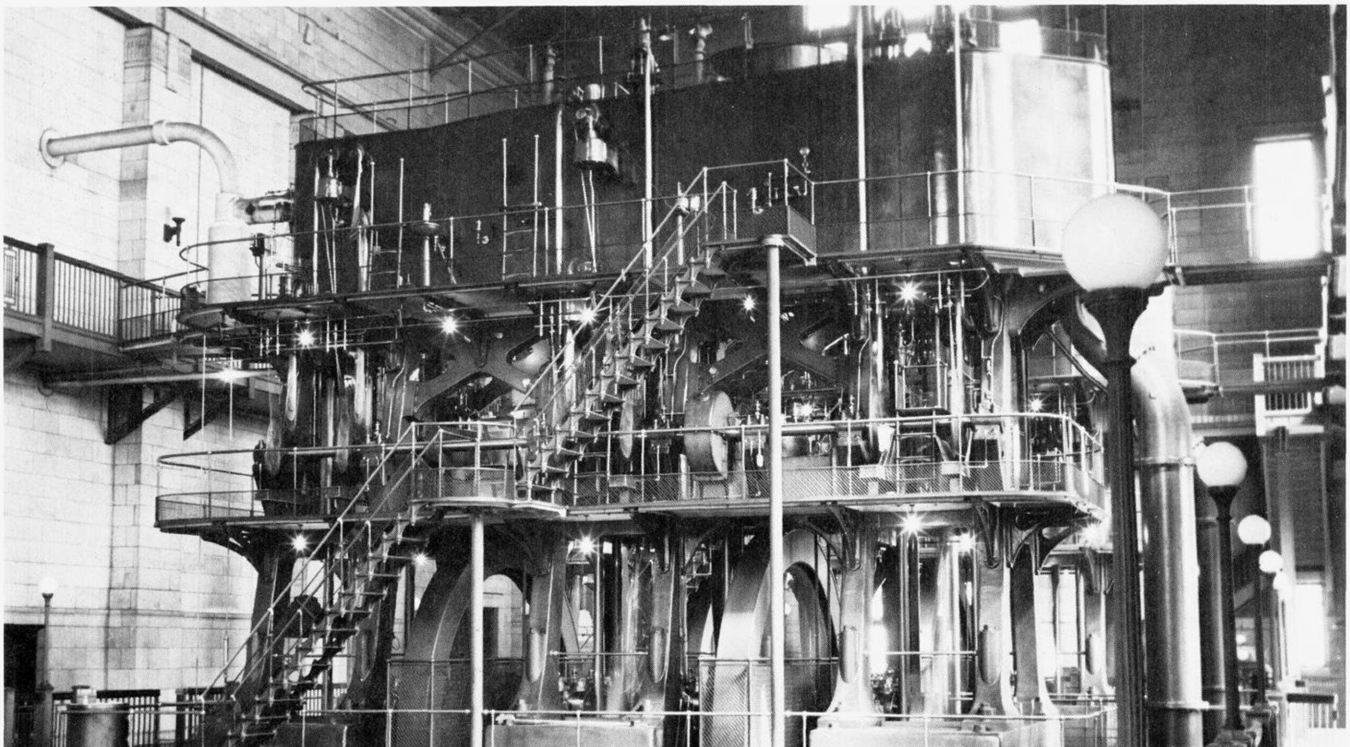
FILTER WASHING

When the accumulated waste matter clogs the filter bed to a point where a reduction in the rate of filtration is apt to be produced, it becomes necessary to "wash" the bed. This is accomplished by closing the inlet and outlet valves to the filters and reversing the flow, using filtered water from the wash water tank. The wash water is forced up from the bottom, agitating the filter bed so that the sand is raised and held in suspension while the dirt and accumulated matter is washed into the troughs directly above the bed and into the waste system. When the filter bed is clean, as indicated by clean wash water rising through it, the valve is closed, and as the water recedes, the sand, which has been held in suspension, grades itself hydraulically as it settles back into its original position. The filter bed is now ready to be placed back in service. The complete washing process takes from five to ten minutes. The wash water is reclaimed by leading it from the filter wash drain to a recovery basin, where again the sludge is removed and the reclaimed water is sent back to the rapid mix basin. This water then goes through the entire treatment process once again.

FILTER GALLERY — LINNWOOD



FILTER WASHING



A VERTICAL TRIPLE EXPANSION CRANK AND FLY-WHEEL PUMP, IN SERVICE FROM 1924-1968 AT RIVERSIDE PUMPING STATION.

WATER PUMPING — HISTORY

The original North Point Pumping Station, on the lake shore across from Bradford Beach, was placed into operation on September 14th, 1874. Because of the increasing water demands of a growing community, this station was revised several times until 1929, when the station was expanded to the size it remained until it was retired from service. After 1929, North Point contained eight pumping engines of the vertical triple expansion crank and flywheel type with a total combined pumping capacity of 126 MGD. This plant remained in service until October, 1962, when it was replaced by an electrically powered pumping station constructed at the same location. Old North Point station was demolished in 1965.

The first high-pressure pumping station in Milwaukee was located on the southwest corner of Chestnut and Eighteenth Streets, and was operated from July of 1878 until September of 1887. On this date the new high-service pumping station on North Avenue between Tenth and Eleventh Street was completed and placed into service. This station was in service until November of 1924.

Riverside Pumping Station, located on the west bank of the Milwaukee River at Chambers Street, was placed into operation in July of 1924, and originally contained four triple expansion steam pumping engines. These engines, each taller than a three story building, made very efficient use of steam, because the same steam performed work in three successively larger cylinders before its energy was used up (hence the term "triple expansion"). Although two of these engines were retired before 1955, the other two performed faithfully until 1968 when they were scrapped and replaced by electrically powered pumps. Meanwhile the first of three steam turbine powered pumps was installed in 1928, and remained in service until 1967, when the Riverside electrification program was begun.

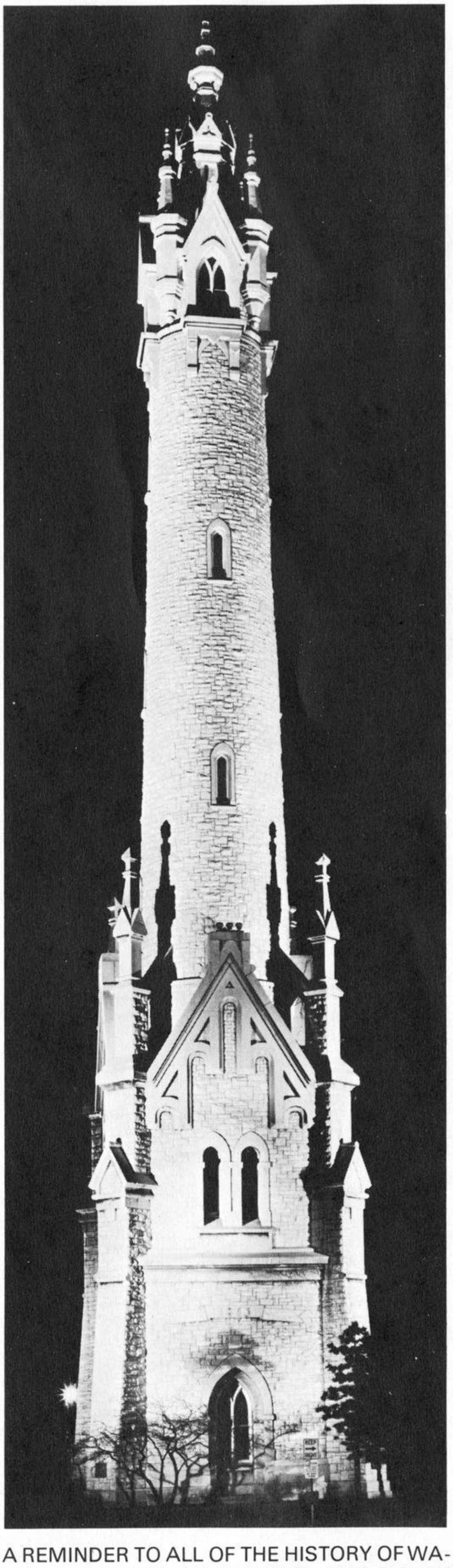
Unlike modern centrifugal (revolving bladed) pumps, steam pumping engines operated somewhat like the old hand pumps still found at some picnic sites today. Each upward stroke of the plunger forced water in the pump cylinder out into the water mains. This uneven action provided the basis for a structure which is today a Milwaukee Landmark. Since the 1873 original pumping equipment consisted of only two pumping engines, some means had to be devised to prevent a pulsating action in the mains, from the up-and-down strokes of the pumps. A standpipe four feet in diameter and 125 ft. high was therefore erected on the high ground above North Point Pumping station, and enclosed in ornamental stonework for esthetical reasons and to prevent freezing during winter. The standpipe smoothed out the pulsations of the pumps in the early years; afterwards, when no longer needed it was still kept in good repair and formally declared a Milwaukee Landmark in 1968. In the following year, it was declared a National Landmark of the American Water Works Association.

WATER PUMPING — PRESENT

In a normal year, the Milwaukee Water Works pumps about 59 billion gallons of treated water to its customers. This averages 162 million gallons daily or 180 gallons per day for each person served.

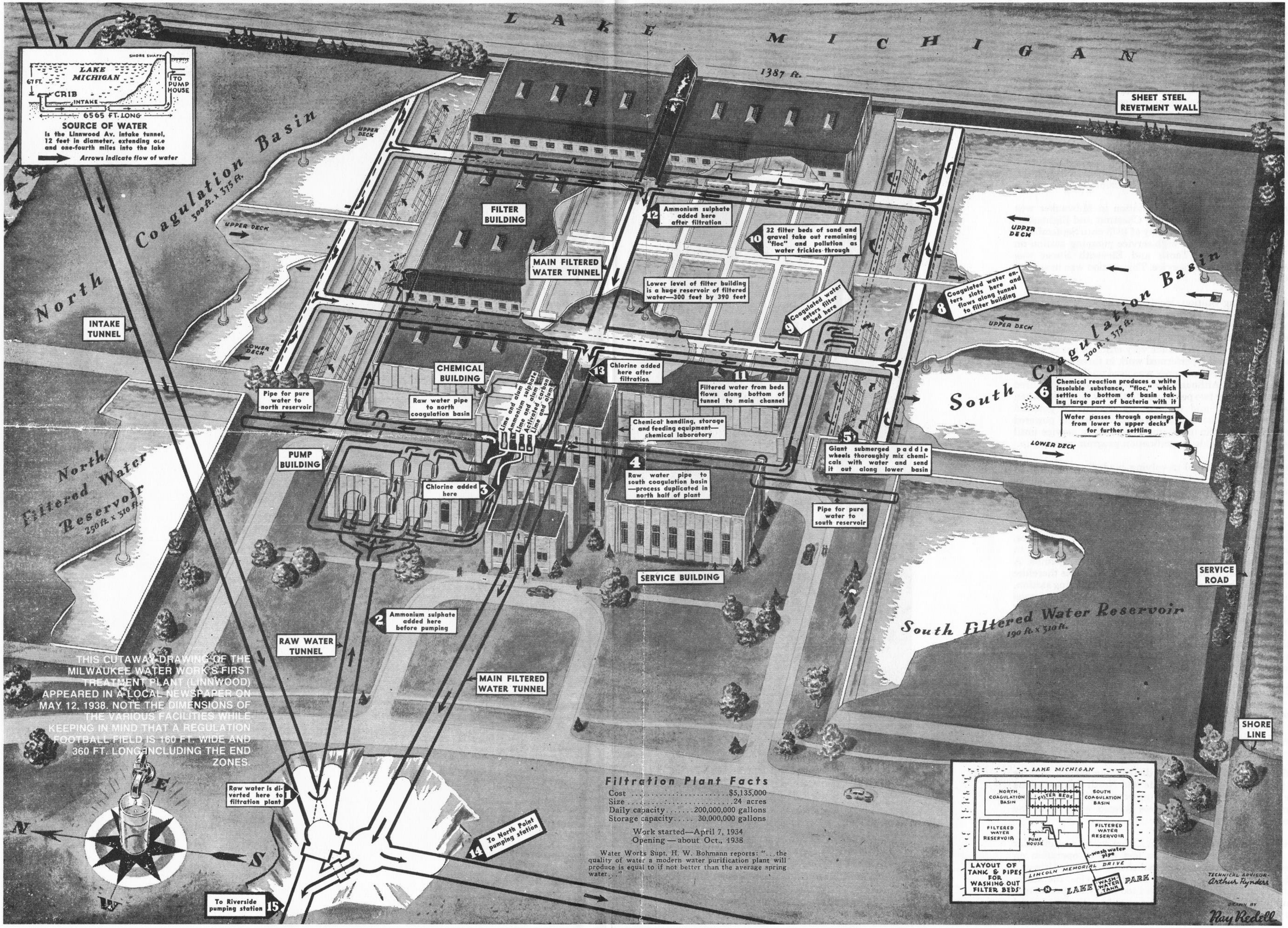
After filtration, water enters the distribution system at three major pumping stations. Riverside and North Point stations receive filtered water from the Linnwood Purification Plant. Howard Pumping Station receives filtered water from the Howard Purification Plant.

The original North Point Pumping Station, with its spectacular steam pumping engines, had its last day of operation on October 16, 1962, and was demolished in 1965. Although capable of many more years of reliable service, the steam pumping equipment was considered too costly to operate and maintain, as it required nearly 60 men to keep the boilers and pumps in operation.



A REMINDER TO ALL OF THE HISTORY OF WATER SUPPLY IN MILWAUKEE, THE NORTH POINT TOWER IS NOW AN OFFICIAL MILWAUKEE LANDMARK.

New Filtration Plant and How It Will Operate — Journal Artist Shows 14 Steps From Lake Water to Pure Drinking Water



THIS CUTAWAY DRAWING OF THE MILWAUKEE WATER WORK'S FIRST TREATMENT PLANT (LINNWOOD) APPEARED IN A LOCAL NEWSPAPER ON MAY 12, 1938. NOTE THE DIMENSIONS OF THE VARIOUS FACILITIES WHILE KEEPING IN MIND THAT A REGULATION FOOTBALL FIELD IS 160 FT. WIDE AND 360 FT. LONG INCLUDING THE END ZONES.

The new North Point Pumping Station, located on the lake shore adjacent to the site of the original North Point Station, was completed and placed into service in July of 1963. This unmanned, blast-resistant station contains three 25 MGD electrically-driven 1,000 horsepower pumps to supply the low-service area, and three 30 MGD electric, 2,250 horsepower pumps for the high-service area. North Point contains a central control board, but pumping operations are controlled from the Linnwood Purification Plant "load center."

Riverside Pumping Station has also undergone a complete changeover from steam-powered to electrically-powered pumping equipment. It is also remotely controlled from the Linnwood Load Center. In contrast to North Point, the new pumps were installed in the original building, erected in 1924. Riverside Station now contains eight pumps, having a total capacity of 210 MGD.

The Howard Avenue Pumping Station, placed in service in June of 1962, contains eight electrically-operated centrifugal pumping engines; three 50 MGD and one 35 MGD pumps to supply the high-service area, three 23 MGD pumps to supply the low-service area, and one 23 MGD pump to serve as a wash water pump; this pump is also available for delivering water to the low-service area. Howard Station is attached to the Howard Avenue Purification Plant and is constructed to be blast-resistant. The station is unmanned, with pumping operations being controlled electrically from the Howard Purification "load center", located in an adjacent building. A 2,500,000 gallon reservoir is situated close to the station.

BOOSTER PUMPING FACILITIES

As water passes through the distribution system, it gradually loses pressure due to distances traveled, friction on the inside surfaces of the mains, and higher elevations found in some areas. Rather than to pump water at exceedingly high pressure from the major pumping stations, it is considered a better practice to boost the pressure at various points where needed. The Milwaukee Water Works has several booster pumping stations described below, all of which are unmanned and operated remotely from the downtown Control Center, located in the Municipal Building, 841 North Broadway.

Kilbourn Reservoir, constructed in 1874, is the oldest structure in service in the Milwaukee water system. This irregularly shaped, cement-lined structure with earth embankments, has a capacity of 22,000,000 gallons. Located in Kilbourn Park, this reservoir provides storage within the system near the top of the hydraulic grade and is efficiently used with either a filling or pumping cycle to match the variable consumption in the low-service system.

Plans are in progress to add a roof to the now open reservoir.

Kilbourn Booster Pumping Station, adjacent to the reservoir, was placed into service in May of 1957. This station pumps water from the reservoir into the distribution system, particularly during periods of "peak" demand, thereby improving pressures in the low-service area. Kilbourn Station contains three electrically-driven centrifugal pumps having a combined capacity of 60 MGD.

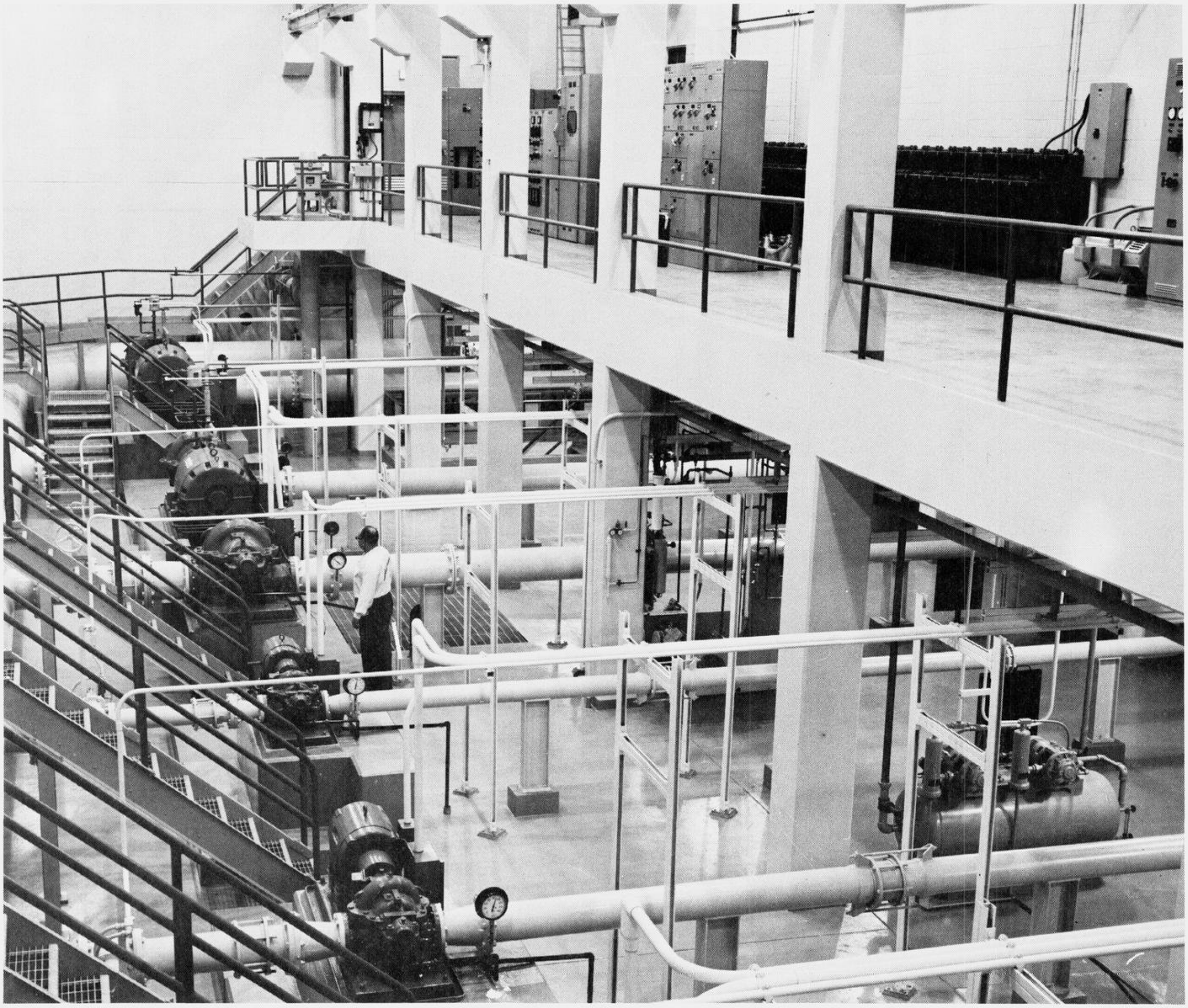
The Menomonee Valley Booster Station, located on South 44th Street near County Stadium, has been in service since 1934. This station houses three 30 MGD electric centrifugal pumps, with space for a fourth. There are also three six-million gallon steel water storage tanks located on the station grounds.

Lincoln Avenue Booster Station, South 37th and West Lincoln Avenue, has been in service since 1956. This station contains four electric pumps with a combined capacity of 26 MGD. There are two six-million gallon steel water storage tanks adjacent to this station.

Lake Station, which was acquired in 1954 through the consolidation of the former town of Lake with the City of Milwaukee, consists of a booster pumping station and a one-million gallon elevated storage tank. The station contains two electric pumps with a combined capacity of 6 MGD.

Florist Avenue Booster Pumping Station, located at North 84th Street and West Florist Avenue, was placed into operation in 1965, and serves the northwestern areas of Milwaukee County. It contains eight electric pumps with a combined capacity of 58.4 MGD. The station design is such that its capacity can eventually be expanded to 94 MGD. Located nearby is a 12-

RIVERSIDE PUMPING STATION



FLORIST AVENUE BOOSTER PUMPING STATION

million gallon storage tank. Enough land is owned at the Florist site to erect two more 12-million gallon storage tanks.

Grange Avenue Booster Pumping Station, 5353 South 43rd Street, was completed in March, 1968. It contains five electric pumps, each with a capacity of 5 MGD, and serves the southwestern areas of our system.

The Milwaukee water distribution system contains four underground "in-line" booster pumping stations. Oklahoma Station, located at South 74th Street and West Oklahoma Avenue, was placed in service in 1957. This station contains four pumps having a combined capacity of 3.5 MGD. The Bluemound Station, at North 87th and West Adler Streets, has been in service since 1959. Bluemound Station houses three electric pumps with a total capacity of 4.7 MGD. Capitol Station, in operation since 1959 and located at 4000 North 79th Street, contains four pumps with a combined capacity of 4.2 million gallons daily. Lisbon Booster Station, at N. 76th St. and W. Lisbon Ave., was placed in service in 1977 and contains three pumps with a combined capacity of 18 million gallons daily.

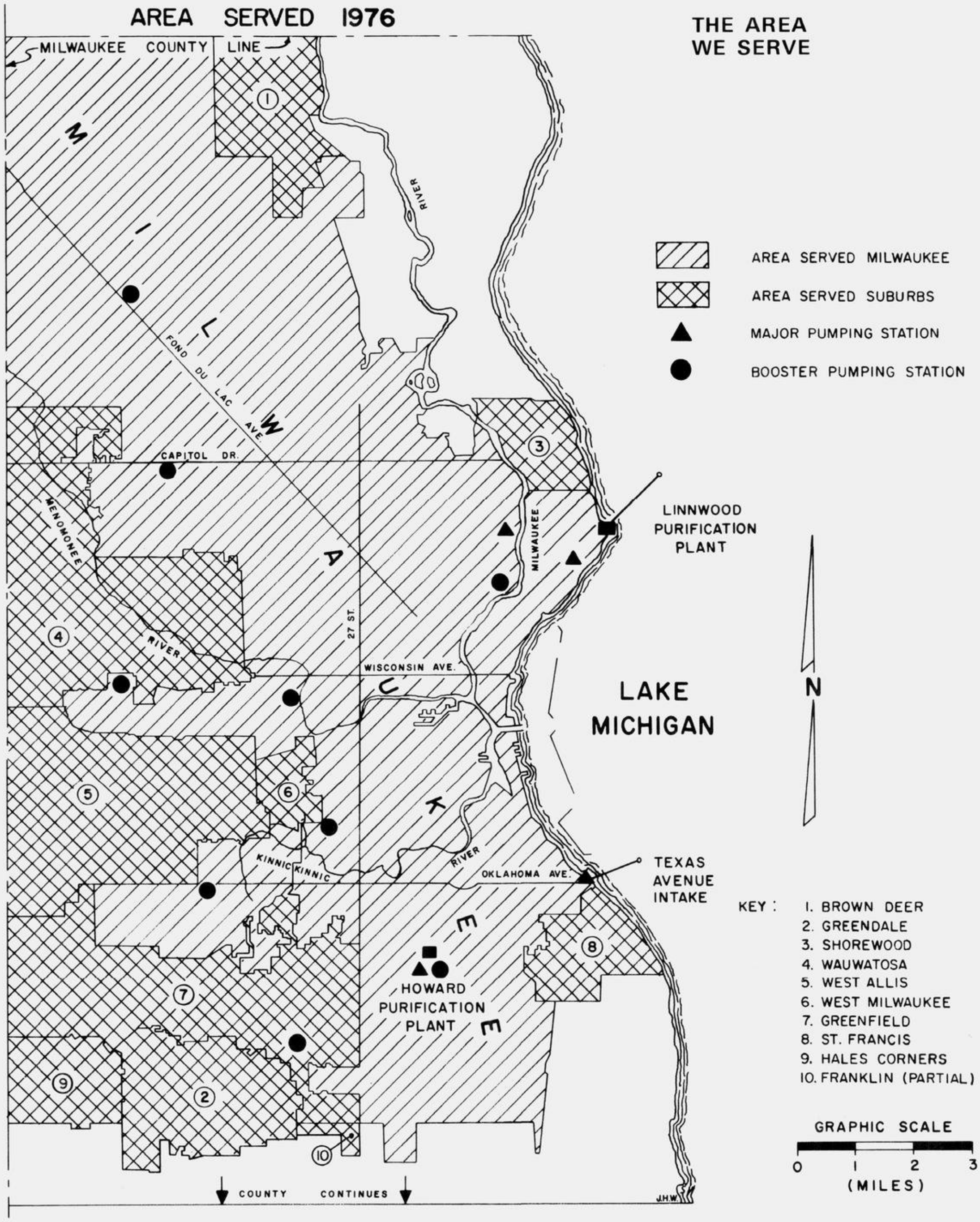
In addition to the reservoirs and ground level storage tanks previously described, the system contains two elevated steel water storage tanks, with capacities as follows:

Lake Tank (4001 S. 6th St.)	1,000,000 gallons
Greenfield Tank (8755 W. Waterford St.)	2,000,000 gallons

These tanks, added to the other storage facilities, bring the total storage capacity to 137.3 million gallons. The reservoirs and tanks assist in handling peak demands, and eliminate the necessity for huge investments in treatment and pumping equipment which would be idle most of the year.

Water from ground level storage tanks is pumped out of the tanks during peak demand hours, after which the tanks are allowed to refill. Elevated storage tanks on the other hand, provide for minute-by-minute changes in demand, for they are connected each by a single large pipe to the water mains system, and "ride the line", i.e., the height of the water in the tank varies with the pressure in the mains. Most water is pumped directly to consumers and never reaches a water tank.

THE AREA WE SERVE



THE MAP ABOVE SHOWS PART OF THE MILWAUKEE COUNTY AND THE AREA SERVED BY THE MILWAUKEE WATER WORKS, TOTALING OVER 151 SQUARE MILES, OR 62 PERCENT OF THE TOTAL AREA AT THE END OF 1976. SHOWN ON THE MAP ARE TWO PURIFICATION PLANTS, TWO WATER INTAKES, FOUR MAJOR PUMPING STATIONS (ONE OF WHICH IS A RAW WATER PUMPING STATION), AND VARIOUS BOOSTER PUMPING STATIONS WHICH ASSIST IN MAINTAINING PROPER PRESSURE THROUGHOUT THE SYSTEM.

MENOMONEE VALLEY BOOSTER PUMPING STATION. EACH STEEL TANK HOLDS 6 MILLION GALLONS OF FILTERED WATER.

The Control Center, located in Room 403 of the Municipal Building, contains centralized electronic data telemetering, recording and supervisory control equipment. The information system measures 43 critical pressures, flows and water storage levels at fifteen widely separated stations, telemeters the information over telephone lines to the Control Center, recording it automatically by typewriter. This installation, completed in 1959 and constantly being expanded, was the first such automatic recording system to be used by a water utility in the United States. The "supervisory control" system provides for the turning on or off of electric pumps at various booster stations throughout the waterworks system.

Low pressures and other abnormal conditions are known at once through the record provided by the Control Center. Often, potential trouble can be detected before it develops into serious difficulty.

WATER DISTRIBUTION SYSTEM

The Milwaukee Water Works system contains approximately 1,830 miles of water mains, 17,700 hydrants and over 161,000 service lines.

The general arrangement of the distribution system in Milwaukee is what is known as the "grid" system. This means that water mains are cross-connected with the mains laid in cross streets. At intervals of one-half mile, larger mains, usually from 12 to 16 inches in diameter, are laid; between these mains, pipes of six and eight inches are laid; thus forming a grid network.

Water mains in the Milwaukee system range in size from six to sixty inches in diameter. Gate valves are set at nearly every street intersection for the purpose of shutting off the water supply in case of emergency or repairs.

Water mains are generally laid on the north and east side of a street. In streets where the roadway is 50 feet or more in width, the mains are laid on both sides of the street. Mains are laid at a depth of 6½ feet to the centerline, which protects them from frost.

Connected to the distribution mains are service pipes for supplying water to the premises for domestic, commercial, industrial, and municipal purposes, including fire protection. The services range in size from five-eights inch to sixteen inches in diameter.

Each water service line is controlled by a gate valve (curb stop) encased in a cast iron curb box, the removable cover of which is level with the grade of the sidewalk or street. These valves afford the utility control of the service for the provision or termination of the premises water supply for any purpose.

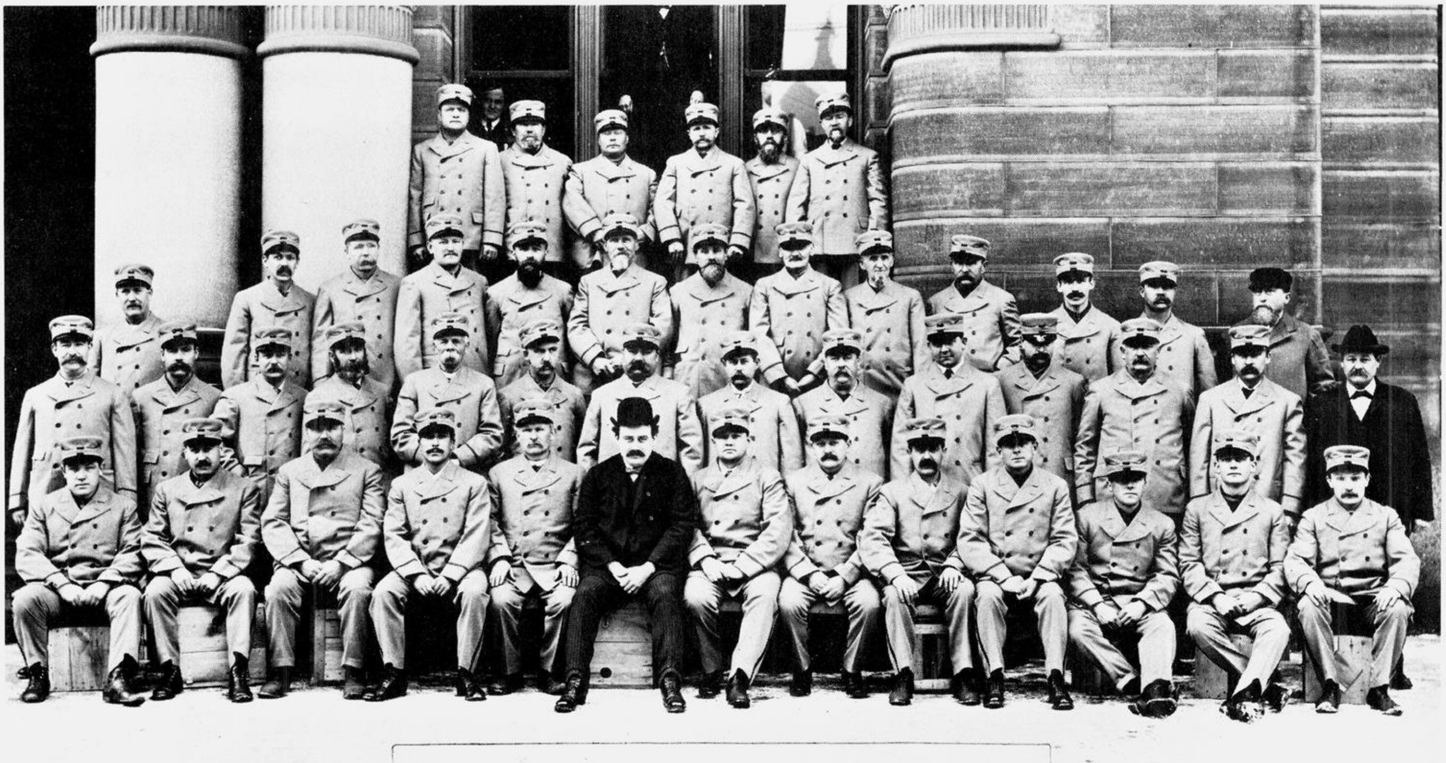
METERS — EARLY YEARS

At first, customers paid a flat rate for water, based on the size of their service pipe. By 1881, the deficiencies of this system were becoming apparent, and a study was made which indicated that 52% of water pumped into the distribution system was wasted by consumers. Moreover, under the law, a customer could not be required to install a meter unless it could be proven that he was grossly wasteful of water. A campaign was therefore launched to encourage customers to voluntarily install meters, offering lower rates for low consumption. Inspections were made of unmetered accounts and those wasting water were forced to install meters. In 1913, the Railroad Commission of Wisconsin (succeeded by the Public Service Commission) issued an order requiring all remaining unmetered accounts to install meters.

METERS — PRESENT

All of the more than 160,000 water meters in the Milwaukee system are owned by the Milwaukee Water Works. In order to achieve optimum performance, a variety of meter styles and sizes are used to accommodate the wide range of applications found in a system of this size. Among the more commonly used styles are the positive displacement, compound and turbine meters. Sizes ⅝" through 2" are generally positive displacement meters and are used in establishments whose water consumption is not of great volume.

In 1972, the Milwaukee Water Works began using magnetic flow meters for wholesale accounts. For customers whose water demands may have flow rates that vary greatly, the compound meter is used. This is generally the combination of the positive displacement and turbine meter. The operation of each meter section is governed by the opening or closing of a weighted valve occasioned by the change in flow on the meter outlet line as a result of water used.



EMPLOYEES OF THE METERS & DISTRIBUTION DIVISION, 1903

Turbine and magnetic flow meters are used where the range of flow is small, and the meters will measure accurately.

When meters function properly, both customer and Utility benefit. It is for this reason that all water meters in the Milwaukee system receive a periodic test and are then serviced, repaired or replaced.

SUBURBAN WATER SERVICE

The Milwaukee Water Works was serving ten suburban communities at the end of 1976. Five of these communities are served on a "wholesale" basis. In addition to the remaining five suburbs that receive water on a retail basis, there are a small number of individuals in other suburban communities who are receiving Milwaukee water. These limited number of customers are receiving Milwaukee water by special arrangement, usually because they are more conveniently located to receive Milwaukee water than the water supplied by the community in which they reside.

Wholesale service to a community means that the suburb buys water from the Milwaukee utility at a contracted rate and resells it to its suburban customers.

Retail service provides pure Milwaukee water directly to the consumer. All the essential services such as production of, distributing, and accounting for water are provided at low retail water rates.

WATER RATES

The charges made for water are based on the quantity used as indicated by the water meter. Meters are read and bills are rendered on a quarter-year basis.

Water rates are made up of two items: first, a service charge for the different size meters, which is actually a "demand charge" to meet the cost of the utility plant necessary to provide quantities of pure water to the tap at adequate pressure any time it is needed; second, a commodity charge for the water furnished to cover the cost of purifying and pumping the water, distribution, meter reading, accounting, billing, maintenance of utility plant, payment of taxes, bond principal and interest payments and all the other necessary costs incurred by an efficient and successful water utility.

Water itself is free and, in this part of the country, quite plentiful. However, the cost of making the water safe to drink, and of delivering the pure product to a convenient tap in the home is expensive. Yet water is cheap at any price; as Benjamin Franklin once said, "When the well's dry, they know the worth of water."

FUTURE CONSIDERATIONS

At the beginning of this decade, one could read articles predicting dramatic, almost revolutionary changes in water systems by the close of the century. Now it seems that many factors, including inflation, are acting to slow down the timetable for such improvements, and for the next few decades, water management may have to be satisfied with refinements in present techniques. These refinements will nonetheless be very important to water utilities and ratepayers alike, because they will reduce the rise in operating costs, thereby helping to keep down the rise in water rates. Two examples of such refinements are granular media filtration and use of coagulant aids.

Granular media filtration involves placing a layer of anthracite over the fine sand layer at the top of the filter. The coarse anthracite grains catch much of the sediment which tends to clog the fine sand layer. The result is a faster filtration rate and longer filter runs between backwashings.

The use of coagulant aids involves feeding a polymer coagulant aid in addition to the alum coagulant. The purpose of the coagulant aid is to form a more filterable floc and also to reduce the amount of the alum feed, thereby reducing the total sludge.

The Milwaukee Water Works is watching these developments with interest, and is experimenting with both of them. It has been found that granular filter media can increase the filtering capacity of the plants, but presently there is no imperative need to do this. The polymer coagulant aids may speed up the settling of coagulated material, but the main reason for using this aid will be to reduce the volume of sludge being generated. The Milwaukee Water Works has taken advantage of other refinements in the areas of remote control of pumping and treatment, improved equipment and improved techniques for repairing broken water mains. As a result, Milwaukee Water Works has 140 fewer employees now than ten years ago.

One problem that all water utilities face is the uneven rate of water consumption. On an average day, the Milwaukee customers use 170 million gallons of water. On a hot summer day, this use may rise to a rate of over 400 million gallons per day (for a period of two to four hours). On a Sunday or holiday in winter, this use may drop to less than 100 million gallons in 24 hours. Therefore the water system must be designed to handle both the maximum rate and also the minimum day. A partial solution to this problem is to encourage customers who can do so (wholesale communities) to take water at a lower rate flow during peak hours than during non-peak hours. They would handle their peak hour by withdrawing from their storage. This is an important consideration for the future since several bordering communities may eventually decide to request water from the Milwaukee system. It will be an advantage, if it is practical, to add the consumption of several additional communities to our system without costly expansion of our facilities to take care of their short term peak usages.

For many water utilities in other areas, tomorrow means solving increasingly difficult problems of inadequate supply from wells and rivers. Brackish water may have to be treated and wastewater may have to be recycled. In Milwaukee, the Lake Michigan supply is almost without limit. Milwaukee can therefore expend its energies to improve its present system, making it more efficient to benefit both utility and ratepayer.

IS THERE A GROUND WATER SHORTAGE IN SOUTHEASTERN WISCONSIN?*

by Douglas S. Cherkauer, Assistant Professor of Geological Sciences, University of Wisconsin-Milwaukee and Vinton W. Bacon, Professor of Civil Engineering, University of Wisconsin-Milwaukee

The answer is "no".

Three clear conclusions can be drawn on the studies of this question:

First: Neither now nor in the distant future need the communities dependent on ground water run short.

Second: Costs of development of additional ground water supplies will be considerably less than recent engineering estimates of developing and transporting Lake Michigan water either through a new, separate system or through the City of Milwaukee system.

Third: Ground water supplies can be adequate and dependable provided certain facilities are embodied in the long-range planning, designs, and financing.

The areas and municipalities under study are those north and west of the City of Milwaukee shown in Map 1.

GROUND WATER DRAWDOWNS

There are a number of reasons why the fear of running out of well water has developed and why utilizing Lake Michigan is held as the only solution. It is true that individual household and private wells have "gone dry". This is a great inconvenience and causes considerable expense to the owner, whatever the solution. But usually this problem occurs in relatively shallow wells, and except for clusters of 10 to 20 wells in very localized areas, the number has been small. New industrial and commercial developments, subdivisions, and condominiums, locating adjacent to residential areas, have caused increased drawdown of the ground water, aggravating water levels in private wells. There are cases also where dewatering for construction of deep sewers has caused wells to go dry. Deepening of the well is the usual solution.

Where municipal wells have suffered reduction in capacity due to lowering of the water table, the solution has been to lower the pump or to deepen the well, or both. Also new wells are drilled as the distribution system is extended or as new real estate or commercial developments occur. These new well systems often supplement the older systems through interlocking the water mains.

It is very true that heavy pumping of wells in the deep sandstone aquifer (defined later) has reduced water levels by about 350 feet in Milwaukee and Waukesha, and about 875 feet in the Chicago region (Young 1976, Southeastern Wisconsin Regional Planning Commission [SEWRPC], 1976). Using a digital computer model of the sandstone aquifer in Southeastern Wisconsin and estimated pumpage to year 2,000, the Southeastern Wisconsin Regional Planning Commission predicted drawdowns from 1974 through 1980, 1990, and 2000. Maximum predicted drawdown is centered on New Berlin and is more than 300 feet from 1974 through 1990 and 450 feet from 1974 through 2000. These predictions should cause concern, but not because they indicate a water shortage.

An engineering report on sources of water supply (Consoer, Townsend, and Associates, [CTA] 1976) for Mequon, Brookfield, Bayside, River Hills, Thiensville, Menomonee Falls, and Germantown sets forth three alternate engineering plans for water sources:

Plan No. 1 - Further development of community well water supplies

Plan No. 2 - Purchase of Lake Michigan water from the City of Milwaukee

Plan No. 3 - Development of jointly-owned independent water supply from Lake Michigan.

Although recognizing ". . . . the consensus of opinion that there will be sufficient ground water available in the deep sandstone strata to meet the needs of the seven municipalities at least until the year 1990," nevertheless, the report recommended that Lake Michigan water (Plans 2 and 3) should be selected rather than continue or augment the use of ground water from well systems. Commenting on the well water supply system (Plan 1) the report states:

> "Studies made in preparing this report [CTA] indicate that although the continued use of a well supply (or adoption of a well supply in the case of some communities) may appear to be the least expensive source of water supply, it does not provide long term solutions to the problems of unsatisfactory quantity and quality associated with a well water supply."

Thus with such a positive recommendation for Lake Michigan water and such a negative position on wells and ground water, it is understandable why some of the municipal officials would cast doubts on well water supplies for the future. That this worry is not justified will be discussed subsequently.

Present water rationing will also be advanced as demonstrating that ground water supplies are "going dry". It is true that overdraft on the underground supplies is lowering the water levels and that the drought is preventing adequate recharge. The rationing is a wise precautionary measure to prevent the situation from getting worse while municipalities are planning for new or deepened wells. As will be demonstrated now, the water is available in the underground basins for the economic taking.

GROUND WATER AVAILABILITY

Aquifer Systems

The ground water systems of southeastern Wisconsin have been thoroughly described in numerous publications of the Southeastern Wisconsin Regional Planning Commission (SEWRPC 1969, 1970, 1976; Young, 1976), and the U.S. Geological Survey (Foley, et. al, 1953; Hutchinson, 1970). For the purposes of this paper, the ground water resources can be divided into three aquifer systems:

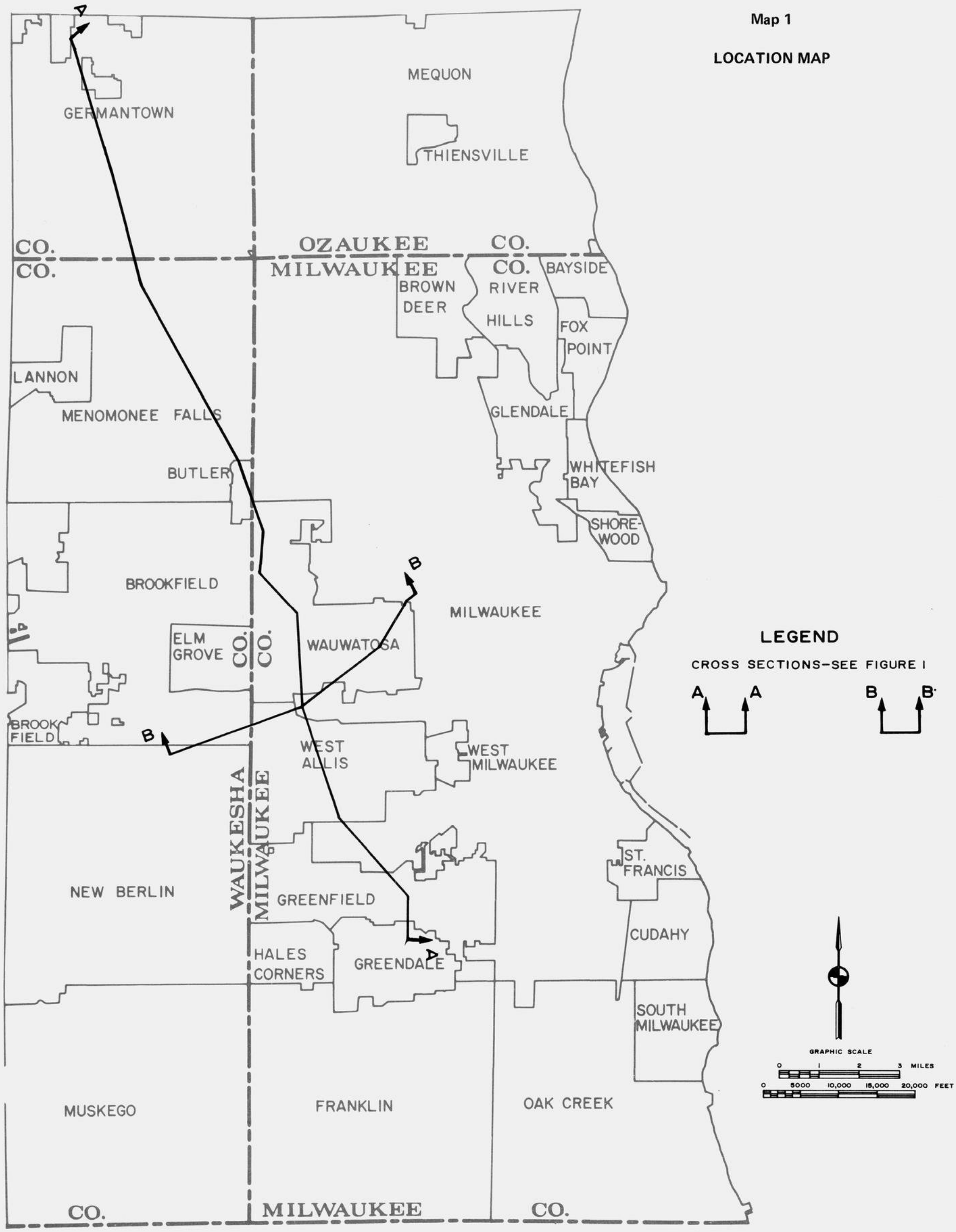
1) Sand and gravel deposits in the glacial drift,

2) Shallow dolomite units of Silurian age, and

**The authors acknowledge the support provided by the Wisconsin Water Conditioning Association for the conduct of this study.*

Map 1

LOCATION MAP



Source: University of Wisconsin-Milwaukee, U. S. Geological Survey, and SEWRPC.

3) The deep sandstone aquifer, consisting of a series of sandstones, dolomites and shales of Cambrian - Ordovician age which are hydraulically a single unit.

The complete geologic column is given in Table 1. The sand and gravel aquifer is extremely variable in extent and properties. In some places it is capable of supplying high-capacity wells (Gonthier, 1975). However, because data on it in the area of interest are limited, it will not be considered in the overall assessment of available ground water. In those areas where it is productive, it would provide an additional source.

Shallow Dolomite Aquifer

The shallower of the two principal aquifers is often hydraulically connected to the sand and gravel aquifer. The surface of the dolomite is a pre-glacial erosion surface, resulting in a variable thickness for the unit (Table 2 and Figure 1). Mean thicknesses have been obtained from published maps (SEWRPC, 1970, 1976; Gonthier, 1975). The unit is a typical fractured carbonate aquifer with water stored in and flowing through fractures in an otherwise dense rock. Consequently, porosity, storage coefficient and permeability are all quite variable. Without detailed local knowledge of the fracture pattern in the dolomite,

Table 1

GENERALIZED STRATIGRAPHY AND AQUIFER PROPERTIES IN SOUTHEASTERN WISCONSIN

System	Geologic Unit	Dominant Lithology	Saturated Thickness (ft.)	Hydrologic Unit	Areal Extent	Yield
Quaternary	Holocene and Pleistocene deposits	Unsorted mixture of clay, silt, sand, gravel, and boulders	0-300	Sand and gravel aquifer	Entire report area, but aquifer is localized as outwash, alluvium, and buried deposits	Small to large yields, not extensively developed for large yields
Devonian	Undifferentiated	Shale and dolomite	0-155	Niagara aquifer	Near Lake Michigan north from Milwaukee	Some small yields where creviced
Silurian	Undifferentiated	Dolomite	0-560		Eastern two-thirds of report area	Small to large yields depending upon number and size of solution channels and crevices
Ordovician	Maquoketa Shale	Shale	0-270	Confining bed	Eastern three-fourths of report area	Generally cased out in deep wells; very small yields locally from minor amounts of interbedded dolomite
	Galena Dolomite, Decorah and Platteville Formations		0-340	Leaky confining bed in recharge area	Entire report area except southeastern corner of Jefferson County	Small to moderate yields from crevices; developed as sole unit only where Maquoketa Shale is absent
	St. Peter Sandstone	Sandstone	0-260	Sandstone aquifer	Entire report area except Hartford area and southeastern corner of Jefferson County	Moderate yields; generally not used as sole unit; tends to cave
	Prairie du Chien Group	Dolomite	0-150		Missing or very thin in much of report area	Small yields
Cambrian	Trempealeau Formation	Dolomite	0-10(?)		Entire report area except Hartford area	Small yields generally but some large yields in areas of well developed solution channels
	Franconia and Galesville Sandstones	Sandstone	0-225		Entire report area except Hartford and part of Milwaukee area	Moderate to large yields especially from lower part
	Eau Claire Sandstone	Sandstone, siltsone, and shale	0-160		Entire report area except Hartford area	Small yields, decreasing to south
	Mount Simon Sandstone	Sandstone	0-1.500		Entire report area except Hartford area	Moderate to large yields; not fully penetrated east and south of Waukesha
Precambrian	Undifferentiated	Crystalline rock	Unknown	Confining bed	Entire report area	Very small yields locally from crevices

Source: U. S. Geological Survey

Table 2

AQUIFER PROPERTIES

Community	Sandstone Aquifer				Dolomite Aquifer		
	Mean Thickness (feet)	Transmissivity (gpd/ft)	1976 total Storage (gal)	1976 Permissible Mining Yield (gal)	Mean Thickness (feet)	1976 Total Storage (gal)	1976 Permissible Mining Yield (gal)
Bayside	700[4]	25000[2]	1.8×10^{10}	0	450[6]	1.2×10^{10}	4.7×10^{9}
River Hills	700[4]	25000[2]	4.0×10^{10}	0	400[6]	2.3×10^{10}	9.2×10^{9}
Mequon	600[4]	20000[2]	2.9×10^{11}	0	300[3,6]	1.4×10^{11}	5.8×10^{10}
Thiensville	600[4]	20000[2]	6.3×10^{9}	0	400	4.2×10^{9}	1.7×10^{9}
Germantown (Village & Town)	900[1]	13000[2]	3.4×10^{11}	1.0×10^{11}	300[3]	1.1×10^{11}	4.4×10^{10}
Menomonee Falls	1000[1]	18000[2]	3.7×10^{11}	1.1×10^{11}	200[1]	7.5×10^{10}	3.0×10^{10}
Brookfield (City & Town)	1500[3,8]	23000[2]	5.6×10^{11}	1.5×10^{11}	200[1]	6.7×10^{10}	2.2×10^{10}
Elm Grove	1500[3,8]	25000[2]	5.1×10^{10}	1.4×10^{10}	200[1]	6.8×10^{9}	2.7×10^{9}
New Berlin	1700[3,8]	25000[2]	6.5×10^{11}	1.5×10^{11}	200[1]	7.7×10^{10}	3.1×10^{10}

Superscripts in parentheses refer to the following sources of information:

(1) Wisconsin Geological and Natural History Survey Information Circular 29
(2) SEWRPC Technical Report No. 16
(3) SEWRPC Planning Report No. 26
(4) SEWRPC Planning Report No. 13
(6) Lawton, Dennis R., unpublished Master's Thesis, UWM
(8) Young, Harley, U. S. Geological Survey, personal communication

Storage is the product of community area, aquifer thickness and porosity. For both aquifers a porosity of 0.05 was assumed.[2,3] Usable storage is that portion of the water which can be removed without damage to the aquifer. In the dolomite it is assumed to be the upper 40%.[1] In the sandstone it is the percentage above the Franconia Fm. or 30%[1] whichever is smaller. Usable storage in the sandstone in the Ozaukee County communities is negligible because of poor quality.

it is impossible to accurately predict the yield in undrilled parts of the aquifer. In fact, permeability is so variable that Schicht, et al (1976) argue it is possible to put in a dry well anywhere in the aquifer, even in otherwise productive areas. On the other hand, there are some recognizable patterns. Well yields and specific capacities are generally lowest in bedrock valleys, or valleys on the top of the dolomite, and highest on bedrock ridges (Walton, 1970; Lawton, 1977).

A porosity and specific yield of 5% have been assumed for the entire unit (SEWRPC, 1976a). Undoubtedly there is substantial variation about this mean value, but it is believed to be a conservative estimate. Actual porosities are probably greater in the highest parts of the aquifer where solution and preglacial unloading fracturing predominate.

Generally the potentiometric surface of the dolomite aquifer is a water table and closely parallels the land surface (SEWRPC, 1970, 1976; Foley, et. al, 1953; Hutchinson, 1970). Recharge is provided by precipitation which infiltrates through the glacial drift. Consequently, water levels show major seasonal fluctuations. On the other hand, over long periods of time, water levels in undeveloped parts of the aquifer have remained relatively constant (Devaul, 1967; Erickson, 1972; Roensch, 1977). This stability indicates a natural balance between recharge and discharge.

In areas where discharge is artificially increased by pumping, the natural balance is lost and water levels decline. Water levels in the southeastern quadrant of Mequon, where pumping is concentrated, have declined at an average rate of 2.4 feet/year for the 5-7 years that they have been monitored (Roensch, 1977). Similar rates of decline have been experienced elsewhere in the developed portions of the study area.

The Mequon data provide us with an opportunity to calculate an average rate of recharge for a large area. According to the conservation of mass principle, the difference between inflow and discharge from a ground water aquifer causes changes in the quantity of water stored in that aquifer. If discharge (pumpage), change of storage and all other forms of inflow are measured, then the recharge can be calculated by:

$$\text{Recharge} = \text{Pumpage} - \text{Other Inflow} - \frac{\Delta\,\text{Storage}}{\text{time}} \quad (1)$$

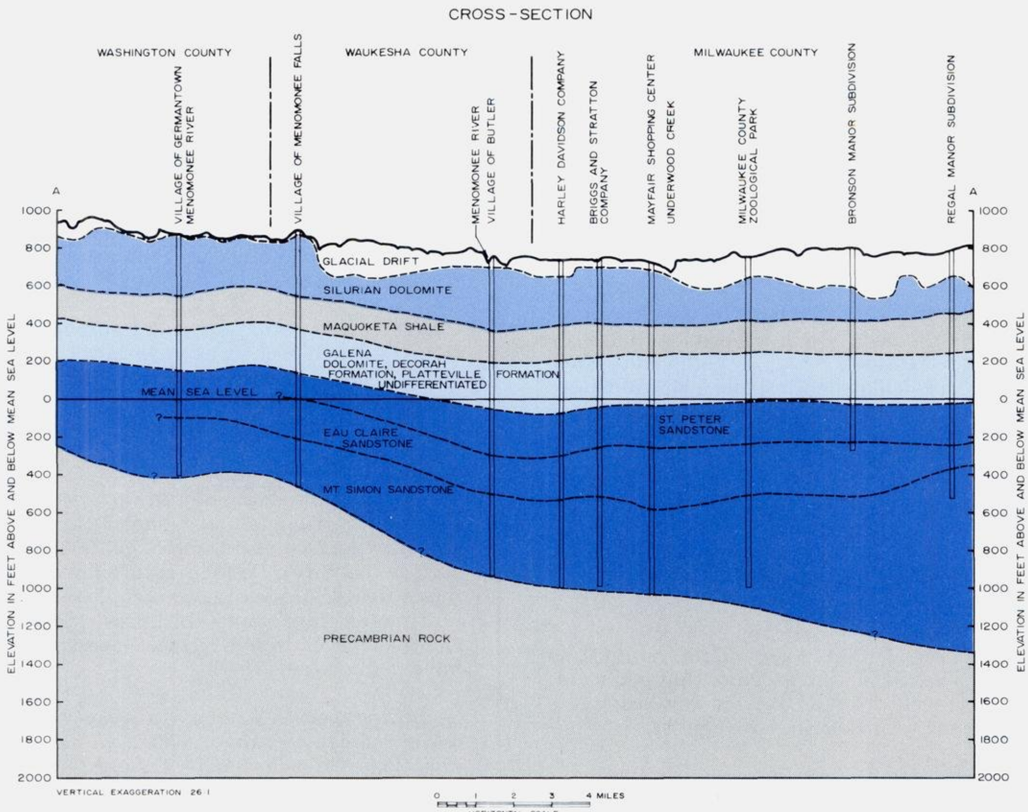
Assuming that the mean measured rate of decline (2.4 ft./yr) is valid throughout the entire southeastern quadrant of Mequon (10.5 mi.^{2}), the annual loss in storage is:

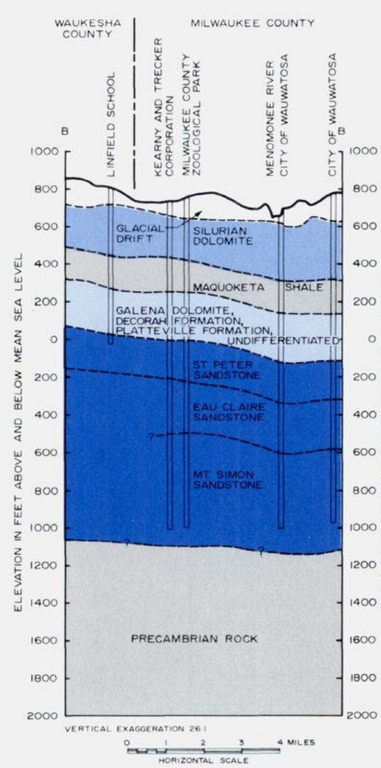
$$\begin{aligned}\Delta\,\text{Storage} &= \text{(annual change in water table)} \times \text{(area of the quadrant)} \times \text{(specific yield of aquifer)} \quad (2)\\ &= -2.4\ \text{ft.} \times 10.5\ \text{mi}^2 \times 0.05\\ &= -3.51 \times 10^7 \text{ft.}^3 = -2.63 \times 10^8\ \text{gallons, and}\end{aligned}$$

$$\frac{\Delta\,\text{Storage}}{\text{time}} = \frac{-2.63 \times 10\ \text{gallons}}{365\ \text{days}} = -0.72\ \text{mgd}$$

Figure 1

STRATIGRAPHIC CROSS SECTIONS THROUGH THE MENOMONEE RIVER WATERSHED SHOWING THE GENERAL AVAILABILITY OF GROUND WATER FROM THE BEDROCK UNITS





LEGEND

GROUNDWATER AVAILABILITY (YIELD IN GALLONS PER MINUTE)

- OVER 300 GOOD AQUIFER
- 50 - 300 MODERATE TO GOOD AQUIFER
- 5 - 49 POOR TO FAIR AQUIFER
- NOT AN AQUIFER LITTLE OR NO WATER

Source: U. S. Geological Survey.

Mequon data for the lowest water levels on record for the period 1971-1975 were used to construct a potentiometric surface map for the southeastern quadrant. A major cone of depression exists under the quadrant, inducing flow into the area from the aquifer to the west and inducing recharge from Lake Michigan. These inflows to the quadrant were calculated using flow nets and Darcy's law. Inflow from the west:

$$I_n = \text{Permeability (K)} \times \text{Hydraulic gradient (I)} \times \text{Width of aquifer section through which flow occurs (w)} \times \text{Aquifer thickness (b)} \qquad (3)$$

$$I_n = 19 \frac{\text{gpd}}{\text{ft}^2} \times 0.0075 \times 4 \text{ mi} \times 200 \text{ ft.}$$
$$= 0.60 \text{ mgd.}$$

Permeability was estimated at 19 gpd/ft.^{2}, which is an average value for low and high capacity wells in Waukesha County (Gonthier, 1975). It is felt this is a relatively high value, which in turn produces a high calculated inflow and a low calculated recharge. This choice will again produce a conservative estimate of ground water availability. Mean aquifer thickness (Table 2) was used in the calculation.

Induced recharge from the Lake was calculated as:

$$I_\ell = KIwb$$
$$= 19 \text{ gpd/ft.}^2 \times .0013 \times 2 \text{ mi} \times 200 \text{ ft.}$$
$$= 0.5 \text{ mgd.}$$

This value is definitely a maximum, again minimizing calculated recharge. The calculation assumes that permeable bedrock is in direct contact with the Lake and that recharge is induced through the entire thickness of the aquifer.

Incorporating these calculated values into equation (l) with the estimated pumpage for the quadrant of 1.14 mgd (Roensch, 1977) allows calculation of recharge:

$$\text{Recharge} = 1.14 \text{ mgd} - 0.60 \text{ mgd} - 0.05 \text{ mgd} - (-0.72 \text{ mgd})$$
$$= 1.2 \text{ mgd for a 10.5 square mile area}$$
$$= 0.115 \text{ mgd/mi}^2.$$

Chances are that Mequon's recharge value could be extrapolated throughout the study area because similar or more permeable soils exist in the other communities. Schicht, et al. (1976) actually found higher recharge rates throughout most of northeastern Illinois, a geologically similar area. However, because we are unable to evaluate the quantity of recharge induced from the Milwaukee River, we will conservatively assume an average regional recharge rate to the dolomite of 90000 gpd/ mi^2. It is also important to note that the entire quadrant considered has sanitary sewer service. No septic system recharge occurs in Mequon, but in communities where it does, total recharge would be higher.

The quantity of water stored in the dolomite is immense (Table 2). Total storage has been calculated as the product of aquifer volume in a community (community area x mean thickness) and specific yield. It is then arbitrarily assumed that the uppermost 40% of this volume of water can be withdrawn, or mined, from the aquifer without change to the aquifer. The value of 40% is consistent with USGS practice in SE Wisconsin (Gonthier, 1975). The usable portion of the storage is called the permissible mining yield (Walton, 1970). The practical sustained yield for the aquifer is simply the rate at which it is recharged. Withdrawal at this rate will be in balance with recharge and will not reduce storage.

Water quality in the dolomite aquifer is generally good except for high hardness. In the Menomonee River Watershed, incorporating parts, or all, of the western study communities, SEWRPC found that "water from the dolomite aquifer contains high iron and manganese concentrations and acceptable levels of [sulfate, chloride, fluoride and nitrate)]" (SEWRPC, 1976, p. 30). There are instances, however, where sulfate exceeds USPHS standards (Young, 1977). Hardness values, which range from 70 to over 1000 mg/1 of $CaCO_3$ (SEWRPC, 1976; Lawton, 1977; Holt and Skinner, 1973), do necessitate treatment.

Little information is available on the bacterial or viral quality of the dolomite. However, because the aquifer is in hydraulic contact with the surface and because flow can be very rapid through fractured rock, the dolomite aquifer is particularly susceptible to surface contamination. Care must be taken to prevent contamination if full utilization of the aquifer's resources is desired.

Currently in the study area, almost 13 mgd of water is pumped from the dolomite on an average day (Table 3). Most is pumped from private domestic wells. Only Germantown, Menomonee Falls, and Brookfield use the dolomite aquifer for municipal supplies, pumping approximately 1.6 mgd.

Deep Sandstone Aquifer

The second primary aquifer in the area consists of a series of sandstones, dolomites and shales (Figure 1). Its surface is generally located at a depth of 700-900 feet below the ground surface (SEWRPC, 1976). Because few wells have penetrated the entire thickness of the aquifer, there is disagreement on the anticipated maximum thickness (SEWRPC, 1972, 1976; Gonthier, 1975). In this report, conservative mean thicknesses have been chosen (Table 2).

Aquifer properties for the sandstone aquifer have been well documented by Young (1976). Calibration and testing of a digital model for the aquifer have shown that the estimates of transmissivity made (Young, 1976, Map 11) and incorporated into Table 2 are reasonable. A constant specific yield of 0.05, which has been used for the dewatered part of the aquifer in the SEWRPC model and in models for northeastern Illinois (Prichett and Lonnquist, 1971), was assumed here.

The potentiometric surface for the sandstone aquifer has been declining rapidly for many years (Young, 1976; Schicht, et. al., 1976; Green and Hutchinson, 1965). The decline is largely because discharge from industrial and municipal pumping in the Milwaukee-Waukesha and Chicago areas has greatly exceeded recharge. Natural recharge occurs to the west of the study area where the aquifer outcrops or is hydraulically connected to the ground surface. This recharge flows into the study area through the aquifer from the west.

In the study area, the aquifer is separated from the surface by the Maquoketa Shale, a leaky aquitard. Because heads in the sandstone have been lowered to levels below those in the dolomite by the heavy pumping of the former, leakage is induced through the Maquoketa from the dolomite to the sandstone. Rates of leakage for each community have been calculated using values for the shale's vertical transmissibility and thickness from Young (1976) and the difference in average heads in each aquifer. The quantities are small, ranging in 1976 from 790 gpd for the Village of Thiensville to 53000 gpd for the City of New Berlin. They increase slightly for 1990. Thus the major source of replenishment of water pumped from the sandstone in the study area must come via flow from the west. The Illinois State Water Survey estimates recharge to the sandstone in outcrop areas of about 42000 gpd/mi^2 (Schicht, et. al., 1976), and Young (1977) used values of 50,000 to 150,000 gpd/mi^2, but much of this recharge will be intercepted by the City of Waukesha prior to reaching the study area. It has been necessary to use flow nets to determine the influx.

Table 3

WATER DEMANDS

Community	Percent Served by Utility	1976 Average Day Demands			1990 Average Day Demands			1990 Maximum[5] Day - Total (mgd)
		Sandstone[1] (mgd)	Dolomite[3] (mgd)	Total[2] (mgd)	Sandstone[4] (mgd)	Dolomite[3] (mgd)	Total[5] (mgd)	
Bayside	0	minor	0.42	0.42	0	0.55	0.55	1.1
River Hills	0	0	0.14	0.14	0	0.24	0.24	0.60
Mequon	0	0	1.39	1.39	0	3.3	3.3	6.5
Thiensville	0	0	0.35	0.35	0	0.42	0.42	0.84
Germantown (village & town)	50	0.42	0.98	1.40	1.9	1.4	3.3	8.3
Menomonee Falls	50	0.90	2.80	3.70	4.0	4.0	8.0	16.0
Brookfield (city & town)	20	0.40	3.50	3.90	5.0	7.2	6.2	13.0
Elm Grove	0	0	0.69	0.69	0	1.0	1.0	2.0
New Berlin	15	1.10	2.70	3.80	10.0	3.6	13.6	27.0

1. *Estimated as a percentage of total utility pumpage based on proportion of utility wells into sandstone.*
2. *Obtained by multiplying 1976 population by estimated capita consumption. Brookfield estimated as 100 gpdc, Germantown as 150, Menomonee Falls as 110, New Berlin as 120, all others as 90. Each estimate, except Elm Grove and New Berlin, is 10 gpdc higher than that used by Counser, Townsend and Associates.*
3. *Determined as difference between total and sandstone demands.*
4. *SEWRPC Technical Report No. 16*
5. *Consoer, Townsend and Associates.*

Even greater quantities of water are stored in the sandstone than in the dolomite (Table 2). The same method was used to determine total storage. Usable storage, the permissible mining yield, was calculated as the uppermost 30% of total storage or the quantity of water stored in and above the Franconia Formation, whichever is less. Gonthier (1975) used the former quantity as an arbitrary limit on pumping. The Illinois Water Survey, in assessing the ground water of northeastern Illinois, treated the permissible mining yield as the quantity stored above the Ironton Formation, a unit below the Franconia, but generally absent in the study area. By choosing the minimum, we are again specifically being conservative in our estimates of available water (Table 2). Practical sustained yields (leakage plus flow from west) in the sandstone are relatively small, so mining of the aquifer's water may prove necessary.

Water quality in the sandstone aquifer is quite variable. In the western portion of the study area, SEWRPC (1976) has found the water to be very high in concentrations of sulfate, iron and manganese. It is quite hard (Gonthier, 1975). However, on the whole it is potable and generally used without treatment.

In the northeastern part of the study area, by contrast, the water in the sandstone is generally unpotable (Ryling, 1961). A combination dolomite-sandstone well drilled in 1964 for the Lac du Cours subdivision in southeastern Mequon pumped water containing 1130 ppm sulfate, 1258 ppm total hardness, and 1930 ppm total solids (Holt and Skinner, 1973). The Blossom Heath multiple aquifer well in Bayside pumped water containing 6690 ppm total solids, 2250 ppm sulfate, 1890 ppm chloride and 1720 ppm hardness (Holt and Skinner, 1973). Dolomite wells in this area do not produce such poor quality water, so it must come from the sandstone. Such concentrations would require desalinization before use. In this report, we simply consider the water in the sandstone beneath Bayside, River Hills, Mequon and Thiensville to be unusable. In parts of western and northern Mequon, this assumption may prove unwarranted, but it is again conservative.

Currently, only municipal wells in New Berlin, Brookfield, Menomonee Falls and Germantown pump water from the sandstone in the study area. They pump a total of about 2.8 mgd on an average day (Table 3). Waukesha to the west and several industries in Milwaukee County to the east also used an estimated 13 mgd in 1972 (Young, 1976).

Ground Water Budgets

For each of the communities studied, water budgets were developed for 1976 and anticipated 1990 conditions. Supplies and demands were balanced against one another to determine whether a community was operating at a water surplus or deficit. Each community was treated as a separate entity. That is, only recharge, discharge and ground water flow occurring through or within the boundaries of a community were considered. For the purposes of simplicity, it was assumed that heavy pumping in one study community could not induce flow from an adjacent community for replenishment. Physically this is an impossible assumption, but again it leads to conservative estimates of water availability. Only in small communities such as Thiensville and Elm Grove does this assumption pose problems which are discussed later.

Total demand within a community for ground water was estimated as the product of population and an expected per capita consumption. For 1976 budgets, populations were obtained from SEWRPC (Zimmer, 1977). Consumption rates were estimated at 10 gpdc greater than those used by Consoer, et. al. (1976). The latter report did not encompass Elm Grove and New Berlin, so it was assumed that these communities had consumption rates similar to Bayside and Menomonee Falls, respectively. Checks with the two communities (Giuliani, 1977; Harris, 1977) indicated that the total demands calculated were reasonable, but on the high side (Table 3). For 1990, the population and per capita consumption estimates of Consoer, et. al., (1976) were used.

Demand in 1976 was separated between the two aquifers by reviewing the number of wells in each aquifer in community water supply systems. An arbitrary assessment of the percentage of water contributed by each aquifer was then made for the three relevant communities. New Berlin's municipal pumpage of 1.1 mgd is supplied totally by sandstone wells (Harris, 1977). For Brookfield and Menomonee Falls, it was estimated that 50% of the municipal supply was from the sandstone, and the estimate was 60% for Germantown. All domestic wells were assumed to pump from the dolomite even though many may tap the sand and gravel aquifer.

For 1990 conditions, total demand was obtained using the Consoer, et. al., (1976) population and usage estimates. Anticipated sandstone demand was then obtained from Young (1976). The difference between these two demands was the anticipated dolomite usage.

For the dolomite aquifer, the following modification of equation (1) was then applied:

$$\text{Water Balance} = \text{Recharge} - \text{Demand} - \text{Leakage to Sandstone} \qquad (4)$$

Recharge and leakage were calculated in the manner discussed earlier. Maps from SEWRPC (1970, 1976), Young (1976), Lawton (1977) and Roensch (1977) were used to obtain the appropriate heads for calculating leakage.

Only surface recharge occurring within the boundaries of the community was considered. Induced recharge from lakes and rivers was not considered. Recharge minus leakage is considered the practical sustained yield (Tables 4 and 5).

For the sandstone aquifer, another form of equation (1) was used:

$$\text{Water Balance} = \text{Inflow from Outside Community} + \text{Leakage from Dolomite} - \text{Demand.}$$

Inflow was calculated using flow net analysis on potentiometric surface prepared by Young (1976). For 1990, the map is a computer model projection. Inflow plus leakage is the practical sustained yield (Tables 4 and 5).

Table 4

1976 GROUND WATER BUDGETS

Community	Dolomite Aquifer		Sandstone Aquifer		Total System			
	Practical(1) Sustained Yield (mgd)	Balance(2) for Average Day (mgd)	Practical(1) Sustained Yield (mgd)	Balance(2) for Average Day (mgd)	Practical(1) Sustained Yield (mgd)	Balance(2) for Average Day (mgd)	Permissible(3) Mining Yield (gal)	Years of(4) Supply Mining of 1976 Deficit (yr)
Bayside	0.23	0.19	0(5)	—	0.23	-0.19	4.7×10^9	70
River Hills	0.49	+0.35	0(5)	—	0.49	+0.35	9.2×10^9	—(6)
Mequon	4.0	+2.6	0.90(7)	+0.90	4.0/4.9(8)	+2.6/+3.7(8)	5.8×10^{10}	—(6)
Thiensville	0.09	-0.26	0(5)	—	0.09	-0.26	1.7×10^9	18
Germantown (village & town)	3.1	+2.1	2.0	+1.7	5.2	+3.8	1.4×10^{11}	—(6)
Menomonee Falls	3.15	+0.35	2.1	+1.15	5.25	+1.50	1.4×10^{11}	—(6)
Brookfield (city & town)	2.9	-0.6	2.5	+2.1	5.4	+1.5	1.7×10^{11}	—(6)
Elm Grove	0.29	-0.40	0(9)	0	0.29	-0.40	2.7×10^9	18
New Berlin	3.2	+0.5	2.1	+1.0	5.3	+1.5	1.8×10^{11}	—(6)

(1) For the dolomite, recharge (90,000 gpd/mi^2) minus leakage to sandstone; for sandstone, flow into community plus leakage from dolomite.
(2) Practical sustained yield minus pumpage; negative is deficit, positive is surplus.
(3) Quantity of water in storage which can be removed without damage to aquifer. For dolomite is uppermost 40% of 1976 storage; for sandstone is storage above the Franconia Sandstone or uppermost 30%, whichever is less.
(4) Permissible mining yield divided by annual deficit. Assumes optimum well field design.
(5) Water is saline and unusable.
(6) Communities have water surplus, therefore mining unnecessary.
(7) Water in sandstone under Mequon is saline, but that flowing into city from north is potable. Assumes installation of well field to intercept inflow.
(8) Upper numbers assume no sandstone water is used; lower assume that sandstone inflow from north is fully utilized.
(9) Sandstone inflow to Elm Grove assumed used by Brookfield.

The calculated 1976 water budgets appear in Table 4. Both aquifers are presented separately and then combined. In each case a conscious effort has been made to calculate a realistic, but conservative, water balance by determining minimum values for recharge and maximum values for demand.

Perusal of the total system balance column (Table 4) will reveal quite clearly that a water shortage does not currently exist. Of the 9 communities studied, only 3, Bayside, Thiensville and Elm Grove, are operating at a deficit. In other words, current water supplies are more than adequate to supply current demands perpetually in the other communities. The 3 deficit communities are also the smallest and most densely populated, but primarily the deficit is an artificial problem caused by the individual community budgeting system. Each community is undoubtedly inducing additional flow across its boundaries: Bayside from Lake Michigan; Thiensville from the Milwaukee River and Mequon, where a surplus occurs; and Elm Grove from Brookfield, with a surplus, and Wauwatosa, where ground water is no longer used domestically. In each case enough flow may be induced to balance current demands, but also in each case, the community is using more water than its own aquifer system can supply.

Inherent in the calculations is also the assumption that somehow all the available water can be used. Uniform pumping over an entire community is required, rather than concentrated pumping in a few locations. Furthermore, a community-wide surplus does not mean that water shortages can't occur in some parts of the community. Despite a sizable 1976 surplus of water, Mequon has had a number of wells run dry in 1977 (Roensch, 1977). All were located in the heavily pumped, southeastern quadrant, and all were relatively shallow. Concentrated pumping in that quadrant simply lowered the water table below those wells, even while other parts of the community had no water problems.

For communities operating at a deficit, it is also possible to tap the water stored in the aquifers. Removal of water from storage is referred to as mining. The permissible mining yield defined earlier has been calculated for each community (Table 4). Dividing it by the annual deficit provides the number of years for which the stored water could make up the deficit (Table 4).

The 1990 projected water budgets (Table 5) reveal that even with the increased demands anticipated, there will still not be an overall water shortage. Three communities would still

Table 5

PROJECTED 1990 GROUND WATER BUDGETS

Community	Dolomite Aquifer		Sandstone Aquifer		Total System			
	Practical(1) Sustained Yield (mgd)	Balance(2) for Average Day (mgd)	Practical(1) Sustained Yield (mgd)	Balance(2) for Average Day (mgd)	Practical(1) Sustained Yield (mgd)	Balance(2) for Average Day (mgd)	Permissible(3) Mining Yield (gal)	Years of(4) Supply Mining of 1976 Deficit (yr)
Bayside	0.23	-0.32	0(5)	—	0.23	-0.32	3.5×10^9	30
River Hills	0.49	+0.25	0(5)	—	0.49	+0.25	9.2×10^9	—(12)
Mequon	3.9	+0.6	0.80(6)	+0.80	3.9/4.7(7)	+0.6/+1/4(7)	5.4×10^{10}	-/-(12)
Thiensville	0.09	-0.33	0(5)	—	0.09	-0.33	0.2×10^9	2(8)
Germantown (village & town)	3.0	+2.1	2.8	+1.4	5.8	+3.5	1.4×10^{11}	—(12)
Menomonee Falls	3.1	-0.9	4.2(9)	+0.2	7.3	-0.7	1.4×10^{11}	400
Brookfield (city and town)	2.9	+1.7	3.2	-1.8	6.1	-0.1	1.6×10^{11}	2000
Elm Grove	0.29	-0.71	0(10)	0	0.29	-0.71	0(8)	0(8)
New Berlin	3.2	-0.4	6.3(11)	-3.6	9.5	-4.0	1.8×10^{11}	120

(1) For the dolomite, recharge (90,000 gpd/mi²) minus leakage to sandstone; for sandstone, flow into community plus leakage from dolomite.
(2) Practical sustained yield minus pumpage; negative is deficit, positive is surplus.
(3) Quantity of water in storage which can be removed without damage to aquifer. For both aquifers is 1976 PMY minus projected usage between 1976 and 1990.
(4) Permissible mining yield divided by annual deficit. Assumes optimum well field design.
(5) Water is saline and unusable.
(6) Potable water flowing to Mequon from north. Assumes well field to intercept inflow.
(7) Upper numbers assume no sandstone water is used; lower assume that sandstone inflow from north is fully utilized.
(8) These figures assume no induced recharge from rivers or induced flow across community boundaries.
(9) Includes 1.4 mgd surplus flowing south from Germantown.
(10) Sandstone inflow to Elm Grove assumed used by Brookfield.
(11) Adjusted for loss of 2.0 mgd in Muskego.
(12) These communities have surplus, therefore mining unnecessary.

operate at a surplus, not even needing to initiate mining. Three others would operate at small deficits, but planned mining of the available stored water would provide at least 100 years of consumption at the 1990 rate in each case. Only three, Bayside, Thiensville and Elm Grove, again, can anticipate water shortages. The same comments made earlier for 1976 still apply for these three communities, but Thiensville and Elm Grove will have to seriously face control of water usage or importation from surrounding communities.

The water balance figures for the total system can be somewhat misleading (Table 5). Although Brookfield, New Berlin and Menomonee Falls all have total deficits, these deficits are not uniformly distributed between aquifers. Brookfield, for example, actually has a major surplus in the dolomite and an equally large deficit in the sandstone. Unless water is transferred from the dolomite to the sandstone or more usage is made of the dolomite, Brookfield's water outlook will not be as positive as indicated in Table 5. Similar situations exist in the other two communities.

Poor quality water in the sandstone eliminates its usage in four communities (Tables 4 and 5). One of these, Mequon, may be able to take advantage of the inflow of potable water from the north. Even without that water, the City will have a surplus in 1990. However, the planned community-wide extraction of the water will be necessary to prevent expansion of current problems.

In short, the calculations presented demonstrate conclusively that the available ground water resources are adequate to provide for water needs in the study area well into the future. Localized problems may develop, but with planning no widespread shortages should occur. It is important to remember, too, that the calculations have specifically been held on the conservative side. Actual conditions may be better.

COSTS OF WELL WATER

The prior section has dealt with adequacy of supply. It might be helpful to decision makers to study a few aspects of well water costs. Present-day costs for the operation of a water supply system using wells accrue from the production and delivery of the water and maintenance of the system. Homeowners in the study area are faced with a ground water supply which is hard enough to necessitate softening, adding a treatment cost to the final, total cost. If communities continue to use well systems, anticipated population growth will require expansion of the well fields. Such expansion will add two more costs to the total figure: one for pumping water from greater depths as water levels decline, and a second for building new wells to supply the increasing demand. All these costs will be calculated for an assumed family of four using 80 gallons per day per capita (gpdc), with a water hardness of 300 ppm (17.5 grains per gallon). Quarterly, the amount of water used in this case is 28,800 gallons; monthly, 9,600 gallons. Where possible the costs will be expressed in cents per 1,000 gallons (¢/1,000 gal.).

Typical Single-Family Water Costs

In Table 6 following, typical water costs (¢/1,000 gal.) are shown for five water utilities in central and eastern Waukesha County. Costs range from a low of 63¢/1,000 gal. to a high of 83¢. Seventy cents per 1,000 gal. appears to be a good representative figure. For basis of future comparisons, it should be kept in mind that these costs include distribution systems.

Monthly softening costs are based on three items, assuming a 10-year (120 month) life for the softener:

1. cost of softener installed \$440, per month $\frac{440}{120}$ \$3.66
   (assuming straight-line depreciation, no interest)
2. Salt 65 lb. per month at 3.4¢ per lb. 2.18
3. Maintenance, \$84 over 120 months 0.70

TOTAL MONTHLY SOFTENING COST \$6.54

Unit Cost = $\frac{6.54}{9.6\text{M gal.}}$ = \$0.68/1,000 gal. = 68¢/1,000 gal.

Table 6

TYPICAL WATER COSTS FOR WATER UTILITIES IN CENTRAL AND EASTERN WAUKESHA COUNTY, WISCONSIN

1	2	3	4	5	6	7	8	9
	Minimum Charge		Next Charges					
Community	First Block in Gallons	\$ for First Block	Next Blocks in Gallons	¢/1,000 Gallons	\$ for Next Blocks	Charges for Min. & Next (Cols. 3+6) \$	Total Charges \$	Total Charges ¢/1,000 Gallons
A	10,000	9.00	18,800	61	11.46	20.46	20.46	71
B	6,000	10.00	14,000 8,800	50 40	7.00 3.52	20.52	20.52	71
C	8,000	8.25	20,800	48	10.00	18.25	18.25	63
D	8,000	8.00	20,800	50	10.40	18.40	18.40	64
E	4,500	5.85	24,300	65	15.80	21.65	24.00(1)	83

(1) Community applies a multiplier of 1.109 to column 7 to produce column 8.

Summary of average costs for the present systems:

Total charges for water, cents per 1,000 gal. (aver.)	$ .70
Softening costs, cents per 1,000 gal.	.68
Total, average, cost of delivered, softened ground water to the customer in the 5 utilities	$1.38

CTA summarized the capital and unit costs for their three alternative plans based on year 1976 as follows:

Plan	Water Source	Capital Costs *	Costs in Cents per 1,000 gallons
1	Well water supplies	$33,500,000	82
2	Lake Michigan through Milwaukee	20,400,000	80
3	Lake Michigan, independent supply	82,000,000	170

*These capital costs do not include the distribution system.

In the above table, the well water supply at 82¢/1,000 gallons compares favorably with the average of 70¢ for the five utilities in Waukesha County. The total average cost to the customer, including softening, of $1.38 per 1,000 gallons is considerably below the $1.70 estimated in the CTA report for an independent supply from Lake Michigan. The $1.70 does not include the distribution system which would further increase the cost disparity.

In northern Illinois (Schicht, et. al., 1976), the cost of raw and treated ground water produced in quantities sufficient, in most cases, to meet the projected ground water demand to 2000 was estimated for the first of their ground water mining schemes. Costs were estimated for 35 townships with demands greater than 1.0 mgd. For the year 2000, costs for treated ground water ranged from 34 to 50.1¢/1,000 gallons (in 1974 dollars). Thus Illinois is estimating treated ground water costs considerably below those in Table 6, indicating that the figures are very much on the safe, or high, side.

Cost Due To A Declining Sandstone Potentiometric Surface

Understandably there are concerns over increased power costs in the face of anticipated declines in the level of the water in the sandstone aquifer. The additional costs due to various projected declines in the potentiometric surface at year 2000 have been calculated using an electrical energy cost of 2.75 cents per kilowatt-hour (kwh) for both energy and demand charges, and a wire-to-water efficiency of 70% (Table 7).

Cost of New Wells

There also seems to be a fear of the costs of new wells, particularly in the deep sandstone. Accordingly, a survey was made of recent well construction, as reported in Table 8 (Ruekert & Mielke, 1977). For the deep sandstone wells, the construction costs varied from a low of $53,500 to a high of $145,600. Generally, construction costs include well, pump, electric drive, transformer, pressure tanks, pump house, piping, and auxiliary equipment to deliver water to just outside the pump house; in other words, no booster pumping station, water mains, storage facilities, distribution system, or other facilities that would be common to a water system regardless of the source.

Assume a capital cost of $100,000 for a deep sandstone well, a 50-year life of the well, 500 GPM capacity, load factor of 50%, 6% interest on the capital, and equal serial bonds. What would a new well alone add to the cost of water? The cost comparisons are shown in Table 8. Table 9 shows these costs over the life of the well.

Summary of Well-Water Costs

The costs summarized below are all in cents per 1,000 gallons, and they are taken at the average point as developed in the text and tables.

Cost of water as delivered by utilities	70¢
Softening costs (paid by user or homeowner)	68
Additional energy costs due to declining water tables	3
Additional construction costs for new deep wells	4
	145

Thus it is evident that the additional charges or costs to stay with the present well system would average in the neighborhood of 7 cents per 1,000 gallons based on present costs.

PLANNING AND MANAGEMENT

Thus far it has been shown that there is sufficient ground water to supply projected needs in the study area far into the future. In addition, costs for continued usage of the ground water are substantially less than for alternative water sources. However, a point of caution should be made. Detailed intra- and even intercommunity planning is in order. The ground water system will serve those communities' needs only if proper management is maintained. If it isn't, then the localized pockets of water shortages, which led to concern in the first place, will only expand.

Certain inherent assumptions have gone into the budget calculations which concern management. In the dolomite, it has been assumed that recharge and water quality will remain constant through time. Thus recharge area must be delineated and protected and caution must be taken to minimize the amount of impervious surfaces allowed in communities. At the same time, extreme care must be taken to avoid aquifer contamination by surface spills, septic tanks, sanitary landfills, road salting and hundreds of other potential sources.

Table 7

ADDITIONAL ENERGY COSTS DUE TO DECLINING WATER TABLES

Decline in Potentiometric Surface at Year 2000	Additional Energy Costs in ¢/1000 gal. (1)	Communities Involved (2)
100′	1.23	
200′	2.46	
300′	3.68	Bayside, River Hills, Mequon, Thiensville, Germantown
400′	4.91	Menomonee Falls, Brookfield, Elm Grove, Waukesha
450′	5.53	New Berlin

(1) Cost formula: (1,000 gal.) (8.33 lbs. per gal.) (feet decline) (3.77×10^{-7} conversion factor ft.-lbs. to kwh) (2.75¢/kwh) ($\frac{1}{.70}$)

(2) SEWRPC Technical Report No. 16. (Young, 1976)

Table 8

COSTS OF RECENT NEW WELLS**

Municipality	Year	Well No.	Type	Depth	Casing Dia.	Formation	Sp. Cap. Gal/ft. d.d.	Pump Inst. GPM	Cost
Brookfield Sq.	1968	—	Deep	1800	16″	S.S.	11.04	1000	$92,400
Brookfield Hills	1970	—	Deep	1327	10″	S.S.	1.8	300	53,500
Brookfield Carriage Hills	1972	—	Deep	1800	12″	S.S.	2.8	500	70,000
Butler	1967	1	Deep	1697	15″	S.S.	5.8	1000	72,000
Dousman	1971	1	Deep	1142	12″	S.S.	4.7	400	62,900
Germantown	1976	—	Deep	1271	10″	S.S.	1.59	400	84,000
Hartland	1973	3	Shallow	135	16″	Gravel	33.3	1000	68,200
Menomonee Falls	1968	5	Deep	1379	16″	S.S.	7.02	1000	84,120
Mukwonago	1967	3	Deep	1500	12″	S.S.	4.2	700	73,000
New Berlin (Greenridge)	1966	—	Deep	1650	12″	S.S.	5.24	615	69,000
New Berlin	1967	1	Deep	1800	15″	S.S.	12.05	1000	83,900
New Berlin (Regal)	1971	—	Deep	1700	12″	S.S.	7.4	700	82,600
New Berlin	1977	2	Deep	2018	15″	S.S.*	18.75	900	145,600
Town Pewaukee	1974	1	Deep	1250	12″	S.S.	4.92	400	90,430
Village Pewaukee	1971	3	Deep	1250	15″	S.S.	4.1	850	79.000
Saukville	1973	3	Shallow	500	20″	Lmstn.	1.81	600	73,900
Sussex (Spring Green)	1971	2	Deep	1248	12″	S.S.	5.9	500	64,000
Sussex Hghts.	1972	3	Deep	1298	12″	S.S.	3.2	500	65,900

Costs Include: Well
Well Pump
Elect. (Est.)
Pump House (Est.)

*S.S. denotes lower sandstone & dolomite aquifers

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July - 1977

Concentration of wells have already proven to be poor planning. Developments involving individual home wells should be thoroughly planned and avoided if possible. Existing concentrations of wells should probably be thinned by introduction of community wells. Well design plans in the dolomite should also recognize the importance of the bedrock topography. Wells put in bedrock valleys simply will not deliver high capacities.

In the sandstone, it will be more difficult to protect recharge areas, because they lie far from the communities concerned. State and regional agencies need to be aware of the potential problems and to protect the recharge areas from being paved over or used in a manner which might lead to recharge contamination. Planners must be totally aware of the location and extent of pockets of unpotable water in the sandstone. Care must be taken to avoid inducing their migration by heavy pumping.

SUMMARY

This study has shown that the suburban communities investigated generally have ample supplies of ground water to meet their current and future needs. In all cases, the conservative calculations made show that the larger communities will continue to operate with a water surplus or only a very slight deficit in the year 1990. Those with deficits have sufficient ground water in storage that planned mining could provide at the anticipated 1990 demands for at least 100 years.

On the other hand, the smaller, densely populated communities are operating with a water deficit right now. The calculation for 1990 for these communities have assumed that they can only tap stored water within their boundaries (i.e. they cannot induce flow from surrounding communities). This is an unrealistic, but intentionally conservative, assumption. Within this artificial framework, the communities of Bayside, Elm Grove, and Thiensville are projected to have serious water supply problems by 1990. In fact, these communities will not run out of ground water, but the data presented lead to the conclusion that the small communities must begin looking beyond their borders for a lasting water supply. They need look only far as their ground-water rich, larger neighbors and begin the machinations of cooperative water planning with them.

In addition to documenting the generally ample supply of ground water, this study has shown that the cost to the water consumer of staying with the present well supply system is

Table 9

COSTS OF A NEW DEEP SANDSTONE WELL [1]

1	2	3	4	5	6
End of Year	Principal Outstanding $	Principal Due End of Year [2] $	Interest on Outstanding Principal at 6% $	Principal plus Interest Payment (Cols. 3+4) $	Costs in Cents per 1000 gallons[3]
1	100,000	2,000	6,000	8,000	6.1
10	82,000	2,000	4,920	6,920	5.3
20	62,000	2,000	3,720	5,720	4.4
25	52,000	2,000	3,120	5,120	3.9
30	42,000	2,000	2,520	4,520	3.4
40	22,000	2,000	1,320	3,320	2.5
50	2,000	2,000	120	2,120	1.6

(1) See text for assumptions.

(2) It is recognized that such small denomination serial bonds would not be issued as a practical matter; computation is to illustrate unit costs of the well.

(3) Cost in cents per 1,000 gal. pumped $= \dfrac{\text{Annual cost (principal + interest, column 5)}}{\text{Total pumpage in year}}$

$$= \frac{(\$)(100)}{(1/2)(500\ \text{GPM})(60)(24)(365)}$$

$$= \frac{(\$)(100¢)}{1.315 \times 10^5}$$

quite reasonable, with increases over present average costs of 7¢/1,000 gallons. It is probably substantially less than that for any scheme to bring in Lake Michigan water to the communities studied, but this cannot be stated for certainty as the CTA cost estimates did not include distribution systems.

However, despite the positive supply and cost picture, a ground water system will not succeed in the future without adequate planning. Communities must work to manage their water resources, to protect recharge areas, and to prevent contamination and concentration of demand.

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SEWRPC STAFF NOTE

The foregoing article by Professors Cherkauer and Bacon reports the findings of their water supply study focused largely on the suburban communities to the north and west of the City of Milwaukee. Their study is the third in a relatively recent series of water supply studies pertaining to some or all of these suburban communities. In order to keep a proper perspective, the reader of the Cherkauer and Bacon article should also be aware of the findings of the previous two studies.

As part of the Milwaukee River watershed plan published in 1971, the SEWRPC examined three water supply alternatives intended to meet future water demand in the City of Mequon and the Villages of Bayside, River Hills, and Thiensville. These three alternatives were: a joint system utilizing a groundwater supply drawn from the dolomite aquifer; a joint system using Lake Michigan as a direct source of supply; and a joint system utilizing Lake Michigan as an indirect source of supply through purchase of water from either the City of Milwaukee Water Utility or the North Shore Water Utility. An economic analysis of these three alternatives was conducted. This analysis, conducted in 1970 and using construction costs and water purchase rates current at that time, indicated that it would be somewhat more economical for the four communities concerned to establish an independent water utility and obtain water directly from Lake Michigan. These studies further concluded that given proper well field management there would be sufficient supply of groundwater to serve the anticipated future demand. The purchase of Lake Michigan water through either the City of Milwaukee or the North Shore Water Utility was concluded to be a viable alternative; however, the cost of this alternative was estimated to be somewhat higher than either the recommended alternative—establishing an independent water utility obtaining water directly from Lake Michigan—or establishing an independent water utility obtaining water from the shallow dolomite aquifer. The results of this study for four communities are set forth in SEWRPC Planning Report No. 13, A Comprehensive Plan for the Milwaukee River Watershed, Volume Two, Alternative Plans and Recommended Plan.

As noted above, the water supply analysis conducted as part of the Milwaukee River watershed study was based on 1970 costs. If that same analysis were to be conducted today using 1977 construction costs and water purchase rates, the alternative of purchasing Lake Michigan water through either the City of Milwaukee or the North Shore Water Utility would be the most economic solution. This change in the rank order of the alternatives flowing from the economic analysis has come about because while construction costs over the seven-year period since the conduct of the Milwaukee River watershed study have risen by about 90 percent, the cost of purchasing treated water has increased by only about 20 percent. This differential in cost would, of course, tend to favor any alternative that was based upon water purchase as opposed to establishing an independent water supply.

A second study followed publication of the SEWRPC Milwaukee River watershed plan. This study was conducted by the four municipalities addressed in the watershed plan—Mequon, Bayside, River Hills, and Thiensville—in concert with the City of Brookfield and the Villages of Menomonee Falls and Germantown. These communities jointly retained the firm of Consoer, Townsend and Associates in March 1976 to conduct this study. The Consoer, Townsend and Associates study is referenced in the foregoing article. Addressing a now much larger geographic service area, the Consoer, Townsend and Associates study examined the same basic alternatives considered by the SEWRPC in the Milwaukee River watershed plan. This report concluded that the purchase of water from the City of Milwaukee was the most economic course of action for the communities concerned.

The Cherkauer-Bacon study set forth above focuses primarily upon the availability of groundwater, concluding that sufficient groundwater reserves are available to meet the water supply demand of communities north and west of the City of Milwaukee. It is important to note that this conclusion is consistent with the findings of both the 1971 SEWRPC Milwaukee River watershed plan and the 1976 Consoer, Townsend and Associates study. Independent estimates of the cost of supplying these communities with Lake Michigan water were not developed by Cherkauer and Bacon. A comparison is drawn, however, by Cherkauer and Bacon between the estimated cost of meeting the demand in these communities through a groundwater system as compared to the estimated cost by Consoer, Townsend and Associates of establishing an independent Lake Michigan supply. Cherkauer and Bacon conclude from that comparison that groundwater would be more economical than Lake Michigan. However, a similar comparison with Lake Michigan as a source of supply through purchase of water from the City of Milwaukee was not made by Cherkauer and Bacon. That comparison, also using the Consoer, Townsend and Associates study costs, would lead to the conclusion that the purchase of Lake Michigan water through Milwaukee would be the most economic solution.

Continued

The following basic conclusions can be drawn from the three studies conducted to date:

1. All three studies agree that the real issue is not whether there is an adequate supply of groundwater. All three studies agree that there is an adequate supply of groundwater in the Milwaukee urbanized area, although there may be some localized problems. Such problems could be overcome, however, through proper management of the groundwater supply.

2. All three studies agree that, given current construction costs and water purchase rates, the most economic solution to groundwater problems in the Milwaukee urbanized area would be througn purchase of Lake Michigan water, primarily through the City of Milwaukee but also perhaps through other water utilities now established along the Lake Michigan shoreline. The real difficulty in effecting such a solution, of course, relates to the political problems that may be encountered in the intergovernmental negotiations necessary to effect transfer of water from one community to another.

The three studies of alternative water supplies together serve a valuable purpose in focusing attention on potential water supply problems in the Milwaukee-metropolitan area. All three studies emphasize the need for close intercommunity cooperation in order to achieve a technically practicable, economically feasible, and environmentally acceptable means of meeting future water supply needs. The studies suggest that the ultimate resolution of existing and potential water supply problems in the Milwaukee area, and, indeed, all of southeastern Wisconsin, must build on a sound technical basis in terms of the conduct of sound inventories of existing and probable future supply of and demand for water, on the volume and movement of groundwater, and in terms of analytic tools and techniques adequate to project groundwater movements and levels under alternative water supply measures.

The Commission staff believes that the water supply and distribution problems now beginning to appear in the southeastern Wisconsin area can best be resolved by a comprehensive regional water supply planning program that makes maximum use of the existing data base in the Region, that explores a full range of alternatives, that uses state of the art tools and techniques, that is fully coordinated with other land use and water resource plans for the Region, and that maximizes public participation in the planning process.

AN OVERVIEW OF THE SOURCES OF WATER POLLUTION IN SOUTHEASTERN WISCONSIN

by K. W. Bauer, P.E., Executive Director, Southeastern Wisconsin Regional Planning Commission

INTRODUCTION

Water resources constitute one of the most important elements affecting the overall quality of the environment, as well as the growth and development of an area. Water resources not only condition, but are conditioned by, regional growth and development. Any meaningful comprehensive regional planning efforts must, therefore, recognize water resources as an important element of a limited natural resource base to which both rural and urban development must be adjusted if serious developmental and environmental problems are to be avoided. This is particularly true in southeastern Wisconsin, an intensely urbanized seven-county Region in which about 40 percent of the state's population live on about 5 percent of the state's area.[1] The large resident population, the highly industrialized economy, the areawide diffusion of urban development, and the need for varied recreational opportunities within the Region all combine to make the wise use of the water resources of the area particularly important.

Southeastern Wisconsin is richly endowed with water resources. Properly husbanded, these water resources can constitute a renewable resource which can serve the Region for all time to come. Misused and mismanaged, however, this resource will become the focus of serious and costly developmental and environmental problems and a severe constraint on the sound social, economic, and physical development of the Region. Water pollution is one manifestation of the misuse of water resources; and the public has become increasingly aware of, and concerned over, such pollution, which has seriously interfered with desired water uses.

In order to develop a sound realistic plan for the abatement of water pollution, it is necessary to know, among other information, the number, type, and location of all significant sources of pollution; the type and amount of pollutants contributed by each source to the surface waters of the planning area; and the conditions under which such contributions occur. This information must be known for all "point" sources contributing pollutants to the streams and lakes of the planning area through clearly identifiable wastewater discharge points — such as sewage treatment plant outfalls, sanitary and combined sewer flow relief points, and industrial wastewater outfalls — and for all known "non-point," or diffuse, sources contributing pollutants through rural and urban runoff, atmospheric washout and fallout, and groundwater inflow. Accordingly, a comprehensive inventory of the sources of water pollution in southeastern Wisconsin was conducted by the Southeastern Wisconsin Regional Planning Commission as a part of its areawide water quality management planning efforts for the Region. This inventory not only established the number and spatial distribution of all known sources of pollution but also estimated the amounts and strengths of the wastewaters contributed. A review of the findings of this inventory can contribute to a better understanding of the nature and scope of the water pollution problem in the Region.

[1] *The seven counties comprising the Southeastern Wisconsin Region are: Kenosha, Milwaukee, Ozaukee, Racine, Walworth, Washington, and Waukesha.*

CATEGORIES OF POLLUTION SOURCES

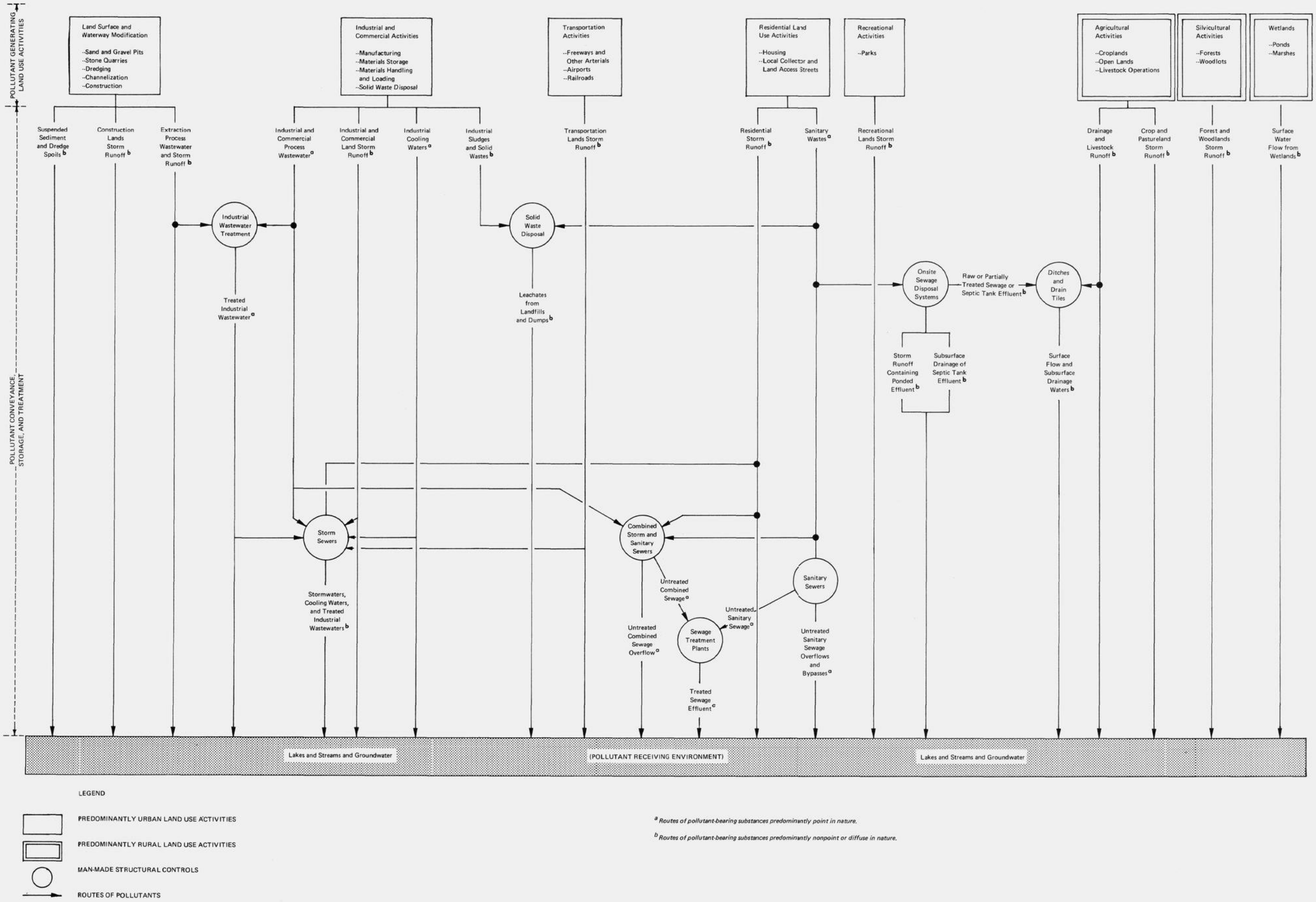
For the purpose of the inventory, pollution sources were identified as set forth in Figure 1 and were categorized as urban and rural. The urban sources were defined as including public sanitary sewerage systems — including separate and combined sewer flow relief devices and sewage treatment plant outfalls; private sewage treatment plant outfalls; existing privately owned, on-site sewage disposal systems serving both urban type land subdivisions and farmsteads; and industrial wastewater outfalls. The urban storm sewerage systems which collect and convey rainfall and snowmelt runoff from areas which contribute pollutants as diffuse sources were also classified as urban sources. Rural sources were defined as including livestock raising operations and unsewered rainfall and snowmelt runoff, which contribute pollutants from croplands, orchards, pastures, woodlands and wetlands, wildlife habitat areas, and direct contributions from atmospheric washout and fallout to surface waters. It should be noted that both the urban and rural sources may include both point and non-point sources. Non-point sources have not been historically considered as primary pollutant sources.

From the multitude of pollutants which can be measured, the inventory concentrated on five which are widely recognized as major pollutants or as indicators of the presence of pollution: total nitrogen, total phosphorus, five-day biochemical oxygen demand, sediment, and fecal coliform. The first two pollutants are contributed by sewage treatment plants, domestic septic tanks, sewer overflows, industrial wastes, and surface runoff from both rural and urban lands. When these elements are present in excessive amounts and in certain forms, excessive growth of algae and other aquatic plants may occur giving rise to unsightly scum, unpleasant odors, and depletion of the oxygen content of the water, with possible attendant fish kills when the plants die and decay. Ammonia, one form which nitrogen may take in water, is directly toxic to aquatic life. Biochemical oxygen demand is a measure of the concentration of putrescible organic substances in wastewaters and, therefore, of the potential decrease in dissolved oxygen concentration that may occur in a stream or lake as a result of pollution by such substances. Combined with knowledge of the reaeration characteristics of a stream or lake, this measure may be used to determine where dissolved oxygen concentrations may reach critically low levels for the preservation of fish and other desirable forms of aquatic life.

Suspended solids are a measure of all inorganic and organic substances that occur in suspension in the stream or lake water and, as such, are an important indicator of not only such forms of pollution as raw sewage but, importantly, of eroded soil. Eroded soil particles — which may range in size from very fine clay particles to coarse sand particles — may be washed into the receiving bodies of water by runoff. Such particles may carry with them nutrients, biochemical oxygen demand, pathogenic organisms, poisonous heavy metals, and other pollutants, such as pesticides. Such particules, however, themselves constitute a form of pollution by reducing water clarity, interfering with natural feeding patterns, causing abrasive injuries to fish, clogging fish gills, smothering fish spawning beds and desirable forms of bottom life, and clogging waterways, thereby obstructing navigation and causing local flooding. As sediment, the soil particles also function as a storage site for the chemical pollutants they may carry.

Figure 1

SOURCES AND ROUTES OF MOVEMENT OF WATER POLLUTANTS



[a] *Routes of pollutant-bearing substances predominantly point in nature.*

[b] *Routes of pollutant-bearing substances predominantly nonpoint or diffuse in nature.*

Source: SEWRPC.

Fecal coliform organisms are an indicator of the potential presence in the water of bacteria and viruses that can cause serious illness in man and other animals, such as dysentery, hepatitis, typhoid and paratyphoid fevers, serious kinds of food poisoning, mononucleosis, smallpox, and poliomyelitis. The presence of fecal coliforms is indicative of the contamination of water by intestinal wastes of warm blooded animals and, as such, is an indicator of pollution from separate and combined sewage overflows, septic tank effluent, and runoff from feedlots and other animal raising operations.

POLLUTION LOADINGS

Table 1 sets forth the absolute and proportional pollution load contributed by each of the major pollution sources within the Region for each of the five major pollutants. Because of the geography of the Region, the data in the table are provided for three principal areas: the Region as a whole, that part of the Region which drains to inland lakes and streams and thereby indirectly to Lake Michigan or to the Mississippi River drainage; and that part of the Region which drains directly to Lake Michigan. The latter, however, includes major point sources of pollution, such as the large sewage treatment plants located on the Lake Michigan shoreline which discharge their treated effluent directly to the Lake and which serve large tributary drainage areas — areas which may cross even the major watershed divides, as shown on Map 1.

A review of Table 1 indicates that in an average year about 45.92 million pounds of nitrogen, 6.73 million pounds of phosphorus, 117.00 million pounds of biochemical oxygen demand, 6.7 million tons of sediment and 3.2×10^{17} fecal coliform organisms are discharged to the inland lakes and streams and to Lake Michigan from all sources of pollution within the seven-county Region. Of these total estimated amounts, urban sources contribute about 43 percent of the nitrogen, 66 percent of the phosphorus, 52 percent of the biochemical oxygen demand, and 55 percent of the sediment, as well as about 50 percent of the fecal coliform pollution. Rural sources thus contributed about 57 percent of the nitrogen, 34 percent of the phosphorus, 48 percent of the biochemical oxygen demand, 45 percent of the sediment, and about half of the fecal coliform pollution.

The largest urban point sources of pollution include municipal sewage treatment plants with respect to nitrogen, phosphorus, and biochemical oxygen demand, and combined sewer overflows with respect to fecal coliform pollution. Contrary to popular belief, industrial discharges do not constitute a major source of urban point source pollution within the Southeastern Wisconsin Region. The largest urban non-point sources include extractive industries, transportation, and construction, the latter particularly with respect to sediment and attendant nutrients. On-site septic tank sewage disposal systems also constitute an important source of urban pollution, particularly with respect to biochemical oxygen demand and fecal coliform.

The largest rural sources of pollution are all non-point sources and include livestock raising operations and cropland. Both are major sources of nutrients and biochemical oxygen demand, while livestock raising operations constitute the major source of fecal coliform pollution, and an important phosphorus source, and cropland the major source of sediment and nitrogen pollution.

Although urban point sources contribute a significant proportion of the nitrogen, phosphorus, and biochemical oxygen demand within the Region as a whole, because of the diversion of large amounts of partially treated municipal sewage directly to Lake Michigan, urban point sources are relatively minor sources of pollution with respect to the inland lakes and streams of the Region. For example, while urban point sources contribute 32 percent of the nitrogen, 34 percent of the phosphorus, and 25 percent of the biochemical oxygen demand within the Region as a whole, these same sources contribute only 7, 14, and 7 percent of the respective pollutant loads to the inland lakes and streams of the Region. Conversely, these urban point sources are major contributors of pollution to Lake Michigan, with 95, 93, and 87 percent, respectively.

With respect to the inland lakes and streams of the Region, non-point sources constitute the overwhelming preponderance of pollution, contributing 93 percent of the nitrogen, 86 percent of the phosphorus, 93 percent of the biochemical oxygen demand, 60 percent of the fecal coliform organisms, and almost all of the sediment. The variations in the relative importance of the major categories of sources of pollution within the Region are illustrated in Figure 2. This figure illustrates the relative importance of the non-point, or diffuse sources, as opposed to the point sources of pollution for the Region as a whole, the inland lakes and streams of the Region, and Lake Michigan. Rural non-point sources of pollution are particularly important with respect to the inland lakes and streams, contributing almost 78 percent of the nitrogen, 45 percent of the phosphorus, 60 percent of the biochemical oxygen demand, 52 percent of the fecal coliform organisms, and 47 percent of the sediment loadings to these streams, with cropland and pasture lands constituting the singularly most important source of nitrogen and sediment, and livestock constituting the singularly most important source of phosphorus, biochemical oxygen demand and fecal coliform organisms.

CONCLUSIONS

The Southeastern Wisconsin Regional Planning Commission, as a part of its areawide water quality management planning effort, has identified all significant sources of water pollution within the seven-county Southeastern Wisconsin Region and has estimated the relative pollutant loading from these sources to the various major inland lakes and streams of the Region and to Lake Michigan. The following conclusions may be drawn about the existing sources of water pollution in southeastern Wisconsin.

1. Point sources of pollution — sewage treatment plant outfalls, sanitary and combined sewer flow relief devices, and industrial wastewater outfalls — are no longer the dominant source of pollution in most of the inland watersheds of the Region. Of the point sources of pollution, municipal sewage treatment plant discharges constitute the most important source with respect to the inland lakes and streams; and such treatment plant discharges, together with combined sewer overflows, constitute the most important remaining direct sources of pollution with respect to Lake Michigan. Point source contributions can be expected to be rapidly reduced in the future as a result of state and federal pollution abatement requirements and improved point source wastewater treatment technologies.

2. Industrial wastewater discharges are only a minor source of water pollution within the Region contributing 1.5 percent or less of the total of any of the five most basic pollutants. Such discharges can, however, constitute important sources of such "exotic" pollutants as poisonous metals and dangerous chemicals.

3. Cropland runoff is the largest single contributor of nitrogen and sediment within the Region.

4. Livestock operations are the major source of phosphorus and biochemical oxygen demand.

Table 1

ESTIMATED TOTAL OF AVERAGE ANNUAL LOADS OF POLLUTANTS TO RECEIVING WATERS OF SOUTHEASTERN WISCONSIN: 1975

		Total Region Including L. Mich.		Total Inland Lakes and Streams		Lake Michigan — Direct Drainage and Direct Point Source Contributors	
Source	Parameter	Load	% of Total	Load	% of Total	Load	% of Total
Municipal Sewage Treatment Plants	Total Nitrogen	13,897,660	30.3	1,917,960	5.8	11,979,700	93.1
	Total Phosphorus	2,028,760	30.1	459,920	9.2	1,568,840	91.0
	Biochemical Oxygen Demand	23,321,140	19.9	2,122,520	2,3	21,198,620	84.4
	Fecal Coliform	2.95×10^{16}	9.2	2.9×10^{16}	9.7	9.0×10^{14}	4.1
	Sediment	23,065	0.3	1,620	0.0	21,445	6.8
Private Sewage Treatment Plants	Total Nitrogen	114,510	0.2	101,360	0.3	13,150	0.1
	Total Phosphorus	38,770	0.6	38,150	0.8	620	0.0
	Biochemical Oxygen Demand	384,540	0.3	140,160	0.2	244,380	1.0
	Fecal Coliform	6.2×10^{13}	0.0	6.2×10^{13}	0.0	– –	0
	Sediment	215	0.0	85	0.0	130	0.0
Combined Sewer Overflows	Total Nitrogen	324,670	0.7	275,460	0.8	49,210	0.4
	Total Phosphorus	162,350	2.4	137,740	2.7	24,610	1.4
	Biochemical Oxygen Demand	3,246,750	2.8	2,754,690	3.0	492,060	2.0
	Fecal Coliform	1.04×10^{17}	32.5	8.8×10^{16}	28.9	1.6×10^{16}	72.7
	Sediment	4,870	0.1	4,130	0.1	740	0.2
Industrial Discharges	Total Nitrogen	291,720	0.6	116,470	0.4	175,250	1.4
	Total Phosphorus	48.810	0.7	41,280	0.8	7,530	0.4
	Biochemical Oxygen Demand	1,654,430	1.4	1,423,700	1.5	230,730	0.9
	Fecal Coliform	3.3×10^{12}	0.0	3.3×10^{12}	0.0	– –	0
	Sediment	22,845	0.3	6,065	0.1	16,780	5.3
Sanitary Sewerage Overflow	Total Nitrogen	28,820	0.1	21,590	0.1	7,230	0.1
	Total Phosphorus	9,610	0.1	7,200	0.1	2,410	0.1
	Biochemical Oxygen Demand	287,980	0.2	215,670	0.2	72,310	0.3
	Fecal Coliform	5.0×10^{15}	1.6	3.3×10^{15}	1.1	1.1×10^{15}	5.0
	Sediment	135	0.0	100	0.0	35	0.0
Point Source Total	Total Nitrogen	14,657,380	31.9	2,432,840	7.4	12,224,540	95.0
	Total Phosphorus	2,288,300	34.0	684,290	13.7	1,604,010	93.1
	Biochemical Oxygen Demand	28,894,840	24.7	6,656,740	7.2	22,238,100	88.6
	Fecal Coliform	1.4×10^{17}	43.7	1.2×10^{17}	39.7	1.8×10^{16}	81.8
	Sediment	51,130	0.8	12,000	0.2	39,130	12.3
Residential	Total Nitrogen	635,430	1.4	590,610	1.8	44,820	0.4
	Total Phosphorus	50,840	0.8	47,250	0.9	3,590	0.2
	Biochemical Oxygen Demand	3,860,220	3.3	3,587,940	3.9	272,280	1.1
	Fecal Coliform	2.6×10^{15}	0.8	2.4×10^{15}	0.8	1.8×10^{14}	0.8
	Sediment	43,290	0.6	40,235	0.6	3,055	1.0
Commercial	Total Nitrogen	235,220	0.5	221,120	0.7	14,100	0.1
	Total Phosphorus	19,610	0.3	18,440	0.4	1,170	0.1
	Biochemical Oxygen Demand	2,550,720	2.2	2,397,840	2.6	152,880	0.6
	Fecal Coliform	8.5×10^{14}	0.3	8.1×10^{14}	0.3	4.0×10^{13}	0.2
	Sediment	9,730	0.1	9,145	0.1	585	0.2
Industrial	Total Nitrogen	138,620	0.3	125,980	0.4	12,640	0.1
	Total Phosphorus	11,550	0.2	10,500	0.2	1,050	0.1
	Biochemical Oxygen Demand	608,900	0.5	553,380	0.6	55,520	0.2
	Fecal Coliform	1.0×10^{15}	0.3	9.3×10^{14}	0.3	7.0×10^{13}	0.3
	Sediment	8,045	0.1	7,310	0.1	735	0.2
Extractive	Total Nitrogen	481,740	1.0	481,740	1.5	0	0
	Total Phosphorus	361,330	5.4	361,330	7.2	0	0
	Biochemical Oxygen Demand	963,480	0.8	963,480	1.0	0	0
	Fecal Coliform	0	0.0	0	0.0	0	0
	Sediment	602,175	9.0	602,175	9.4	0	0
Transportation	Total Nitrogen	710,650	1.5	563,880	1.7	146,770	1.0
	Total Phosphorus	50,530	0.8	41,750	0.8	8,780	0.5
	Biochemical Oxygen Demand	4,634,650	4.0	3,637,390	4.0	997,260	4.0
	Fecal Coliform	1.9×10^{15}	0.6	1.5×10^{15}	0.5	4.2×10^{14}	1.8
	Sediment	599,480	8.9	465,885	7.3	133,595	42.1
Recreation	Total Nitrogen	104,300	0.2	99,880	0.3	4,420	0.0
	Total Phosphorus	3,820	0.1	3,700	0.1	120	0.0
	Biochemical Oxygen Demand	43,850	0.0	41,350	0.0	2,500	0.0
	Fecal Coliform	7.5×10^{13}	0.0	6.9×10^{13}	0.0	6.2×10^{12}	0.0
	Sediment	7,085	0.1	6,680	0.1	405	0.1

Table 1 (continued)

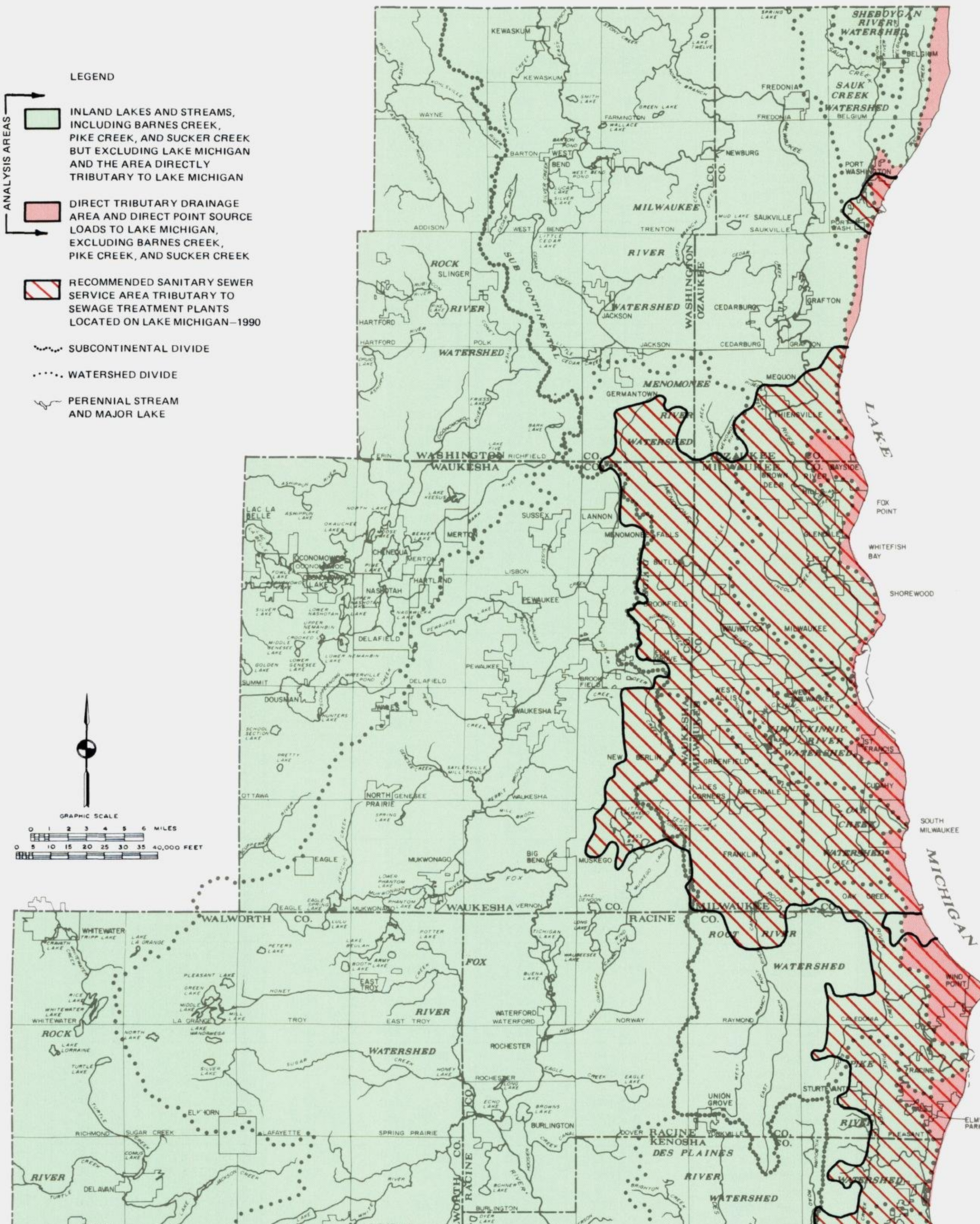
Source	Parameter	Total Region Including L. Mich. Load	% of Total	Total Inland Lakes and Streams Load	% of Total	Lake Michigan — Direct Drainage and Direct Point Source Contributors Load	% of Total
Construction	Total Nitrogen	1,901,100	4.1	1,813,020	5.5	88,080	0.7
	Total Phosphorus	1,425,850	21.2	1,359,790	27.1	66,060	3.8
	Biochemical Oxygen Demand	3,802,200	3.2	3,626,040	3.9	176,160	0.7
	Fecal Coliform	0	0.0	0	0.0	0	0
	Sediment	2,376,375	35.5	2,266,275	35.5	110,100	34.7
On-Site Sewage Disposal Systems	Total Nitrogen	1,085,950	2.4	1,055,940	3.2	30,010	0.2
	Total Phosphorus	249,900	3.7	242,810	4.8	7,090	0.4
	Biochemical Oxygen Demand	15,442,670	13.2	15,015,370	16.3	427,300	1.7
	Fecal Coliform	1.9×10^{16}	5.9	1.8×10^{16}	6.0	1.0×10^{15}	4.5
	Sediment	2,650	0.0	2,575	0.0	75	0.0
Urban Non-Point Totals	Total Nitrogen	5,263,000	11.5	4,952,170	15.0	310,830	2.4
	Total Phosphorus	2,173,430	32.3	2,085,570	41.6	87,860	5.1
	Biochemical Oxygen Demand	31,906,690	27.3	29,822,790	32.5	2,083,900	8.3
	Fecal Coliform	2.5×10^{16}	7.8	2.4×10^{16}	7.9	1.7×10^{15}	7.3
	Sediment	3,648,750	54.4	3,400,280	53.3	48,470	78.3
Urban Sources Total	Total Nitrogen	19,920,380	43.4	7,385,010	22.3	12,535,370	97.6
	Total Phosphorus	4,461,730	66.3	2,769,860	55.3	1,691,870	98.2
	Biochemical Oxygen Demand	60,801,530	52.0	36,479,530	39.7	24,322,000	96.9
	Fecal Coliform	1.7×10^{17}	50.0	1.5×10^{17}	47.6	2.0×10^{16}	90.9
	Sediment	3,699,880	55.2	3,412,280	53.5	287,680	90.7
Livestock Operations	Total Nitrogen	7,188,180	15.7	7,078,700	21.4	109,480	0.9
	Total Phosphorus	1,670,400	24.8	1,645,050	32.8	25,440	1.5
	Biochemical Oxygen Demand	28,145,270	24.1	27,716,590	30.2	428,680	1.7
	Fecal Coliform	1.6×10^{17}	50.0	1.6×10^{17}	52.3	2.5×10^{15}	11.4
	Sediment	88,590	1.3	87,240	1.4	1,350	0.4
Cropland & Pasture Land + Unused Rural Land	Total Nitrogen	17,954,340	39.1	17,809,620	53.8	144,720	1.1
	Total Phosphorus	552,420	8.2	548,040	10.9	4,380	0.3
	Biochemical Oxygen Demand	19,314,620	16.5	19,143,390	20.8	171,230	0.7
	Fecal Coliform	0	0.0	0	0.0	0	0
	Sediment	2,874,330	42.9	2,847,490	44.6	26,840	8.5
Silvicultural	Total Nitrogen	392,670	0.9	377,680	1.1	14,990	0.1
	Total Phosphorus	23,990	0.4	22,990	0.5	1,000	0.1
	Biochemical Oxygen Demand	790,290	0.7	755,320	0.8	34,970	0.1
	Fecal Coliform	1.1×10^{14}	0.0	1.1×10^{14}	0.0	1.6×10^{12}	0
	Sediment	21,600	0.3	20,600	0.3	1,000	0.3
Water Areas	Total Nitrogen	466,420	1.0	428,110	1.3	38,310	0.3
	Total Phosphorus	24,520	0.4	24,050	0.5	470	0.0
	Biochemical Oxygen Demand	7,945,600	6.8	7,792,350	8.5	153,250	0.6
	Fecal Coliform	0	0.0	0	0.0	0	0
	Sediment	16,300	0.2	15,990	0.3	310	0.1
Rural Non-Point	Total Nitrogen	26,001,610	56.6	25,694,110	77.7	307,500	2.4
	Total Phosphorus	2,271,430	33.7	2,240,130	44.7	31,300	1.8
	Biochemical Oxygen Demand	56,195,780	48.0	55,407,650	60.3	788,130	3.1
	Fecal Coliform	1.6×10^{17}	50.0	1.6×10^{17}	52.4	2.5×10^{15}	11.4
	Sediment	3,000,820	44.8	2,971,320	46.5	29,500	9.3
Total Non-Point	Total Nitrogen	31,264,610	68.1	30,646,280	92.6	618,330	4.8
	Total Phosphorus	4,444,860	66.0	4,325,700	86.3	112,070	6.5
	Biochemical Oxygen Demand	88,102,470	75.3	85,230,440	92.8	2,872,000	11.4
	Fecal Coliform	1.8×10^{17}	56.3	1.8×10^{17}	60.3	4.2×10^{15}	19.1
	Sediment	6,649,570	99.2	6,371,600	99.8	277,970	87.6
Total Sources	Total Nitrogen	45,921,990	100.0	33,079,120	100.0	12,842,870	100.0
	Total Phosphorus	6,733,150	100.0	5,009,990	100.0	1,723,160	100.0
	Biochemical Oxygen Demand	116,997,310	100.0	91,887,180	100.0	25,110,130	100.0
	Fecal Coliform	3.2×10^{17}	100.0	3.0×10^{17}	100.0	2.2×10^{16}	100.0
	Sediment	6,700,700	100.0	6,383,600	100.0	317,180	100.0

NOTE: Nitrogen, phosphorus, and biochemical oxygen demand loads are in pounds per year. Sediment is presented in tons per year, and fecal coliform as membrane filter fecal coliform counts per year.

Source: SEWRPC

Map 1

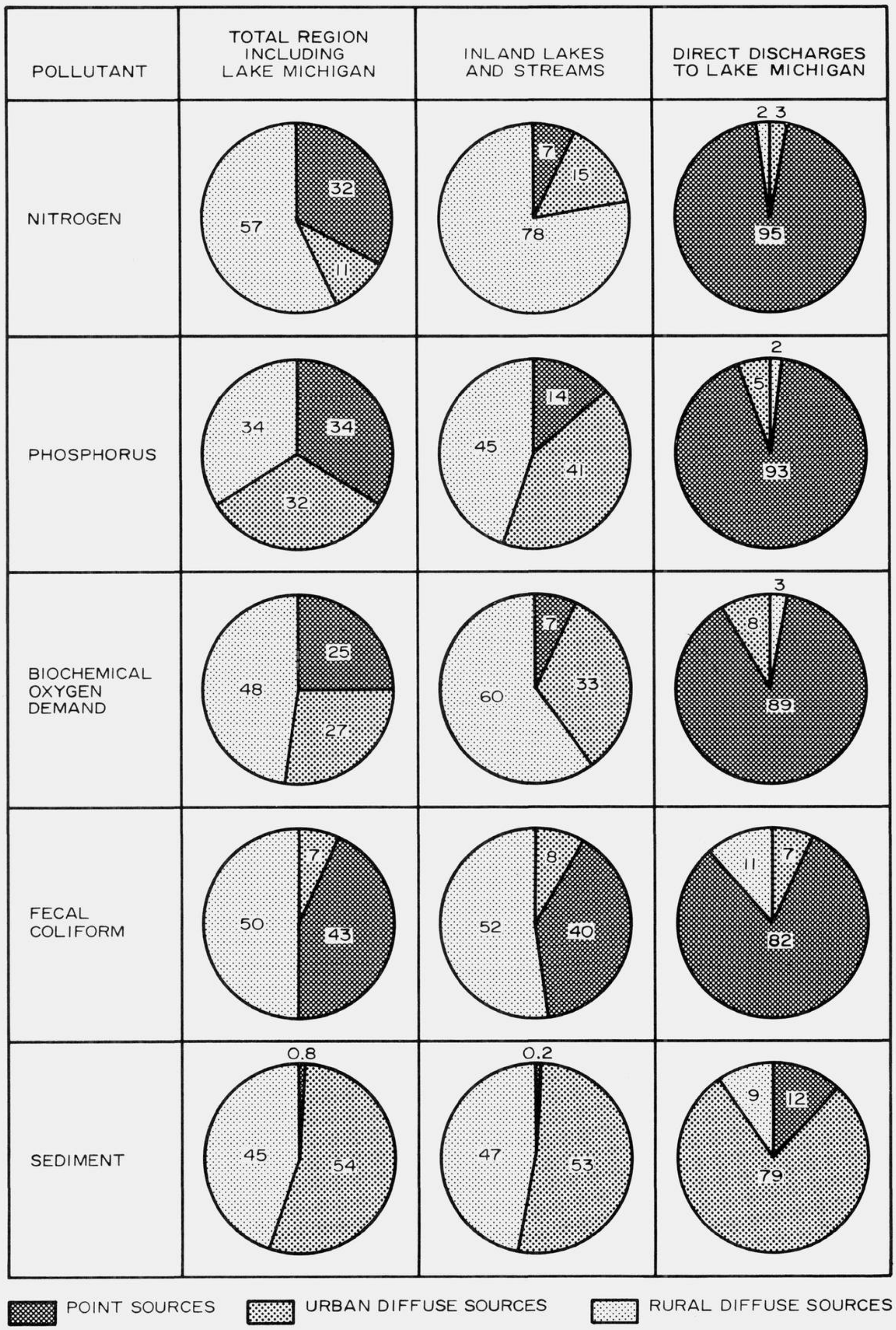
POLLUTANT LOADING ANALYSIS AREAS FOR SOUTHEASTERN WISCONSIN



Source: SEWRPC.

Figure 2

PERCENTAGE DISTRIBUTION OF POLLUTANT LOADS TO SURFACE WATERS IN SOUTHEASTERN WISCONSIN



Source: SEWRPC.

5. Runoff from construction activities is the second largest single contributor of phosphorus and next to cropland the largest source of sediment within the Region.

6. Livestock raising operations and septic tank sewage disposal systems, along with combined sewer overflows and sewage treatment plant effluents are contributors of almost all of the fecal coliform organisms within the Region.

7. There are two major sets of water pollution sources in the Region. The most important pollutant loads directly contributed to Lake Michigan from the Region are by point sources of pollution. The most important categories of pollutant sources to the inland lakes and streams are the non-point, or diffuse, sources.

IMPLICATIONS FOR PLANNING

An inventory of pollution sources alone cannot indicate whether established water use objectives and water quality standards are being met in the receiving waters. Other studies of the Regional Planning Commission, which involve the collection of a massive amount of data on the actual quality of the receiving waters and on the trends in such quality over a period of more than a decade, however, and which have been fully documented in Commission reports, clearly indicate that existing stream and lake water quality in the Region does not generally meet the applicable objectives and standards and that surface water pollution is a widespread and serious problem. The results of that inventory combined with the inventory results summarized in this article must then be analyzed in combination with data about the existing and probable future nature of land use development within the Region to specifically identify the nature of the pollution problem, to develop alternative solutions thereto, and to select the most cost-effective solution from among those alternatives.

A fortuitous aspect of the inventory findings is that the major sources of water pollutants to the inland waters of the Region — construction activities, cropland runoff, livestock raising operations, and on-site sewage disposal systems — can be relatively easily controlled in a cost-effective manner. The state-of-the-art of the control and management of construction sediment, cropland soil erosion, livestock waste, and septic tank effluent are all better developed and more widely accepted than are the techniques for control of urban storm water runoff. By contrast, it is unfortunate that the pollution sources identified in the inventories as most important are probably not generally recognized as such by citizens of the Region. Because of the major importance of both rural and urban non-point sources of pollution, increasing emphasis in water pollution abatement efforts within the Region will have to be placed on the non-point sources if established water use objectives and water quality standards for the inland lakes and streams of the Region are to be met. Continued emphasis will have to be placed on the abatement of point sources of pollution, particularly with respect to Lake Michigan.

The increased emphasis on abatement of non-point sources of pollution will require some new approaches to plan implementation. While the well established relationships between the Wisconsin Department of Natural Resources, the Regional Planning Commission, and the local municipal units of government for point source abatement can probably be relied upon also for the abatement of the urban non-point sources, that relationship will have to be strengthened and broadened to address the difficult problem of pollution from urban storm water runoff. The relative cost effectiveness of "end of pipe" treatment of such run-off, as opposed to improved municipal "housekeeping" in the form of more frequent and efficient street cleaning operations, control of litter, and control of the use of fertilizers and other chemicals on urban lawns, will have to be investigated in a cooperative manner on a community-by-community basis.

Rural non-point pollution source abatement will require greatly strengthened relationships between the Wisconsin Department of Natural Resources, the local Soil and Water Conservation Districts of the seven counties, the Regional Planning Commission, and general purpose local units of government. Since literally thousands of individual landowners and managers will have to be involved in any rural non-point pollution source abatement effort, education will have to become an important part of the abatement program. Moreover, if individual landowners are to be enlisted in the water pollution abatement effort, new public funding programs will have to be developed to provide to individual landowners the type of assistance now provided by the federal and state governments to municipalities for point source abatement.

Given what is now known about the sources of pollution in southeastern Wisconsin, attainment of the established water use objectives and standards will be a difficult task, indeed, one requiring the understanding and good will of all concerned.

THE EFFECT OF SAMPLE RATE ON SOCIOECONOMIC AND TRAVEL DATA OBTAINED THROUGH STANDARD HOME INTERVIEW:
An Analysis of the Mass Transit Nonuser Survey

by Jean M. Lusk, SEWRPC Planner

INTRODUCTION

As a part of the 1972 regional inventory of travel, a special home interview survey—the mass transit nonuser survey—was conducted during the months of June and July in six relatively small residential areas of the Region. The areas were carefully selected to represent both older sections of the Region in which transit service had been maintained at a relatively high level but where transit utilization was known to have declined substantially, and newer sections of the Region where transit utilization had not met expectations despite extensions of transit service to these developing areas. Of the six small residential areas, two were located in Milwaukee, two in Waukesha, and one each in Kenosha and Racine. Map 1 indicates the boundaries of each area.

The principal purposes of conducting the mass transit nonuser survey were threefold: 1) identification of reasons why the area residents had reduced the amount of travel, or did not travel by transit on a regular basis; 2) identification of the kinds of changes that might be required in the transit system which could induce respondents to begin, resume, or increase travel by mass transit on a regular basis; and 3) determination of the differences occurring in the resulting socioeconomic and travel data when varying home interview sample rates are used. Analysis of data relating to the first two purposes of this survey may be found in SEWRPC Planning Report No. 25, A Regional Land Use Plan and A Regional Transportation Plan for Southeastern Wisconsin—2000, Volume One, Inventory Findings. The following article is addressed solely to findings related to the last of the three purposes.

To provide data sufficient for examination of the differences resulting from application of differing sample rates, a home interview survey was conducted in each of the six test areas at a sample rate of approximately 30 percent. The home interview survey included personal and household socioeconomic characteristic data and detailed information characterizing the trips made by household members on an average weekday (see Appendix A for copies of survey forms). Sample rates obtained in these surveys were in Kenosha, 26 percent; in Racine, 28 percent; in Waukesha-South, 31 percent; in Waukesha-North, 32 percent; in Milwaukee-South, 31 percent; and in Milwaukee-North, 29 percent. For ease of discussion, these sample rates will be referred to as the 30 percent sample.

Selected for sampling were 2,205 households. Of this sample, 1,831 households, or 83 percent, provided the information necessary to the survey, these 1,831 households being considered to represent the approximately 7,500 total year round housing units within the combined six areas. The samples obtained in the survey were then utilized as the basis of random selections to obtain the equivalent of 20 percent, 10 percent, 5 percent, and 3 percent sample rates for each of the six areas. Each sample rate group was independently expanded and summarized. This article examines the similarities and differences in data obtained through the five differing sample rates in each of the six small residential areas.

SURVEY FINDINGS

Characteristics of the Households

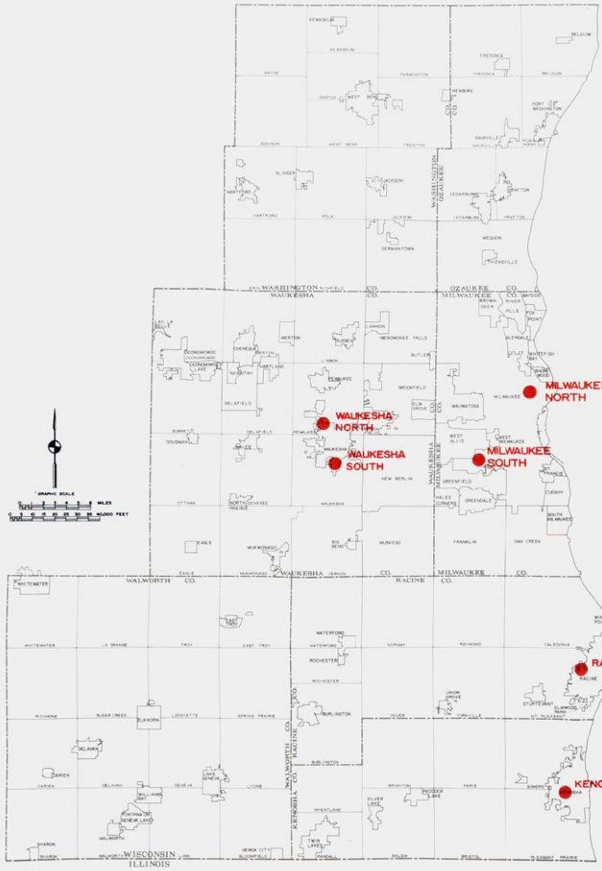
As shown in Table 1, the expanded number of occupied housing units in each of the small residential areas indicated by the differing sample rates varied from the results of the 30 percent sample by less than 4 percent and in most cases varied less than 1 percent. Also shown in Table 1 are the populations and average persons per household found by each sample rate in each test area. The 20 percent and 10 percent samples population figures are within 3 percent of the 30 percent sample populations for each area with the exception of a difference of 7 percent occurring in the Waukesha-North 10 percent sample. Greater variations from the 30 percent sample are found in the 5 and 3 percent samples, with differences ranging from 1 to 16 percent. Average persons per household found in the 20 and 10 percent samples are quite consistent with the 30 percent sample, being within one tenth of a person per household in each area with the exception of a difference of 0.3 person per household shown in the Waukesha-North 10 percent sample. Both the 5 and 3 percent sample rate groups vary from the 30 percent samples by up to 0.5 persons per household.

Although the numbers of automobiles available reported in the smaller samples, as shown in Table 2, differ from the numbers reported in the 30 percent samples, the averages of autos per household are within 0.2 of an auto in each area for each sample rate group with the single exception of a difference of 0.5 auto per household shown in the Waukesha-North 3 percent sample. Differences from the 30 percent sample data in the numbers of automobiles available are no greater in any area than 3 percent in the 20 percent sample rate group; 5 percent in the 10 percent sample rate group; 15 percent in the 5 percent sample rate group; and, 35 percent in the 3 percent sample rate group.

Median household annual income reported in each sample rate within each area was substantially similar to the median income found in the 30 percent sample in the given area with the only major exceptions occurring in two areas each of the 5 percent and 3 percent sample

Map 1

LOCATION AND BOUNDARIES OF HIGH SAMPLE TEST AREAS IN THE SOUTHEASTERN WISCONSIN REGION

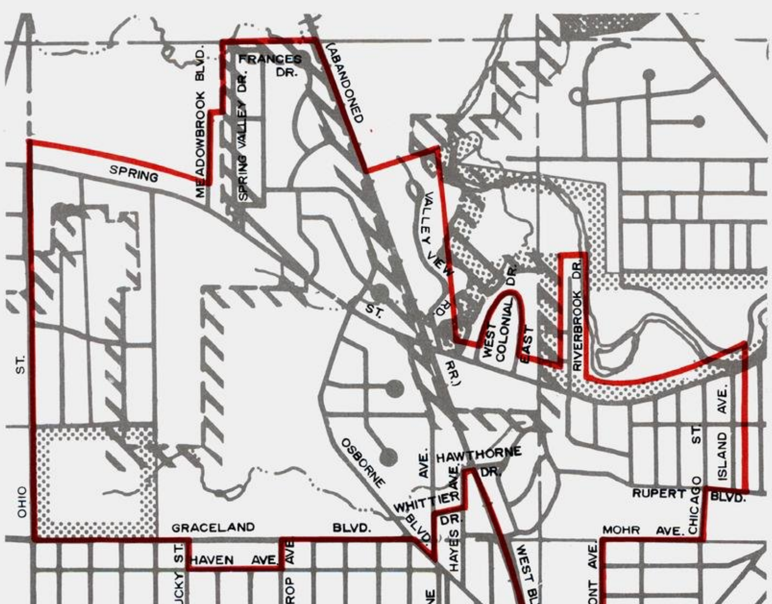


Source: SEWRPC.

KENOSHA

SCALE: 1" = 2000'

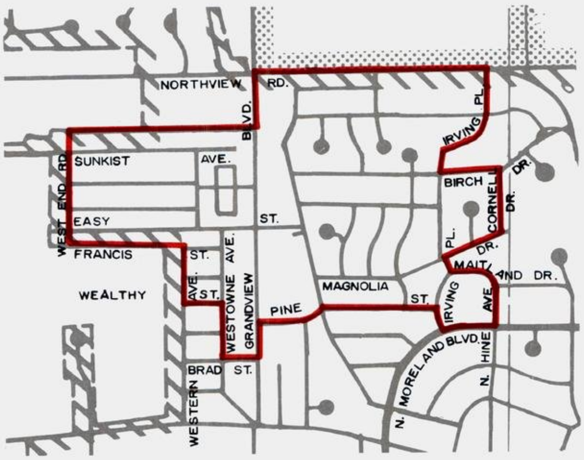
RACINE



SCALE: 1" = 2000'

Map 1 (continued)

WAUKESHA-NORTH

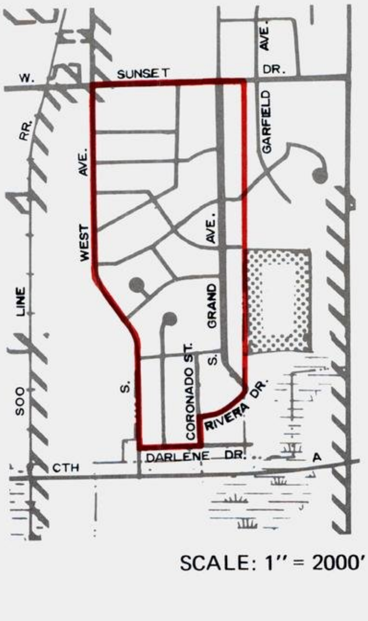


SCALE: 1" = 2000'

MILWAUKEE-NORTH

SCALE: 1" = 2000'

WAUKESHA-SOUTH



SCALE: 1" = 2000'

MILWAUKEE-SOUTH

SCALE: 1" = 2000'

Table 1

OCCUPIED HOUSING UNITS AND POPULATIONS IN SIX TEST AREAS OF THE SOUTHEASTERN WISCONSIN REGION AS REPORTED BY DIFFERING SAMPLE RATES

Test Area	Sample Rate	Indicated Occupied Housing Units	Percent Difference	Indicated Populations	Percent Difference	Indicated Persons Per Household	Difference in Persons Per Household Average
Area 1 (Kenosha)	26 percent	1,269	N/A	3,644	N/A	2.9	N/A
	20 percent	1,270	0.1	3,640	- 0.1	2.9	0.0
	10 percent	1,260	- 0.6	3,744	2.7	3.0	0.1
	5 percent	1,280	0.9	4,065	11.6	3.2	0.3
	3 percent	1,247	- 1.7	3,742	2.7	3.0	0.1
Area 2 (Racine)	28 percent	1,217	N/A	3,860	N/A	3.2	N/A
	20 percent	1,217	0.0	3,981	3.1	3.3	0.1
	10 percent	1,217	0.0	3,952	2.4	3.2	0.0
	5 percent	1,217	0.0	3,341	- 13.4	2.7	- 0.5
	3 percent	1,217	0.0	4,439	15.0	3.6	0.4
Area 3 (Waukesha-South)	31 percent	566	N/A	1,793	N/A	3.2	N/A
	20 percent	560	- 1.1	1,754	- 2.2	3.1	- 0.1
	10 percent	585	3.4	1,840	2.6	3.1	- 0.1
	5 percent	546	- 3.5	1,507	- 16.0	2.8	- 0.4
	3 percent	553	- 2.3	1,554	- 13.3	2.8	- 0.4
Area 4 (Waukesha-North)	32 percent	656	N/A	2,746	N/A	4.2	N/A
	20 percent	654	- 0.3	2,706	- 1.5	4.1	- 0.1
	10 percent	649	- 1.1	2,552	- 7.1	3.9	- 0.3
	5 percent	659	0.5	2,592	- 5.6	3.9	- 0.3
	3 percent	659	0.5	2,830	3.1	4.3	0.1
Area 5 (Milwaukee-South)	31 percent	1,893	N/A	6,308	N/A	3.3	N/A
	20 percent	1,887	- 0.3	6,229	- 1.3	3.3	0.0
	10 percent	1,887	- 0.3	6,314	0.1	3.3	0.0
	5 percent	1,897	0.2	6,209	- 1.2	3.3	0.0
	3 percent	1,851	- 2.2	6,457	2.4	3.5	0.2
Area 6 (Milwaukee-North)	29 percent	1,727	N/A	5,754	N/A	3.3	N/A
	20 percent	1,720	- 0.4	5,840	1.5	3.4	0.1
	10 percent	1,725	- 0.1	5,774	0.3	3.3	0.0
	5 percent	1,735	0.5	5,673	- 1.4	3.3	0.0
	3 percent	1,704	- 1.3	4,834	- 16.0	2.8	- 0.5

NOTE: N/A—not applicable.

Source: SEWRPC.

Table 2

AUTOMOBILES AVAILABLE AND AUTOS PER HOUSEHOLD IN SIX TEST AREAS AS REPORTED BY DIFFERING SAMPLE RATES

Test Area	Sample Rate	Indicated Autos Available	Percent Difference	Indicated Autos Per Household	Difference in Autos Per Household
Area 1 (Kenosha)	26 percent	1,476	N/A	1.2	N/A
	20 percent	1,519	2.9	1.2	0.0
	10 percent	1,502	1.8	1.2	0.0
	5 percent	1,617	9.6	1.3	0.1
	3 percent	1,467	- 0.6	1.2	0.0
Area 2 (Racine)	28 percent	1,821	N/A	1.5	N/A
	20 percent	1,854	1.8	1.5	0.0
	10 percent	1,809	- 0.7	1.5	0.0
	5 percent	1,551	- 14.8	1.3	- 0.2
	3 percent	1,933	6.2	1.6	0.1
Area 3 (Waukesha-South)	31 percent	743	N/A	1.3	N/A
	20 percent	758	2.0	1.4	0.1
	10 percent	755	1.6	1.3	0.0
	5 percent	677	- 8.9	1.2	- 0.1
	3 percent	587	- 21.0	1.1	- 0.2
Area 4 (Waukesha-North)	32 percent	1,024	N/A	1.6	N/A
	20 percent	1,002	- 2.1	1.5	- 0.1
	10 percent	1,067	4.2	1.6	0.0
	5 percent	1,054	2.9	1.6	0.0
	3 percent	1,357	32.5	2.1	0.5
Area 5 (Milwaukee-South)	31 percent	2,609	N/A	1.4	N/A
	20 percent	2,568	- 1.6	1.4	0.0
	10 percent	2,635	1.0	1.4	0.0
	5 percent	2,538	- 2.7	1.3	- 0.1
	3 percent	2,540	- 2.6	1.4	0.0
Area 6 (Milwaukee-North)	29 percent	1,288	N/A	0.7	N/A
	20 percent	1,298	0.8	0.8	0.1
	10 percent	1,346	4.5	0.8	0.1
	5 percent	1,434	11.3	0.8	0.1
	3 percent	835	- 35.2	0.5	- 0.2

NOTE: N/A—not applicable.

Source: SEWRPC.

rate groups. Namely, the Waukesha-South and Racine 5 percent samples differ from the 30 percent samples by 10 percent and 11 percent, respectively, and the Waukesha-South and Milwaukee-North 3 percent samples vary by 32 percent each (see Table 3).

Characteristics of the Populations
Among the socioeconomic data obtained in the home interview portion of the mass transit nonuser survey, the major characteristics were the sex, race, age, and licensed driver status of the household members. In each of the six areas, application of the differing sample rates resulted in similar distributions of socioeconomic data although greater variations from the 30 percent samples were observed as the sample rate declined.

As shown in Table 4, the percentage distributions of the populations in the six areas by male and female differ by no more than five percentage points for any sample rate with the exception of a difference of nine percentage points found in the Waukesha-South 3 percent sample. The proportion of licensed drivers in the populations 15 years of age and older in each of the six areas is, for the most part, also very similar among sample sizes. As shown in Table 5, the only notable exceptions occur in the 3 percent samples in Milwaukee-South with a difference in the distributions of 5 percent from the 30 percent sample and in Milwaukee-North with a difference of 8 percent from the 30 percent sample. By race, the population in each area for each sample rate varied by no more than four percentage points from the distribution of the 30 percent sample with the exceptions of a 9 percent larger white population and a 10 percent smaller black population reported in the Milwaukee-North 5 percent sample, and a 6 percent larger population of "other" races found in the Waukesha-South 3 percent sample (see Table 6). Due to the increased effect of sampling variability as the specificity of the item being examined increases, considerably greater variations were found between sample rate groups when the population was arrayed by age group as shown in Table 7. Noticeable voids occur in the age brackets of 55 or older in the Waukesha-North and Waukesha-South 3 percent samples and in the 65 years of age or older age group of the Waukesha-South 5 percent sample.

In summary, socioeconomic characteristics of households and populations, although generally similar for all sample rates within an area, show greater variations in the lower sample rate groups as the specificity of, or the number of possible responses to, the item being examined increases. For example, percentage distributions of the sexual, racial, and licensed driver status of the study area populations were fairly similar for each sample rate group within each area. For each of these items the possible response is limited to one of two or three choices, e.g., sex is either male or female. On the other hand, showing greater variability as the sample rate declines is the distribution of the number of automobiles available, which is collected as the actual number garaged at the household and generally ranges between a response of zero to five; the population of the areas, which is collected as the actual number of persons living in the household and generally ranges between one and seven; and the median household annual income, which is collected by assigning the income to one of 10 possible categories. Distributions of the populations by age group indicate the most frequent, significant variations among sample rate groups, as would be expected, since for this item the actual age from five years to 99 years is collected and the data is subsequently analyzed by utilizing 10 distinct age groups.

Table 3

1972 MEDIAN HOUSEHOLD ANNUAL INCOME IN SIX TEST AREAS AS REPORTED BY DIFFERING SAMPLE RATES

Sample Rate	Indicated Median Household Annual Income in Dollars											
	Area 1 (Kenosha) (in dollars)	Percent Difference	Area 2 (Racine) (in dollars)	Percent Difference	Area 3 (Waukesha-South) (in dollars)	Percent Difference	Area 4 (Waukesha-North) (in dollars)	Percent Difference	Area 5 (Milwaukee-South) (in dollars)	Percent Difference	Area 6 (Milwaukee-North) (in dollars)	Percent Difference
30 percent[a]	8,200	N/A	10,500	N/A	11,000	N/A	11,800	N/A	11,300	N/A	6,200	N/A
20 percent	8,500	3.7	10,500	0.0	11,300	2.7	12,300	4.2	11,300	0.0	6,100	- 1.6
10 percent	8,700	5.9	11,200	6.7	11,200	1.8	11,700	- 0.8	11,400	0.9	6,600	6.5
5 percent	8,600	4.9	9,400	- 10.5	12,100	10.0	11,900	0.8	10,800	- 4.4	6,600	6.5
3 percent	8,600	4.9	10,300	- 1.9	7,500	- 31.8	12,000	1.7	11,900	5.3	4,200	- 32.3

[a] *Thirty percent is an approximate figure. Actual sample rates obtained are: Kenosha, 26 percent; Racine, 28 percent; Waukesha-South, 31 percent; Waukesha-North, 32 percent; Milwaukee-South, 31 percent; and, Milwaukee-North, 29 percent.*

Source: SEWRPC.

Table 4

PERCENTAGE DISTRIBUTION OF THE POPULATIONS BY SEX IN SIX TEST AREAS AS REPORTED BY DIFFERING SAMPLE RATES

Test Area	Sample Rate	Indicated Male (percent)	Difference in Percent Distribution	Indicated Female (percent)	Total (percent)
Area 1	26 percent	48.8	N/A	51.2	100.0
(Kenosha)	20 percent	48.8	0.0	51.2	100.0
	10 percent	52.4	3.6	47.6	100.0
	5 percent	53.8	5.0	46.2	100.0
	3 percent	50.0	1.2	50.0	100.0
Area 2	28 percent	50.1	--	49.9	100.0
(Racine)	20 percent	50.0	0.1	50.0	100.0
	10 percent	48.1	2.0	51.9	100.0
	5 percent	48.1	2.0	51.9	100.0
	3 percent	54.3	4.2	45.7	100.0
Area 3	31 percent	49.3	N/A	50.7	100.0
(Waukesha-South)	20 percent	49.8	0.5	50.2	100.0
	10 percent	51.0	1.7	49.0	100.0
	5 percent	51.6	2.3	48.4	100.0
	3 percent	40.0	9.3	60.0	100.0
Area 4	32 percent	48.4	N/A	51.6	100.0
(Waukesha-North)	20 percent	47.9	0.5	52.1	100.0
	10 percent	51.2	2.8	48.8	100.0
	5 percent	47.6	0.8	52.4	100.0
	3 percent	46.0	2.4	54.0	100.0
Area 5	31 percent	49.7	N/A	50.3	100.0
(Milwaukee-South)	20 percent	50.3	0.6	49.7	100.0
	10 percent	47.8	1.9	52.2	100.0
	5 percent	49.4	0.3	50.6	100.0
	3 percent	46.4	3.3	53.6	100.0
Area 6	29 percent	46.0	N/A	54.0	100.0
(Milwaukee-North)	20 percent	44.4	1.6	55.6	100.0
	10 percent	46.9	0.9	53.1	100.0
	5 percent	46.3	0.3	53.7	100.0
	3 percent	42.4	3.6	57.6	100.0

NOTE: N/A—not applicable.

Source: SEWRPC.

Table 5

PERCENT OF POPULATIONS 15 YEARS AND OLDER WITH LICENSE TO DRIVE AS REPORTED IN SIX TEST AREAS BY DIFFERING SAMPLE RATES

Sample Rate	Indicated Percent of Population 15 Years and Older with License to Drive by Area											
	Area 1 (Kenosha)	Difference in Percent Distribution	Area 2 (Racine)	Difference in Percent Distribution	Area 3 (Waukesha-South)	Difference in Percent Distribution	Area 4 (Waukesha-North)	Difference in Percent Distribution	Area 5 (Milwaukee-South)	Difference in Percent Distribution	Area 6 (Milwaukee-North)	Difference in Percent Distribution
30 percent[a]	75.4	N/A	85.2	N/A	83.7	N/A	81.2	N/A	73.4	N/A	46.8	N/A
20 percent	76.4	1.0	86.1	0.9	82.8	- 0.9	81.1	- 0.1	73.2	- 0.2	46.7	- 0.1
10 percent	78.5	3.1	86.6	1.4	83.8	0.1	82.7	1.5	71.8	- 1.6	47.1	0.3
5 percent	75.0	- 0.4	83.8	- 1.4	85.4	1.7	85.1	3.9	71.7	- 1.7	50.3	3.5
3 percent	76.9	1.5	87.0	1.8	85.2	1.5	83.3	2.1	78.4	5.0	39.3	- 7.5

NOTE: N/A—not applicable.

[a] Thirty percent is an approximate figure. Actual sample rates obtained are: Kenosha, 26 percent; Racine, 28 percent; Waukesha-South, 31 percent; Waukesha-North, 32 percent; Milwaukee-South, 31 percent; Milwaukee-North, 29 percent.

Source: SEWRPC.

Table 6

PERCENTAGE DISTRIBUTION OF THE POPULATIONS BY RACE IN SIX TEST AREAS AS REPORTED BY DIFFERING SAMPLE RATES

Test Area	Indicated Race				
	Sample Rate	White (percent)	Black (percent)	Other (percent)	Total (percent)
Area 1 (Kenosha)	26 percent	100.0	0.0	0.0	100.0
	20 percent	100.0	0.0	0.0	100.0
	10 percent	100.0	0.0	0.0	100.0
	5 percent	100.0	0.0	0.0	100.0
	3 percent	100.0	0.0	0.0	100.0
Area 2 (Racine)	28 percent	99.6	0.3	0.1	100.0
	20 percent	99.8	0.0	0.2	100.0
	10 percent	99.0	0.7	0.3	100.0
	5 percent	98.5	1.5	0.0	100.0
	3 percent	97.9	2.1	0.0	100.0
Area 3 (Waukesha-South)	31 percent	97.1	0.2	2.7	100.0
	20 percent	97.6	0.4	2.0	100.0
	10 percent	100.0	0.0	0.0	100.0
	5 percent	100.0	0.0	0.0	100.0
	3 percent	91.4	0.0	8.6	100.0
Area 4 (Waukesha-North)	32 percent	100.0	0.0	0.0	100.0
	20 percent	100.0	0.0	0.0	100.0
	10 percent	100.0	0.0	0.0	100.0
	5 percent	100.0	0.0	0.0	100.0
	3 percent	100.0	0.0	0.0	100.0
Area 5 (Milwaukee-South)	31 percent	99.6	0.0	0.4	100.0
	20 percent	99.4	0.0	0.6	100.0
	10 percent	99.2	0.0	0.8	100.0
	5 percent	99.1	0.0	0.9	100.0
	3 percent	96.9	0.0	3.1	100.0
Area 6 (Milwaukee-North)	29 percent	54.5	42.6	2.9	100.0
	20 percent	54.6	41.4	4.0	100.0
	10 percent	57.8	38.6	3.6	100.0
	5 percent	63.2	32.7	4.1	100.0
	3 percent	58.9	38.7	2.4	100.0

Source: SEWRPC.

Table 7

PERCENTAGE DISTRIBUTION OF THE POPULATIONS BY AGE
IN SIX TEST AREAS AS REPORTED BY DIFFERING SAMPLE RATES

Test Area	Sample Rate	Indicated Percent of Populations by Age Groups (in years)										
		5-9	10-14	15-19	20-24	25-29	30-34	35-44	45-54	55-64	65 +	Total
Area 1 (Kenosha)	26 percent	10.6	9.4	9.4	7.0	7.3	6.2	10.3	9.5	14.0	16.3	100.0
	20 percent	10.0	8.3	9.8	7.6	6.7	5.1	10.6	11.3	14.4	16.2	100.0
	10 percent	10.7	9.7	8.3	8.6	6.2	7.2	9.3	11.4	13.4	15.2	100.0
	5 percent	14.5	11.6	12.2	4.7	4.1	8.1	13.4	6.4	16.3	8.7	100.0
	3 percent	11.4	7.3	9.4	7.3	5.2	3.1	14.6	14.6	15.6	11.5	100.0
Area 2 (Racine)	28 percent	10.1	11.4	11.2	7.0	6.6	5.7	14.0	15.2	8.3	10.5	100.0
	20 percent	11.0	12.0	11.5	6.7	6.7	6.7	13.4	15.0	7.7	9.3	100.0
	10 percent	7.5	11.9	13.8	8.5	9.1	3.5	14.5	14.2	8.2	8.8	100.0
	5 percent	6.1	9.2	9.9	8.4	6.1	5.4	9.9	14.5	13.7	16.8	100.0
	3 percent	14.6	12.6	6.8	9.7	10.7	9.7	11.6	8.7	4.9	10.7	100.0
Area 3 (Waukesha-South)	31 percent	11.4	12.5	10.2	20.8	13.5	7.3	12.5	7.3	3.8	0.7	100.0
	20 percent	10.4	14.2	10.5	19.8	11.9	7.8	13.8	7.5	3.7	0.4	100.0
	10 percent	10.4	13.9	12.5	19.4	10.4	7.0	11.8	8.3	4.9	1.4	100.0
	5 percent	7.8	17.2	7.8	17.2	4.7	14.0	14.1	12.5	4.7	0.0	100.0
	3 percent	17.1	5.7	2.9	31.4	17.2	2.9	17.2	5.7	0.0	0.0	100.0
Area 4 (Waukesha-North)	32 percent	15.2	20.8	12.3	4.7	5.3	7.0	19.4	8.0	4.9	2.4	100.0
	20 percent	13.8	20.6	13.4	4.6	4.5	7.2	18.7	8.9	5.1	3.2	100.0
	10 percent	16.1	20.3	10.1	5.1	3.7	5.5	19.8	11.1	4.6	3.7	100.0
	5 percent	11.4	18.1	11.4	7.6	7.6	9.5	17.2	8.6	5.7	2.9	100.0
	3 percent	12.7	20.6	12.7	9.5	11.1	4.8	15.9	12.7	0.0	0.0	100.0
Area 5 (Milwaukee-South)	31 percent	10.1	12.5	11.4	6.9	6.1	5.7	11.7	18.2	11.0	6.4	100.0
	20 percent	9.6	12.0	11.3	7.1	6.3	6.0	10.9	18.1	11.4	7.3	100.0
	10 percent	9.4	13.0	14.2	6.6	4.6	4.8	12.9	19.5	9.4	5.6	100.0
	5 percent	10.1	14.8	11.4	4.2	5.9	5.5	11.8	17.7	10.6	8.0	100.0
	3 percent	14.6	11.7	10.2	4.4	8.0	7.3	12.4	19.0	10.2	2.2	100.0
Area 6 (Milwaukee-North)	29 percent	12.6	14.6	10.8	9.9	6.8	6.1	9.1	10.0	7.8	12.3	100.0
	20 percent	12.8	14.5	11.4	10.5	6.6	5.9	8.9	9.5	7.7	12.2	100.0
	10 percent	10.4	15.3	11.8	11.3	7.8	5.3	8.2	10.2	7.3	12.4	100.0
	5 percent	13.2	13.2	7.5	11.9	6.2	7.5	10.6	9.2	8.4	12.3	100.0
	3 percent	12.8	16.0	8.0	7.2	5.6	7.2	12.8	6.4	7.2	16.8	100.0

Source: SEWRPC.

Travel Characteristics

Comparisons of tripmaking data obtained at the differing sample rates indicated that for each test area the trip volumes, modal choice, and trip purposes of total internal person travel remained substantially similar although greater variations in these travel aspects are observed as the sample rate declines.

Presented in Table 8 are the numbers of total internal person trips and the average trips per household found in each sample rate group in each of the six test areas. The number and average trips per household of internal person trips are generally similar for all sample rates in each area. The notable exceptions occur in the Kenosha 5 percent sample with differences from the 30 percent sample of 1,416 person trips, or 22 percent, and an average person trip per household of 6.2 as opposed to 5.2; in the Waukesha-South 3 percent sample with differences from the 30 percent sample of 985 person trips, or 21 percent, and an average person trip per household of 6.6 as opposed to 8.2; in the Waukesha-North 3 percent sample with differences from the 30 percent sample of 1,585 person trips, or 25 percent, and an average person trip per household of 7.3 as opposed to 9.8; and, in the Milwaukee-North 3 percent sample with differences from the 30 percent sample of 2,369 person trips, or 33 percent, and an average person trip per household of 2.8 as opposed to 4.1.

Table 8

HOME-BASED, NONHOME-BASED, AND TOTAL INTERNAL PERSON TRIPS GENERATED BY SIX TEST AREAS AS REPORTED BY DIFFERING SAMPLE RATES

Test Area	Sample Rate	Indicated Internal Person Trips							
		Home-based		Nonhome-based		Total			
		Trips	Percent of Total Trips	Trips	Percent of Total Trips	All Trips	Percent Difference	Trips Per Household	Difference in Trips per Household
Area 1 (Kenosha)	26 percent	5,369	81.6	1,212	18.4	6,581	N/A	5.2	N/A
	20 percent	5,516	81.3	1,272	18.7	6,788	3.1	5.3	0.1
	10 percent	5,575	82.2	1,208	17.8	6,783	3.1	5.4	0.2
	5 percent	6,653	83.2	1,344	16.8	7,997	21.5	6.2	1.0
	3 percent	5,696	89.9	640	10.1	6,336	- 3.7	5.1	- 0.1
Area 2 (Racine)	28 percent	8,083	81.7	1,814	18.3	9,897	N/A	8.1	N/A
	20 percent	7,956	80.2	1,959	19.8	9,915	0.2	8.1	0.0
	10 percent	7,998	80.7	1,914	19.3	9,912	0.2	8.1	0.0
	5 percent	8,127	80.4	1,977	19.6	10,104	2.1	8.3	0.2
	3 percent	7,928	83.5	1,565	16.5	9,493	- 4.1	7.8	- 0.3
Area 3 (Waukesha-South)	31 percent	3,729	80.1	929	19.9	4,658	N/A	8.2	N/A
	20 percent	3,791	81.1	883	18.9	4,674	0.3	8.3	0.1
	10 percent	3,942	81.9	873	18.1	4,815	3.4	8.2	0.0
	5 percent	3,255	74.9	1,091	25.1	4,346	- 7.2	8.0	- 0.2
	3 percent	2,470	67.2	1,203	32.8	3,673	- 21.1	6.6	- 1.6
Area 4 (Waukesha-North)	32 percent	5,078	79.0	1,349	21.0	6,427	N/A	9.8	N/A
	20 percent	5,369	81.0	1,263	19.0	6,632	3.2	10.1	0.3
	10 percent	4,787	78.1	1,340	21.9	6,127	- 4.7	9.4	- 0.4
	5 percent	5,443	80.7	1,298	19.3	6,741	4.9	10.2	0.4
	3 percent	3,414	70.5	1,428	29.5	4,842	- 24.7	7.3	- 2.5
Area 5 (Milwaukee-South)	31 percent	11,613	80.5	2,806	19.5	14,419	N/A	7.6	N/A
	20 percent	11,290	80.4	2,746	19.6	14,036	- 2.7	7.4	- 0.2
	10 percent	10,864	78.9	2,899	21.1	13,763	- 4.5	7.3	- 0.3
	5 percent	10,303	75.6	3,324	24.4	13,627	- 5.5	7.2	- 0.4
	3 percent	12,159	84.7	2,189	15.3	14,348	- 0.5	7.8	0.2
Area 6 (Milwaukee-North)	29 percent	5,991	84.0	1,143	16.0	7,134	N/A	4.1	N/A
	20 percent	6,024	83.4	1,199	16.6	7,223	1.2	4.2	0.1
	10 percent	5,919	84.6	1,079	15.4	6,998	- 1.9	4.1	0.0
	5 percent	5,999	83.2	1,212	16.8	7,211	1.1	4.2	0.1
	3 percent	4,278	89.8	487	10.2	4,765	- 33.2	2.8	- 1.3

NOTE: N/A—not available.

Source: SEWRPC.

Variations in travel volumes of the magnitude described above are not unexpected from a low sample rate home interview origin-destination survey. For this reason supplementary data obtained through vehicle counts at preselected screenlines, cutlines, and cordon lines are utilized in the performance of accuracy checks and in the production of sound trip adjustment factors. It should be noted that the trip volumes obtained for the high sample areas represent expanded but otherwise unadjusted data.

Also shown in Table 8 are the number of internal person trips which are home-based and nonhome-based and the percent each represents of total internal person travel within each test area. As a percent of total internal person travel, the distributions of home-based trips in the three largest sample rate groups within each area were within 2 percent while variations from the 30 percent sample data of up to 5 percent were observed in the 5 percent sample distributions and variations of up to 13 percent were found in the 3 percent sample distributions.

Percentage distributions of internal person trips by mode of travel are similar, in most cases, to the 30 percent sample in each area for auto driver and auto passenger travel while bus passenger travel in areas producing few such trips and travel by other modes are both generally understated by the smaller sample rates. The only notable differences in the distributions by mode occur in the Waukesha-South 3 percent sample with a greater proportion of auto driver trips than the 30 percent sample by 12 percent and a smaller proportion of auto passenger trips by 11 percent; in the Milwaukee-North 5 percent sample with a greater proportion of auto driver trips than the 30 percent sample by 9 percent and a smaller proportion of bus passenger trips by 7 percent; and, in the Milwaukee-North 3 percent sample with a smaller proportion of auto driver trips than the 30 percent sample by 7 percent and a greater proportion of bus passenger trips by 8 percent (see Table 9).

The percentage distributions of person travel by trip purpose at destination, as shown in Table 10, indicated very similar patterns which varied by no more than 5 percent within a given purpose for each sample rate group in each area, with only six greater differences, all of which occurred in the 3 percent samples. Those differences from the distributions of the 30 percent

Table 9

PERCENTAGE DISTRIBUTION OF THE TRAVEL MODES OF INTERNAL PERSON TRIPS MADE BY RESIDENTS OF SIX TEST AREAS AS REPORTED BY DIFFERING SAMPLE RATES

Test Area	Sample Rate	Indicated Percent of Internal Person Trips by Mode of Travel				
		Auto Driver	Auto Passenger	Bus Passenger	Other	Total
Area 1 (Kenosha)	26 percent	72.1	26.3	1.0	0.6	100.0
	20 percent	71.5	27.1	1.1	0.3	100.0
	10 percent	74.3	24.4	0.0	1.3	100.0
	5 percent	73.4	25.8	0.0	0.8	100.0
	3 percent	71.5	28.5	0.0	0.0	100.0
Area 2 (Racine)	28 percent	67.0	32.0	0.4	0.6	100.0
	20 percent	68.7	30.4	0.3	0.6	100.0
	10 percent	68.6	30.7	0.4	0.3	100.0
	5 percent	64.4	34.7	0.0	0.9	100.0
	3 percent	64.4	35.6	0.0	0.0	100.0
Area 3 (Waukesha-South)	31 percent	67.4	31.3	0.4	0.9	100.0
	20 percent	64.8	33.6	0.7	0.9	100.0
	10 percent	64.0	33.7	0.4	1.9	100.0
	5 percent	62.0	36.6	0.9	0.5	100.0
	3 percent	79.6	20.4	0.0	0.0	100.0
Area 4 (Waukesha-North)	32 percent	62.7	35.9	0.4	1.0	100.0
	20 percent	61.6	36.4	0.5	1.5	100.0
	10 percent	59.9	38.7	0.0	1.4	100.0
	5 percent	60.9	38.5	0.0	0.6	100.0
	3 percent	63.8	36.2	0.0	0.0	100.0
Area 5 (Milwaukee-South)	31 percent	65.5	29.5	4.7	0.3	100.0
	20 percent	66.1	29.1	4.5	0.3	100.0
	10 percent	66.8	28.7	4.1	0.4	100.0
	5 percent	68.7	26.5	4.8	0.0	100.0
	3 percent	67.8	28.7	3.5	0.0	100.0
Area 6 (Milwaukee-North)	29 percent	53.7	24.7	20.3	1.3	100.0
	20 percent	54.2	25.4	18.8	1.6	100.0
	10 percent	56.7	22.8	19.7	0.8	100.0
	5 percent	62.8	21.9	13.8	1.5	100.0
	3 percent	46.7	23.4	28.5	1.4	100.0

Source: SEWRPC.

Table 10

PERCENTAGE DISTRIBUTION OF THE DESTINATION PURPOSES OF INTERNAL PERSON TRIPS MADE BY RESIDENTS OF SIX TEST AREAS AS REPORTED BY DIFFERING SAMPLE RATES

Test Area	Sample Rate	Indicated Percent of Internal Person Trips by Trip Purpose at Destination						
		Home	Work	Personal Business	School	Social-Recreation	Shopping	Total
Area 1 (Kenosha)	26 percent	40.6	16.4	17.9	1.2	11.6	12.3	100.0
	20 percent	40.4	16.7	18.1	1.2	11.3	12.3	100.0
	10 percent	41.5	17.3	19.1	1.2	9.7	11.2	100.0
	5 percent	41.5	18.5	14.9	0.8	13.7	10.6	100.0
	3 percent	44.9	17.7	11.1	0.0	15.2	11.1	100.0
Area 2 (Racine)	28 percent	40.7	16.3	17.5	0.5	11.4	13.6	100.0
	20 percent	40.1	17.0	17.8	0.6	11.8	12.7	100.0
	10 percent	40.3	16.2	18.6	0.6	11.9	12.4	100.0
	5 percent	40.5	18.5	16.1	0.8	10.9	13.2	100.0
	3 percent	40.8	22.1	16.9	0.5	11.1	8.6	100.0
Area 3 (Waukesha-South)	31 percent	40.1	16.7	17.5	0.5	15.0	10.2	100.0
	20 percent	40.7	17.5	17.7	0.8	15.4	7.9	100.0
	10 percent	41.4	17.7	14.3	0.2	15.5	10.9	100.0
	5 percent	38.0	19.9	19.4	0.0	14.8	7.9	100.0
	3 percent	32.4	16.7	16.7	0.0	14.0	20.2	100.0
Area 4 (Waukesha-North)	32 percent	39.2	17.0	17.3	0.7	13.8	12.0	100.0
	20 percent	40.3	16.6	16.6	0.6	14.1	11.8	100.0
	10 percent	38.4	14.9	17.9	0.8	12.9	15.1	100.0
	5 percent	39.7	17.5	17.2	0.9	12.5	12.2	100.0
	3 percent	34.5	21.6	24.5	0.7	12.9	5.8	100.0
Area 5 (Milwaukee-South)	31 percent	39.9	18.2	17.2	1.0	10.5	13.2	100.0
	20 percent	39.8	17.0	18.2	1.1	9.9	14.0	100.0
	10 percent	38.7	20.7	15.5	1.3	10.8	13.0	100.0
	5 percent	37.5	16.1	20.6	0.3	9.4	16.1	100.0
	3 percent	41.9	18.8	15.2	0.6	10.6	12.9	100.0
Area 6 (Milwaukee-North)	29 percent	41.9	20.3	17.2	1.8	10.1	8.7	100.0
	20 percent	41.6	19.9	17.4	1.5	11.4	8.2	100.0
	10 percent	42.2	20.3	16.0	2.5	8.9	10.1	100.0
	5 percent	41.5	21.0	17.6	0.9	9.8	9.2	100.0
	3 percent	44.5	20.4	16.1	1.5	5.8	11.7	100.0

Source: SEWRPC.

samples which exceeded 5 percent were observed in the 3 percent samples in Kenosha, under trip purpose "personal business" with a difference from the 30 percent sample of 7 percent; in Racine, under trip purpose "work" with a difference of 6 percent; in Waukesha-South, under trip purpose "home" with a difference of 8 percent and under trip purpose "shopping" with a difference of 10 percent; and in Waukesha-North, under trip purpose "personal business" with a difference of 7 percent, and under trip purpose "shopping" with a difference of 6 percent.

An examination of the trip purposes of bus passenger travel in Milwaukee-South and Milwaukee-North, the two areas producing significant numbers of bus passenger trips, disclosed substantial variation within the lower sample rates from the distribution of the same data obtained by the 30 percent samples. Such variation is expected when observing a specific of travel which represents a relatively small percentage of total person trip volumes.[1] For this reason, low sample rate home interview type origin-destination surveys frequently are supplemented by complementary subsurveys. An example

[1] *U. S. Department of Transportation/Federal Highway Administration, Urban Origin-Destination Surveys, 1973, Washington, D. C., pp. 33-34, 36-39.*

of this technique was the conduct by the SEWRPC in 1972 of the mass transit user survey as a portion of the continuing land use-transportation study, as well as other auxiliary origin-destination surveys, supplementary to the regional home interview survey.

The most notable variations in trip purposes of bus passengers from the 30 percent sample occurred in the 5 and 3 percent sample rate groups. The Milwaukee-South 5 percent sample obtained no bus passenger travel for the purpose of shopping, while trips to school, to conduct personal business, and for social-recreational purposes were overrepresented as percentages of total bus passenger travel. The Milwaukee-South 3 percent sample obtained no bus passenger travel for the purposes of conducting personal business, attending school, or shopping while trips for social-recreational purposes were markedly overstated as a percentage of total bus passenger travel. The Milwaukee-North 5 percent sample slightly understated bus passenger trips for social-recreational and shopping purposes while overstating trips made to go to work, conduct personal business, or attend school. The Milwaukee-North 3 percent sample recorded no bus passenger trips for the purpose of attending school or for social-recreation while trips for shopping were overstated as a percentage of total bus passenger travel (see Table 11).

In summary, percentage distributions of major travel modes and major trip purposes, those modes and purposes which incorporate the greatest numbers of trips, such as auto driver and passenger travel and home and work trip purposes, show few significant variations between sample rate groups. On the other hand, bus passenger and other modes of travel and the other remaining trip purposes show more frequent variations between sample sizes. Even within the distribution of bus passenger travel by trip purpose, it is observed that home and work purposes as a percent of total bus passenger travel are fairly consistent between sample rates while the other purposes show increasing variations from data obtained by the 30 percent sample as the sample rate declines. Clearly, as the specificity of the travel characteristic being examined increases, the effects of sampling variability are magnified, reducing the accuracy of the low sample rate survey data.

The Location of Travel

Comparisons at the zonal level of trip data obtained by the differing sample rates in each area indicated that, as expected, the trip patterns from the smaller sample rate groups were substantially different than the patterns obtained by the 30 percent samples. It should be emphasized that these sample rate group data reflect trip patterns resulting from the application of expansion factors and do not reflect modifications which are generally applied to such data in the form of trip adjustment factoring, regression analysis, modal split, or gravity distributions and the accompanying calibrations of such procedures.

Table 12 indicates the number of internal zones attracting total person trips and home-based person trips for each sample rate in each area. It is clearly shown that, as the sample rate declines, the number of internal destination zones declines. The number of destination zones receiving internal person travel found in the 3 percent sample as a percent of the number of such zones indicated by the 30 percent sample amounted to 47 percent in Kenosha, 43 percent in Racine, 20 percent in Waukesha-South, 20 percent in Waukesha-North, 31 percent in Milwaukee-South, and 24 percent in Milwaukee-North. The number of nonhome zones receiving home-based person travel found in the 3 percent sample as a percent

Table 11

PERCENTAGE DISTRIBUTION OF THE DESTINATION PURPOSES OF BUS PASSENGER TRIPS MADE BY RESIDENTS OF TWO TEST AREAS AS REPORTED BY DIFFERING SAMPLE RATES

Test Area	Sample Rate	Indicated Percentage Distribution of Bus Passenger Trips by Purpose at Destination						
		Home	Work	Personal Business	School	Social-Recreation	Shopping	Total
Area 5 (Milwaukee-South)	31 percent	42.0	31.4	13.5	2.4	4.8	5.9	100.0
	20 percent	42.2	32.1	13.8	2.7	3.7	5.5	100.0
	10 percent	40.8	26.5	16.3	4.1	4.1	8.2	100.0
	5 percent	35.7	32.2	17.8	7.1	7.2	0.0	100.0
	3 percent	41.7	33.3	0.0	0.0	25.0	0.0	100.0
Area 6 (Milwaukee-North)	29 percent	45.5	21.1	12.7	4.9	4.9	10.9	100.0
	20 percent	44.4	21.4	12.7	4.0	5.6	11.9	100.0
	10 percent	46.0	23.4	9.7	4.0	4.0	12.9	100.0
	5 percent	43.8	27.1	14.6	6.2	2.1	6.2	100.0
	3 percent	46.2	20.5	12.8	0.0	0.0	20.5	100.0

Source: SEWRPC.

Table 12

NUMBER OF TRAFFIC ANALYSIS ZONES ATTRACTING INTERNAL HOME-BASED PERSON TRIPS AND TOTAL INTERNAL PERSON TRIPS GENERATED BY SIX TEST AREAS AS REPORTED BY DIFFERING SAMPLE RATES

		Indicated Internal Person Trips			
		Home-based		Total	
Test Area	Sample Rate	Number of Attracting Zones	Percent of the Number of Zones Found by Highest Sample Rate	Number of Attracting Zones	Percent of the Number of Zones Found by Highest Sample Rate
Area 1 (Kenosha)	26 percent	50	N/A	53	N/A
	20 percent	46	92.0	50	94.3
	10 percent	34	68.0	35	66.0
	5 percent	29	58.0	33	62.3
	3 percent	24	48.0	25	47.2
Area 2 (Racine)	28 percent	76	N/A	96	N/A
	20 percent	72	94.7	92	95.8
	10 percent	50	65.8	55	57.3
	5 percent	35	46.1	40	41.7
	3 percent	32	42.1	40	41.7
Area 3 (Waukesha-South)	31 percent	94	N/A	107	N/A
	20 percent	68	72.3	76	71.0
	10 percent	46	48.9	52	48.6
	5 percent	24	25.5	28	26.2
	3 percent	17	18.1	21	19.6
Area 4 (Waukesha-North)	32 percent	99	N/A	120	N/A
	20 percent	73	73.7	82	68.3
	10 percent	45	45.5	50	41.7
	5 percent	29	29.3	31	25.8
	3 percent	21	21.2	24	20.0
Area 5 (Milwaukee-South)	31 percent	229	N/A	247	N/A
	20 percent	196	85.6	215	87.0
	10 percent	140	61.1	157	63.6
	5 percent	80	34.9	101	40.9
	3 percent	66	28.8	77	31.2
Area 6 (Milwaukee-North)	29 percent	191	N/A	201	N/A
	20 percent	163	85.3	175	87.1
	10 percent	114	59.7	126	62.7
	5 percent	78	40.8	90	44.8
	3 percent	44	23.0	49	24.4

NOTE: N/A—not applicable.

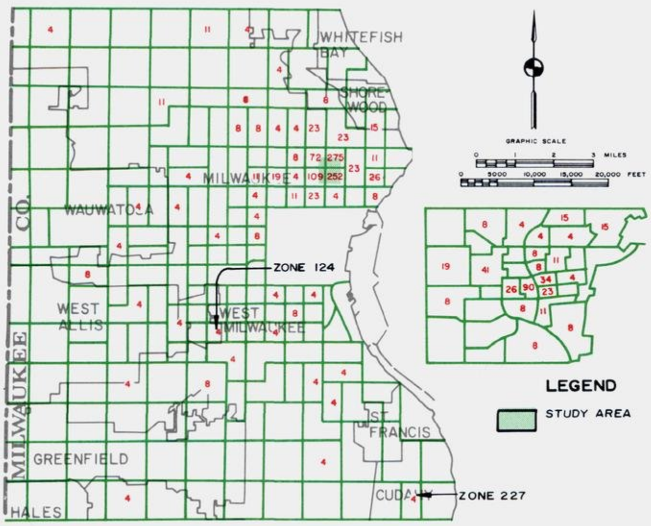
Source: SEWRPC.

of the number of such zones reported by the 30 percent sample showed declines which were very similar to the percent declines found for total person travel. When such travel data were observed by mode, similar patterns also were obtained.

Mapping of total person travel and bus passenger travel destination zones emphasized the differences in travel patterns created by varying sample rates. Providing a typical example of differences in the travel patterns obtained by the varying sample rates are Maps 2a-2e in

Map 2a

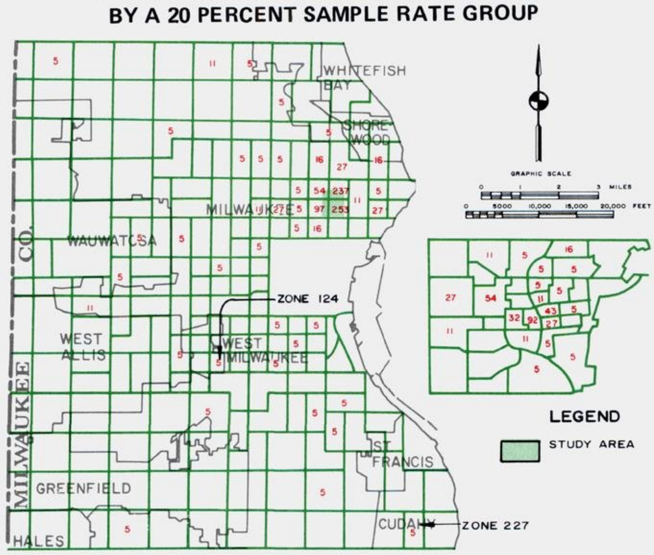
LOCATION BY TRAFFIC ANALYSIS ZONE OF BUS PASSENGER TRIP DESTINATIONS BY RESIDENTS OF THE MILWAUKEE-NORTH TEST AREA AS REPORTED BY A 29 PERCENT SAMPLE RATE GROUP



Source: SEWRPC.

Map 2b

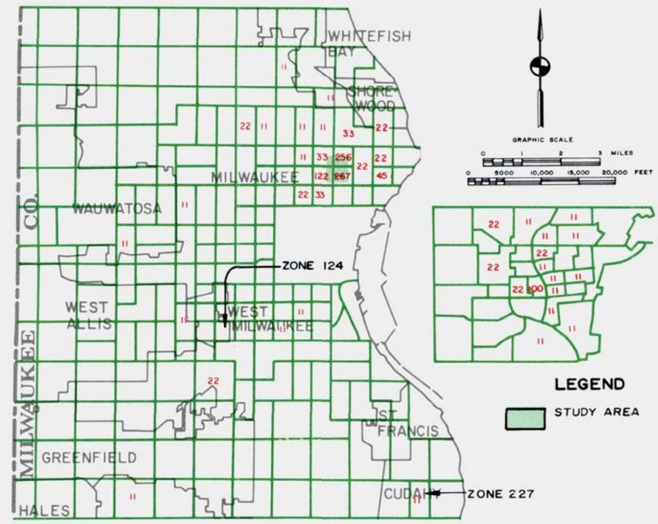
LOCATION BY TRAFFIC ANALYSIS ZONE OF BUS PASSENGER TRIP DESTINATIONS BY RESIDENTS OF THE MILWAUKEE-NORTH TEST AREA AS REPORTED BY A 20 PERCENT SAMPLE RATE GROUP



Source: SEWRPC.

Map 2c

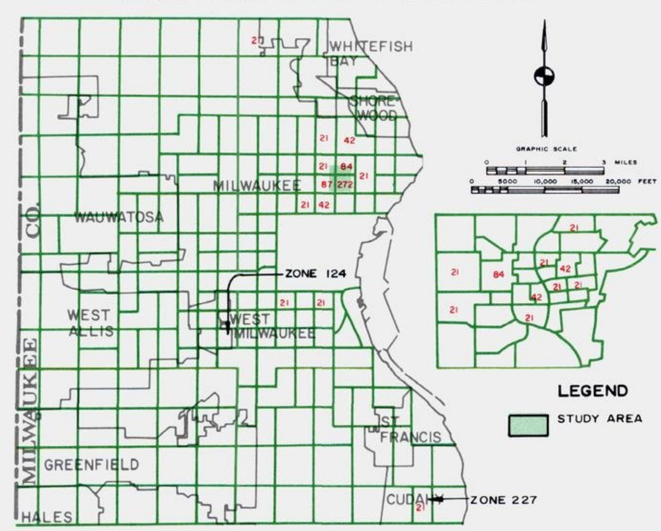
LOCATION BY TRAFFIC ANALYSIS ZONE OF BUS PASSENGER TRIP DESTINATIONS BY RESIDENTS OF THE MILWAUKEE-NORTH TEST AREA AS REPORTED BY A 10 PERCENT SAMPLE RATE GROUP



Source: SEWRPC.

Map 2d

LOCATION BY TRAFFIC ANALYSIS ZONE OF BUS PASSENGER TRIP DESTINATIONS BY RESIDENTS OF THE MILWAUKEE-NORTH TEST AREA AS REPORTED BY A 5 PERCENT SAMPLE RATE GROUP

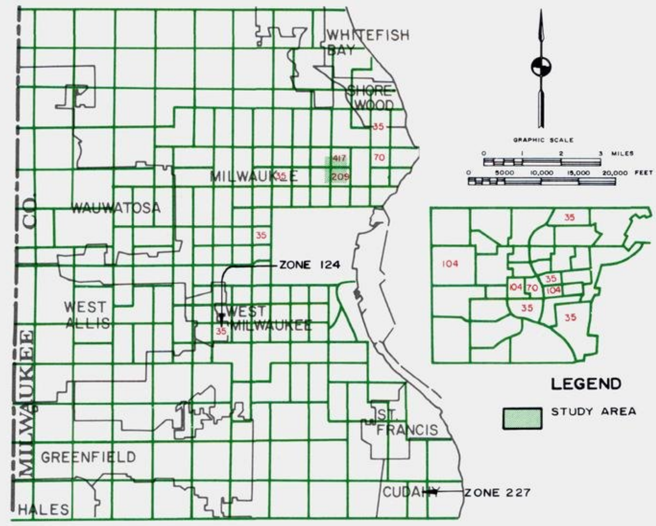


Source: SEWRPC.

which are presented the location and volumes of bus passenger destinations by zone found in each sample rate as generated by residents of the Milwaukee-North test area. As the sample rate declines, the distributional pattern becomes more localized with destinations in the proximity of the home area being emphasized. Nevertheless, despite this general underrepresentation of nonlocal destinations, certain outlying zones may be overstated as attractors of travel by the lower sample rates. For example, zone 124 attracts four bus passenger

Map 2e

LOCATION BY TRAFFIC ANALYSIS ZONE OF BUS PASSENGER TRIP DESTINATIONS BY RESIDENTS OF THE MILWAUKEE-NORTH TEST AREA AS REPORTED BY A 3 PERCENT SAMPLE RATE GROUP



Source: SEWRPC.

trips as reported by the 30 percent sample shown on Map 2a and 35 bus passenger trips as reported by the 3 percent sample shown on Map 2e; zone 227 attracts four bus passenger trips as reported by the 30 percent sample on Map 2a and 21 bus passenger trips as shown by the 5 percent sample on Map 2d.

Such distortion introduces the possibility that the lower sample rate produces "zonal clustering" i.e., a number of zones obtained at a higher sample rate which attract lower volumes of travel being represented in data collected at a lower sample rate by a single zone located near the center of such a group of zones . However, the differences between travel patterns found in the 30 percent sample and in the lower sample rates indicate that the effects of zonal clustering are not readily observable. For example, Map 2a indicates that south of the Milwaukee central business district, 16 zones receive bus passenger travel for a total of 68 bus passenger trips generated by residents of the Milwaukee-North test area. Data from the 5 percent sample rate group shown in Map 2d indicate that only three zones south of the Milwaukee central business district receive bus passenger travel with two of those zones being in close proximity to the central business district and the third zone significantly distant from a central location in the southern part of the city. Data from the 3 percent sample rate group, shown in Map 2e, indicate that only one zone south of the Milwaukee central business district receives bus passenger travel for a total of 35 such trips generated by residents of the Milwaukee-North test area. This zone, zone 124, may be utilized to represent a cluster of zones in the immediate vicinity, but cannot reasonably be assumed to represent the entire 16 zones or 68 trips shown by the 30 percent sample rate group. On the surface, these findings would indicate that the distributional travel pattern obtained by the 30 percent sample rate cannot be adequately represented by expanded but otherwise unmodified data collected at the 5 or 3 percent level.

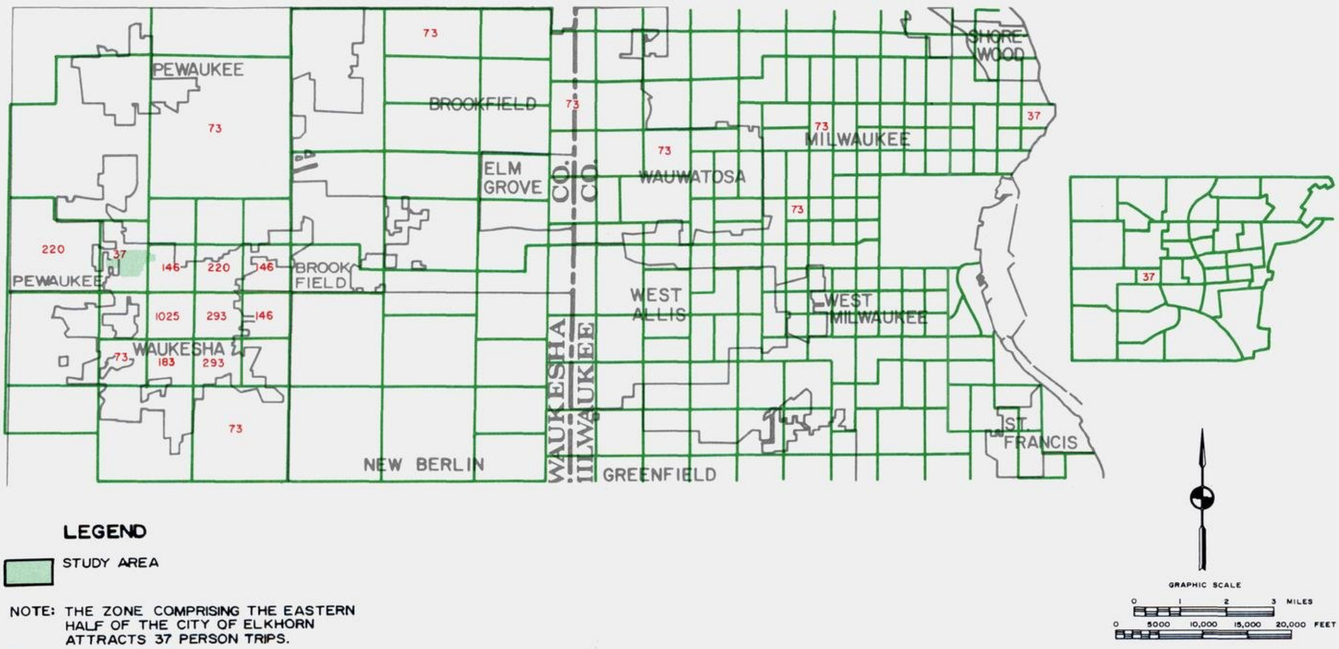
Further analysis was made possible by the availability of the gravity model distribution of home-based travel generated by the home zones which incorporate the test areas as produced by the home interview survey data collected by the SEWRPC in 1972. The 1972 home interview survey was conducted during the months of April through June at an overall 3 percent sample rate for the entire Region. This data was expanded, adjusted, and applied in a gravity distributional model on a 619 zonal basis. Despite the difference of one and one-half months in the survey dates of the 1972 home interview survey and the mass transit nonuser survey and the necessity of utilizing the 1972 home interview data as it pertains to a whole zone, the gravity output of this overall 3 percent survey data provides some very useful comparisons. Shown in Maps 3c and 4c is the gravity model output of such data as can be obtained for the whole zones most closely approximating the mass transit nonuser test areas and therefore considered to represent the equivalent of a 100 percent sampling of home-based travel generated by the whole zones being observed.

Mapping of the nonhome zone trip ends of expanded home-based person travel generated by the test areas for each sample rate group and the 100 percent gravity model output indicated that the same limitations on travel patterns observed by mode in the lower sample rate groups apply to total home-based person travel as well. As examples, the patterns of home-based person travel obtained from the 3 percent sample rate group, the total sample rate group, and the gravity model output for the Waukesha-North test area and/or home zone are shown on Maps 3a, 3b, and 3c. Such travel patterns as obtained for Milwaukee-North are shown on Maps 4a, 4b, and 4c. These maps demonstrate that zonal clustering in the lower sample rate groups does not represent travel patterns shown by the gravity model output (equivalent 100 percent sample) or even the 30 percent sample; that localized travel is emphasized by the lower samples; and, that while the scattered distribution of outlying attracting zones is greatly reduced by travel patterns obtained from the lower percentage samples, certain outlying zones may be overstated as attractors of relatively large trip volumes.

In determining the differences and similarities of travel patterns at the 3 percent, approximately 30 percent, and 100 percent (as shown by gravity model output) levels, it is noted that while the patterns contained within the higher sample rates reflect the patterns obtained at the lower sample rates, the inverse cannot be surmised. The green shaded zones on Map 3c represent zones attracting nine or more home-based person trips, the equivalent number of trips which would be represented by each trip record after application of expansion factors if Waukesha-North 30 percent sample rate group repre-

Map 3a

LOCATION BY TRAFFIC ANALYSIS ZONE OF HOME-BASED PERSON TRIP DESTINATIONS BY RESIDENTS OF THE WAUKESHA-NORTH TEST AREA AS REPORTED BY A 3 PERCENT SAMPLE RATE GROUP



NOTE: THE ZONE COMPRISING THE EASTERN HALF OF THE CITY OF ELKHORN ATTRACTS 37 PERSON TRIPS.

Source: SEWRPC.

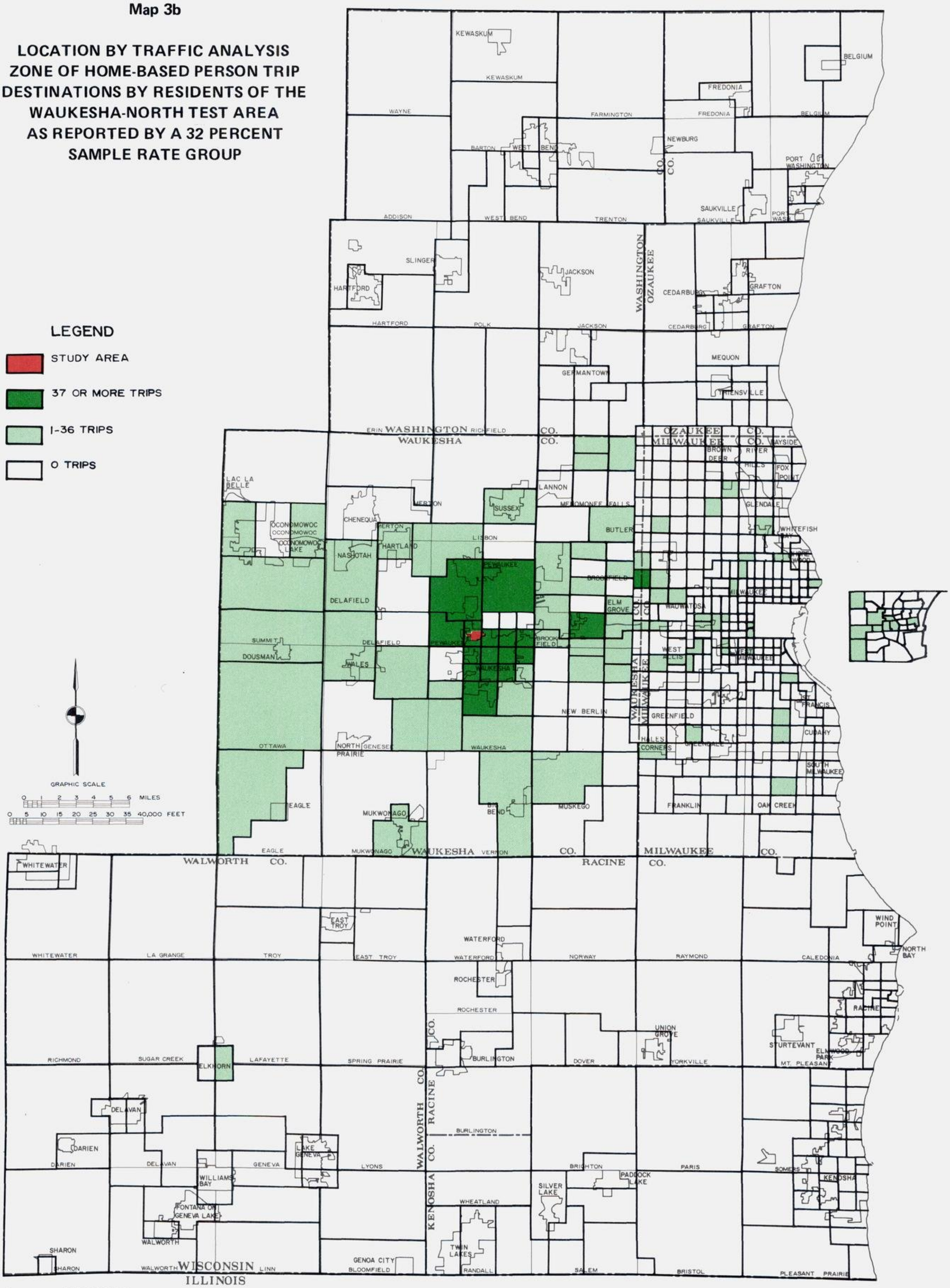
sented the whole zone. The dark green shaded zones on Map 3c represent zones attracting 96 or more home-based person trips, the equivalent number of trips which would be represented by each trip record after application of expansion factors if Waukesha-North 3 percent sample rate group represented the whole zone. The dark green shaded areas in Map 3b represent zones attracting 37 or more trips, the equivalent number of trips which would be represented by each trip record after application of expansion factors to a 3 percent sample survey in the test area. The green shadings on Maps 4c and 4b reflect the same procedures applied to the Milwaukee-North test area with Map 4c green shaded zones representing eight or more trips and dark green shaded zones representing 77 or more trips, and Map 4b dark green shaded zones representing 35 or more trips. The green shadings on Maps 3c and 4c indicate the travel patterns expected to be generated by unmodified, expanded trip data obtained for the Waukesha-North and Milwaukee-North test areas (which represent only a portion of the whole zones) at an approximately 30 percent sample rate. These patterns are markedly similar to the patterns actually obtained by the 30 percent sample rate groups in these test areas. The dark green shaded areas of Maps 3b and 4b and of Maps 3c and 4c show the travel patterns expected to be obtained from the Waukesha-North and Milwaukee-North areas by an unmodified, expanded 3 percent sample rate. These patterns are also markedly similar to the patterns actually obtained by the 3 percent sample rate groups in the test areas. The patterns on Maps 3a through 4c indicate that, although the distribution obtained by the model output or even by the 30 percent sample rate cannot be surmised on the basis of undistributed expanded travel data collected at a low sample rate, the pattern obtained by the lower sample rates is easily observed or predicted from the gravity model output or even, to some extent, from the 30 percent sample rate data.

Low Sample Survey Data and Trip Distribution Model Calibration

The trip distribution model which was calibrated through the use of observed data obtained in an overall 3 percent sample home interview survey is demonstrated through these maps to have adequately represented actual travel patterns and volumes generated by the test areas. These comparisons of the gravity model output with the trip patterns formed by the 3 percent and 30 percent sample rate data indicate that the model output which is presently calibrated on the basis of observed 3 percent sample data would probably show few, if any, substantial differences if it were calibrated through data obtained at a higher sample rate. Further affirming the adequacy of the 3 percent sample data for gravity model calibration is an evaluation of the accuracy of the trip distribution model performed as a function of the continuing regional land use-transportation study. The percent root mean square error expected from trip volume interchanges observed in the overall 3 percent sample 1972 SEWRPC home interview survey was computed and compared to the percent root mean square error of simulated trip volume interchanges resulting from application of the calibrated gravity model. Not only did the gravity model add little to the error inherent in the survey data but also, in some cases, principally within lower volume

Map 3b

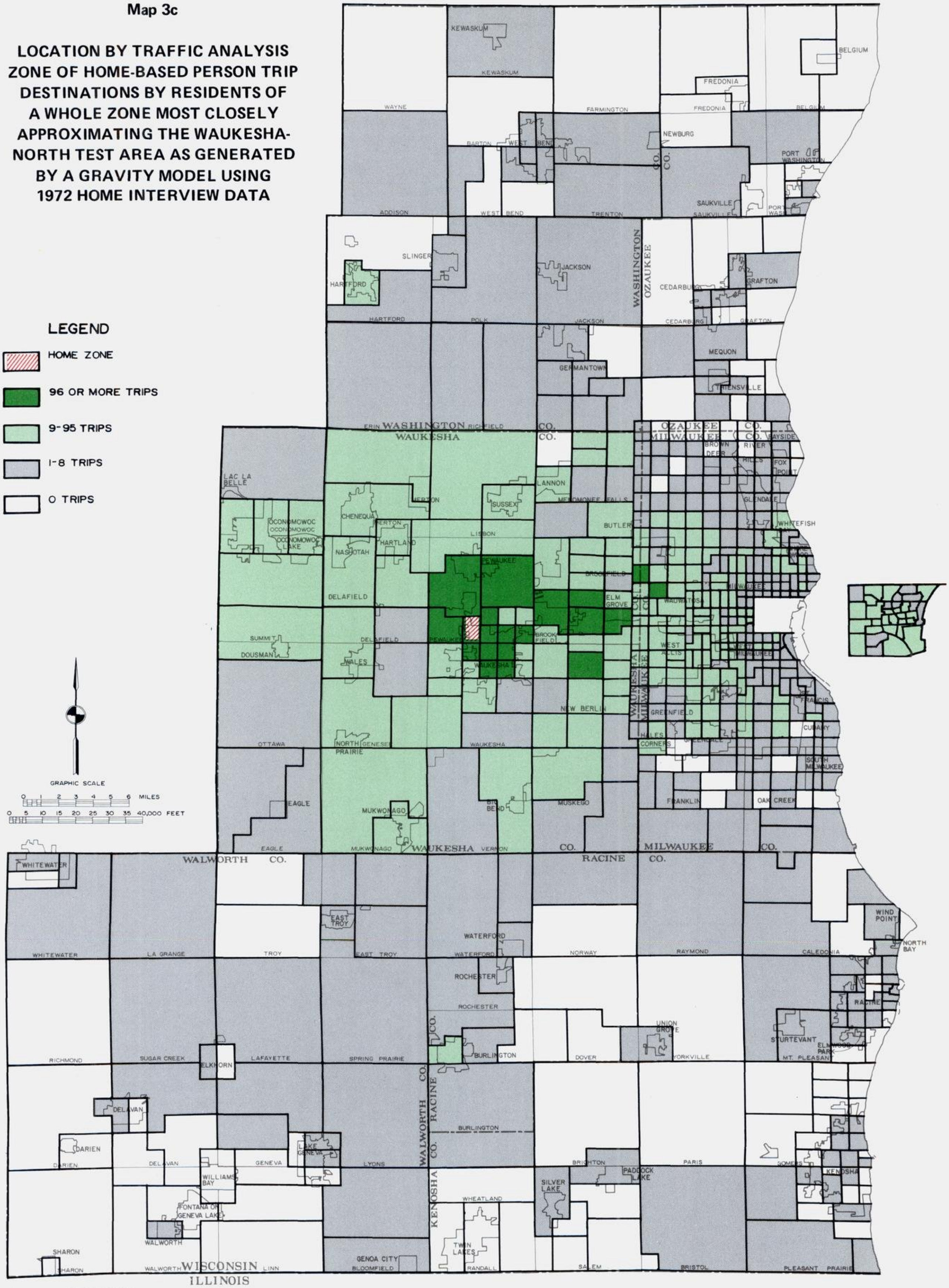
LOCATION BY TRAFFIC ANALYSIS ZONE OF HOME-BASED PERSON TRIP DESTINATIONS BY RESIDENTS OF THE WAUKESHA-NORTH TEST AREA AS REPORTED BY A 32 PERCENT SAMPLE RATE GROUP



Source: SEWRPC.

Map 3c

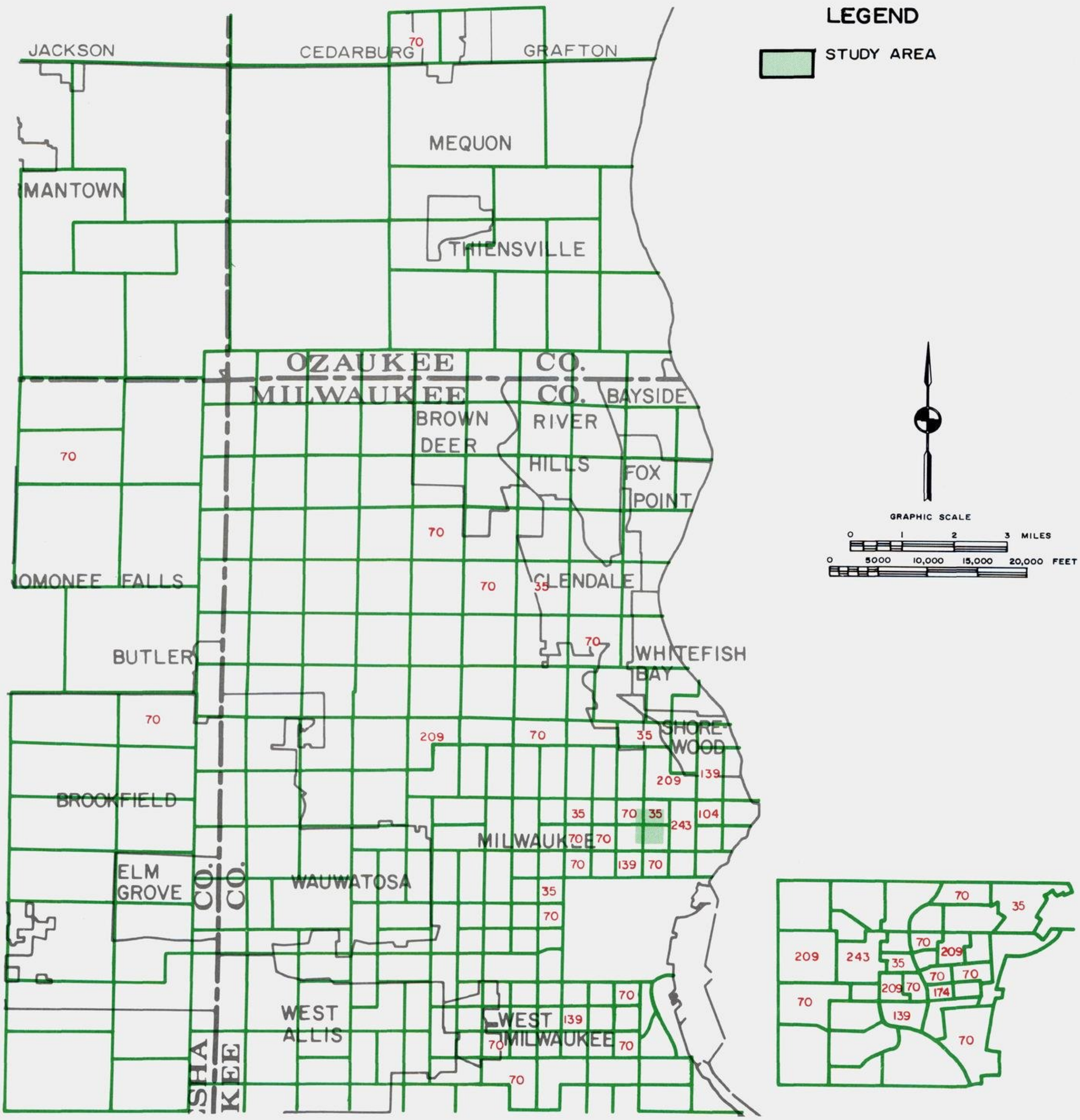
LOCATION BY TRAFFIC ANALYSIS ZONE OF HOME-BASED PERSON TRIP DESTINATIONS BY RESIDENTS OF A WHOLE ZONE MOST CLOSELY APPROXIMATING THE WAUKESHA-NORTH TEST AREA AS GENERATED BY A GRAVITY MODEL USING 1972 HOME INTERVIEW DATA



Source: SEWRPC.

Map 4a

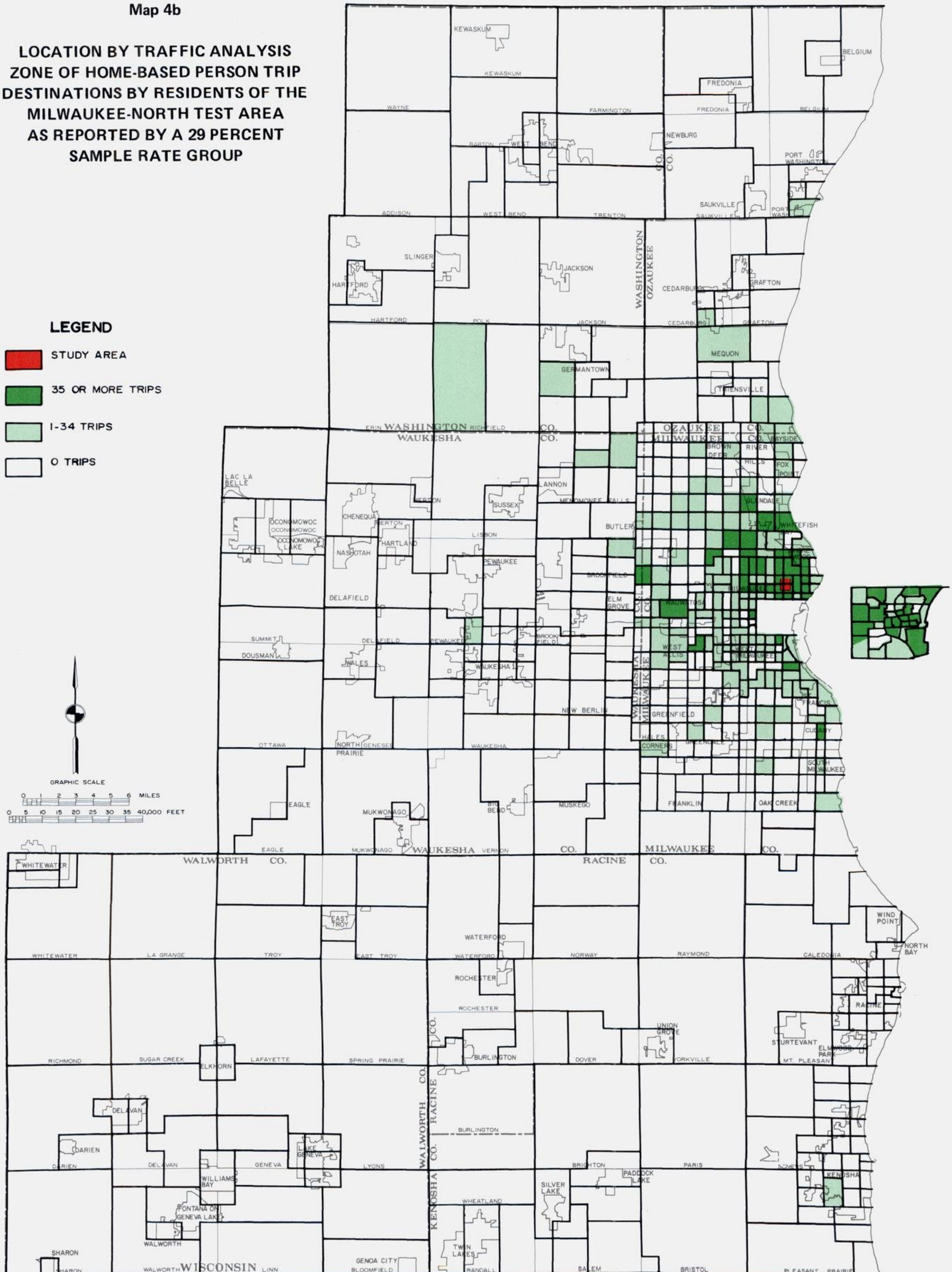
LOCATION BY TRAFFIC ANALYSIS ZONE OF HOME-BASED PERSON TRIP DESTINATIONS BY RESIDENTS OF THE MILWAUKEE-NORTH TEST AREA AS REPORTED BY A 3 PERCENT SAMPLE RATE GROUP



Source: SEWRPC.

Map 4b

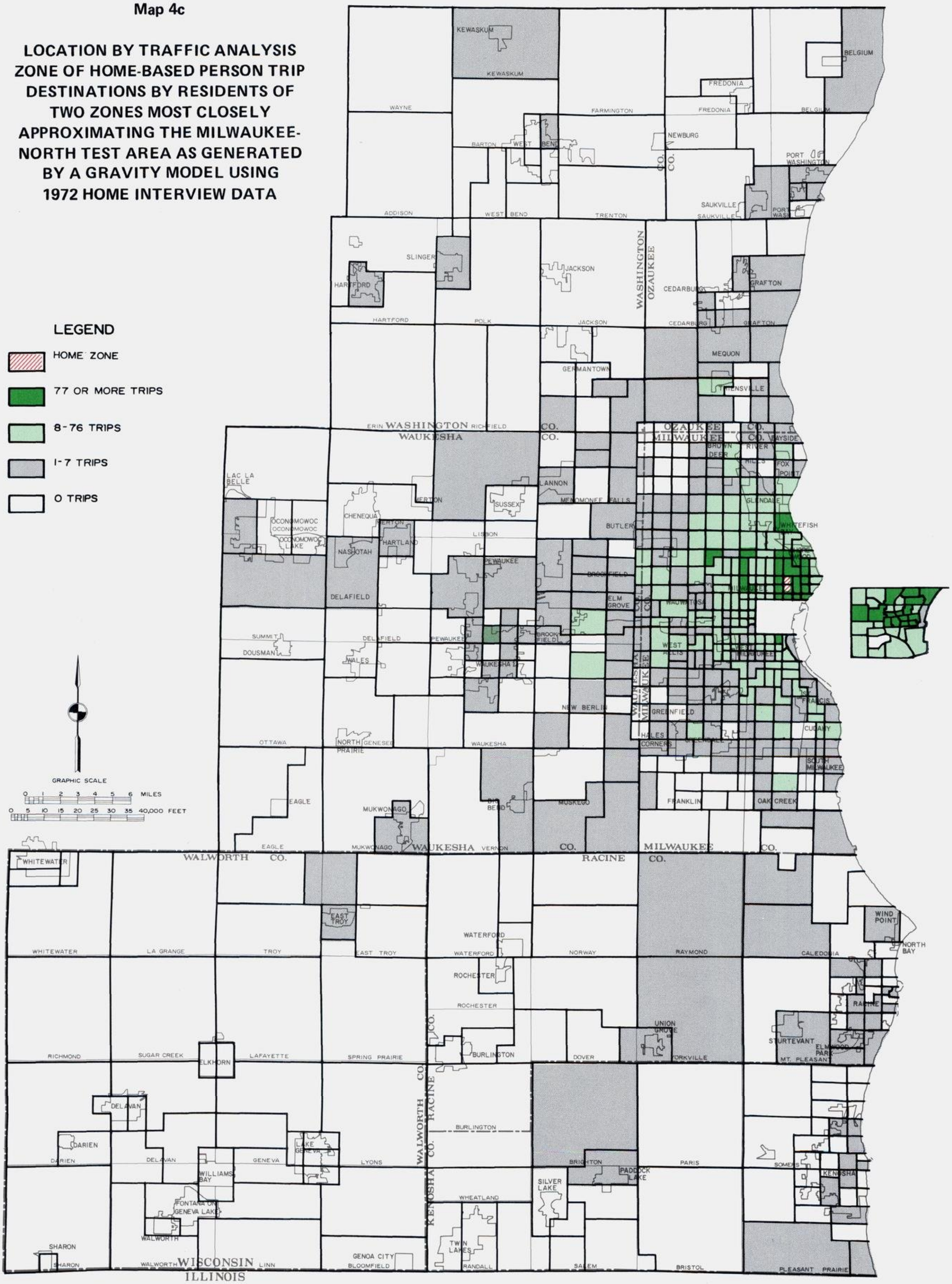
LOCATION BY TRAFFIC ANALYSIS ZONE OF HOME-BASED PERSON TRIP DESTINATIONS BY RESIDENTS OF THE MILWAUKEE-NORTH TEST AREA AS REPORTED BY A 29 PERCENT SAMPLE RATE GROUP



Source: SEWRPC.

Map 4c

LOCATION BY TRAFFIC ANALYSIS ZONE OF HOME-BASED PERSON TRIP DESTINATIONS BY RESIDENTS OF TWO ZONES MOST CLOSELY APPROXIMATING THE MILWAUKEE-NORTH TEST AREA AS GENERATED BY A GRAVITY MODEL USING 1972 HOME INTERVIEW DATA



Source: SEWRPC.

ranges, the percent root mean square error of the gravity output was significantly smaller than that error expected in the observed survey data.[2] This evaluation coupled with the observation that the gravity output extends and reflects the patterns obtained in the test area 30 percent samples underscores the adequacy of the 3 percent sample in an area the size of the Southeastern Wisconsin Region for calibration of the trip distribution model.

Although use of the overall 3 percent sample data within the Southeastern Wisconsin Region appears to be adequate for model calibration and for checking various parameters of existing planning models and, if necessary, adjusting them, the rather wide variances found in certain tabulations of test area socioeconomic or travel characteristics make it important to understand that additional socioeconomic or travel data are required to carry out a detailed analysis of travel habits and patterns. When the low sample rate survey measure of a given socioeconomic characteristic is considered too gross, additional data on population, auto ownership, income, or any other variable necessary for developing the model usually are obtained from U. S. Census of Population tabulations or from tabulations of other state and local agencies. In addition, the 3 percent sample trip data also tend to be too gross to provide detailed measures of low volume travel habits or patterns, although the low sample rate data may provide an overall control for special purpose surveys such as a mass transit user survey or an intercity bus and rail survey which are used in conjunction with the areawide small sample home interview. Therefore, socioeconomic and travel data obtained from a low sample rate survey should not be utilized at a zonal level without supplementary information from secondary sources or complementary surveys as well as a clear understanding on the part of the researcher of the possible effects of sampling variability. Undistributed travel patterns obtained through simple expansion of low sample rate home interview type origin-destination surveys should at no time be utilized to attempt to determine travel patterns or desired lines of travel, either in total or for a given mode, generated by a specific area or zone. Such data should be considered representative of actual travel patterns only after the appropriate modifications in the form of adjustment factoring, regression analysis, modal split, gravity distribution, and accompanying calibrations have been completed, whereupon such data may be utilized with confidence.

SUMMARY

As a portion of the 1972 regional inventory of travel, a 30 percent sample rate home interview survey, the mass transit nonuser survey, was conducted during the months of June and July in six relatively small residential areas of the Region specifically selected to represent both older sections of the Region in which transit service had been maintained at a relatively high level but where transit utilization had been found to decline substantially and newer sections of the Region where transit utilization had not met expectations despite extensions of transit service to these developing areas.

Selected for sampling were 2,205 households. Of this sample, 1,831 households, or 83 percent, provided the information necessary to the survey. These 1,831 households were considered to represent the approximately 7,500 total year round housing units within the combined six areas. The samples obtained in the survey were then utilized as the basis of random selections to obtain the equivalent of 20 percent, 10 percent, 5 percent, and 3 percent sample rates for each of the six areas. The resulting data sets were then utilized for the examination of the differences occurring in socioeconomic and travel data when varying home interview sample rates are used.

The comparisons of these data sets indicated that the socioeconomic characteristics of households and populations, although generally similar for all sample rates within an area, showed greater variations in the lower sample rate groups as the specificity of, or the number of possible responses to, the item being examined increased. For example, percentage distributions of the sexual, racial, and licensed driver status of the study area populations were fairly similar for each sample rate group within each area. For each of these items the possible response was limited to one of two or three choices, e.g., sex is either male or female. The distribution of the number of automobiles available which was collected as the actual number garaged at the household and generally ranged between a response of zero to five, the population of the areas which was collected as the actual number of persons living in the household and generally ranged between one and seven, and the median household annual income which was collected by assigning the income to one of 10 possible categories showed greater variability as the sample rate declined. As would be expected, the most frequent, significant variations among sample rate groups were observed in the distributions of the populations by age group since for this item the actual age from five years to 99 years was collected and the data subsequently analyzed by utilizing 10 distinct age categories.

Comparisons of travel data obtained in the differing sample rate groups indicated that few significant variations between sample rate groups occurred within major travel modes and major trip purposes, those modes and purposes which incorporate the greatest numbers of trips, such as auto driver and passenger travel, and home and work trip purposes. On the other hand, bus passenger and other modes of travel and the other remaining trip purposes showed more frequent variations between sample sizes. Even within the distributions of bus passenger travel by trip purposes, it was observed that home and work purposes as a percent of total bus passenger travel were fairly consistent between sample rates while the other purposes showed increasing variations from data obtained by the 30 percent sample as the sample rate declined. Clearly, as the specificity of the

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[2] *For more complete discussion of this evaluation see SEWRPC Planning Report 25, A Regional Land Use Plan and A Regional Transportation Plan for Southeastern Wisconsin—2000, Volume Two, Chapter IV.*

travel characteristics being examined increases, the effects of sampling variability are magnified, reducing the accuracy of the low sample rate survey data.

Comparisons at the zonal level of trip data obtained by the differing sample rates in each area indicated that, as expected, the trip patterns from the smaller sample rate group were substantially different than the patterns obtained by the 30 percent samples. The number of destination zones receiving internal person travel found in the 3 percent sample as a percent of the number of such zones indicated by the 30 percent sample amounted to 47 percent in Kenosha, 43 percent in Racine, 20 percent in Waukesha-South, 20 percent in Waukesha-North, 31 percent in Milwaukee-South, and 24 percent in Milwaukee-North.

Examination of travel patterns obtained from the varying sample rate groups and from a trip distribution model output indicated that zonal clustering in the lower sample rate groups did not represent travel patterns shown by the gravity model output (equivalent 100 percent sample) or even the 30 percent sample; that localized travel was emphasized by the lower samples; and, that while the scattered distribution of outlying attracting zones was greatly reduced by travel patterns obtained from the lower percentage samples, certain outlying zones were overstated as attractors of relatively large trip volumes.

The trip distribution model which was calibrated through the use of observed data obtained in an overall 3 percent sample home interview survey was demonstrated through comparisons of travel patterns obtained from the differing sample rate groups to have adequately represented actual travel patterns generated by the test areas. It was observed that the gravity output extended and reflected the patterns obtained in the test area 30 percent samples, underscoring the adequacy of the 3 percent sample in an area the size of the Southeastern Wisconsin Region for calibration of the trip distribution model. In addition, the comparisons of the gravity model output with the trip patterns formed by the 3 percent and 30 percent sample rate data indicated that the model output which was calibrated on the basis of observed 3 percent sample data would probably show few, if any, substantial differences if it were calibrated through data obtained at a higher sample rate.

Although use of the overall 3 percent sample data within the Southeastern Wisconsin Region appears to be adequate for model calibration and for checking various parameters of existing planning models and, if necessary, adjusting them, the rather wide variances found in certain of the tabulations of test area socioeconomic or travel characteristics make it important to note that additional socioeconomic or travel data are required to carry out a detailed analysis of travel habits and patterns. Therefore, socioeconomic and travel data obtained from a low sample rate survey should not be utilized at a zonal level without supplementary information from secondary sources or complementary surveys as well as a clear understanding on the part of the researcher of the possible effects of sampling variability. In addition, travel patterns obtained from a low sample rate home interview type origin-destination survey should be considered representative of actual travel patterns in the Southeastern Wisconsin Region only after the appropriate modifications in the form of adjustment factoring, regression, analysis, modal split, gravity distribution, and accompanying calibrations have been completed; whereupon, such data may be utilized with confidence.

FORM T5-52 4/63 REVISED 2/72
SOUTHEASTERN WISCONSIN REGIONAL
PLANNING COMMISSION

HOUSEHOLD HISTORY SURVEY

(PLEASE PRINT IN PENCIL)

INTERVIEWER ____________________ DATE ____________________ SAMPLE NUMBER ☐☐☐☐☐☐

A	B	C	D	E	F	G	H	I	J	K
PRESENT LOCATION	HOME ADDRESS	DATE MOVED IN	HOUSING STATUS	VALUE -OR- RENT	STRUCTURE TYPE	STRUCTURE PROFILE	NUMBER OF BEDROOMS	NUMBER OF PERSONS IN HOUSEHOLD	FAMILY INCOME	COMPARISON OF THIS RESIDENCE WITH PREVIOUS RESIDENCE
(NUMBER OF HOMES) ☐	Street Address City, Village or Town ☐☐☐☐☐☐☐☐ County	Mo. Yr. ☐☐☐☐	1. Rent 2. Own ☐	H E ☐☐☐	☐	1. 3 Stories Or Less 2. 4 Stories Or More ☐	☐	☐☐	☐	1 2 3 4 5 6 7 8 9 10 ☐☐☐☐☐☐☐☐☐☐
LAST LOCATION	HOME ADDRESS	DATE MOVED IN	HOUSING STATUS	VALUE -OR- RENT	STRUCTURE TYPE	STRUCTURE PROFILE	NUMBER OF BEDROOMS	NUMBER OF PERSONS IN HOUSEHOLD	FAMILY INCOME	COMPARISON OF THIS RESIDENCE WITH PREVIOUS RESIDENCE
	Street Address City, Village or Town ☐☐☐☐☐☐☐☐ County	Mo. Yr. ☐☐☐☐	1. Rent 2. Own ☐	H E ☐☐☐	☐	1. 3 Stories Or Less 2. 4 Stories Or More ☐	☐	☐☐	☐	1 2 3 4 5 6 7 8 9 10 ☐☐☐☐☐☐☐☐☐☐
SECOND LAST LOCATION	HOME ADDRESS	DATE MOVED IN	HOUSING STATUS	VALUE -OR- RENT	STRUCTURE TYPE	STRUCTURE PROFILE	NUMBER OF BEDROOMS	NUMBER OF PERSONS IN HOUSEHOLD	FAMILY INCOME	COMPARISON OF THIS RESIDENCE WITH PREVIOUS RESIDENCE
	Street Address City, Village or Town ☐☐☐☐☐☐☐☐ County	Mo. Yr. ☐☐☐☐	1. Rent 2. Own ☐	H E ☐☐☐	☐	1. 3 Stories Or Less 2. 4 Stories Or More ☐	☐	☐☐	☐	1 2 3 4 5 6 7 8 9 10 ☐☐☐☐☐☐☐☐☐☐

FORM T5-53 3/63 REVISED 2/72
SOUTHEASTERN WISCONSIN
REGIONAL PLANNING COMMISSION

HOME INTERVIEW SURVEY

CENSUS TRACT NUMBER

SECTION I

A. TRAVEL DAY AND DATE ______ ______ DISTRICT NUMBER ______ LIST NUMBER ______ LINE NUMBER ______

B. INTERVIEW ADDRESS ______ (STREET NUMBER AND NAME) ______ (MUNICIPALITY) CITY VILLAGE TOWN ______ (COUNTY)

C. STRUCTURE TYPE
1. SINGLE FAMILY
2. TWO FAMILY
3. 3-4 FAMILY APT
4. 5-19 FAMILY APT.
5. 20 OR MORE FAMILY APT.
6. ROOMING HOUSE
7. HOTEL
8. MOTEL
9. INSTITUTION
10. MOBILE HOME. . . . .

MIXED ☐

D. TYPE OF LIVING QUARTERS
HOUSING UNIT
1.
NON-HOUSING UNIT QUARTERS
(PERMANENT) 2. ROOM 3. BED
(TRANSIENT) 4. ROOM 5. BED . . . .

SECTION II

A. HOW MANY VEHICLES IN PERSONAL USE HERE
- AUTOS . . . .
- TRUCKS (INCLUDING CAMPERS). . . . .
- MOTORCYCLES . . . .

B. HOW MANY PERSONS LIVE HERE . . . .

C. HOW MANY PERSONS 5 YEARS AND OVER LIVE HERE . . . .

D. HOW MANY OUT-OF-REGION VISITORS 5 YEARS AND OVER WERE HERE ON TRAVEL DATE . . . .

SECTION V

A. TRIPS REPORTED AT THIS ADDRESS . . . .

B. PERSONS MAKING TRIPS . . . .

C. PERSONS NOT MAKING TRIPS. . . . .

D. PERSONS 16 YEARS AND OVER . . . .

E. PERSONS 16 YEARS AND OVER LICENSED TO DRIVE. . . . . .

COMPLETED OR NON-INTERVIEW CODE . . . .

SECTION III DATA FOR EACH HOUSEHOLD MEMBER AND OUT-OF-REGION VISITOR

A	B	C	D	E	F	G		H		I	J	K
PERSON NO. *	PERSON IDENTIFICATION (Relationship to Head of Household)	SEX AND RACE	DRIVE A CAR	AGE	WORK STATUS	OCCUPATION	CODE	CODE	INDUSTRY	WALK TO WORK	USED TRIP LOG	TRIPS MADE
1		M F W B O	YES NO		E U					YES NO	YES NO	YES NO
2		M F W B O	YES NO		E U					YES NO	YES NO	YES NO
3		M F W B O	YES NO		E U					YES NO	YES NO	YES NO
4		M F W B O	YES NO		E U					YES NO	YES NO	YES NO
5		M F W B O	YES NO		E U					YES NO	YES NO	YES NO
6		M F W B O	YES NO		E U					YES NO	YES NO	YES NO
7		M F W B O	YES NO		E U					YES NO	YES NO	YES NO
8		M F W B O	YES NO		E U					YES NO	YES NO	YES NO
9		M F W B O	YES NO		E U					YES NO	YES NO	YES NO
10		M F W B O	YES NO		E U					YES NO	YES NO	YES NO

EDITING AND SUPERVISORY COMMENTS:

* CIRCLE PERSON NUMBER OF EACH PERSON INTERVIEWED

SECTION VI

CONFIDENTIAL The information contained in this survey will be accorded confidential treatment by the Planning Commission. Individual reports will be used for statistical purposes only.

INTERVIEWER ______

CALLS MADE		APPOINTMENTS	
DATE	TIME	DATE	TIME

REPORT COMPLETED

DATE ______ TIME ______ INITIALS ______

TELEPHONE NUMBER ______

INTERVIEWERS NOTES AND COMMENTS: ______

WERE TRIP LOGS DELIVERED PERSONALLY ? YES ☐ NO ☐

EDIT ______ INITIALS ______ DATE ______ PASS FAIL ______

FOLLOW-UP ______ ASSIGNED TO ______ DATE

FOLLOW-UP EDIT ______ INITIALS ______ DATE

CODING CONTROL

STATION	CODED BY	DATE	STATION	CODED BY	DATE
1			4		
2			5		
3			6		

FORM T5-53A 3/63 REVISED 3/72
SOUTHEASTERN WISCONSIN REGIONAL
PLANNING COMMISSION

INTERNAL TRIP REPORT

SECTION IV

SAMPLE NUMBER 1 2 3 4 5 6

SHEET________ of ________ SHEETS

A	B	C	D	E		F		G		H	I	J		K	L	M	N	O	P	Q
																	AUTO DRIVER ONLY			
PERSON NUMBER	TRIP NUMBER	WHERE DID THIS TRIP BEGIN? (Origin)	WHERE DID THIS TRIP END? (Destination)	TRIP PURPOSE		LAND USE (Describe As Completely As Possible)		TIME OF		MODE OF TRAVEL	CAR POOL	BLOCKS WALKED		* WAS CAR AVAIL	NO. OF PASS.	FWY USED	PARKING DESTINATION	TYPE OF PARKING	DURATION OF PARKING	COST OF PARKING
				FROM	TO	ORIGIN	DESTINATION	START	ARRIVAL			AT ORIGIN	AT DEST							
		101 Street Address City, Village or Town County	201 Street Address City, Village or Town County					: AM PM	: AM PM		YES NO			YES NO		YES NO	301 Street Address			
		102 Street Address City, Village or Town County	202 Street Address City, Village or Town County					: AM PM	: AM PM		YES NO			YES NO		YES NO	302 Street Address			
		103 Street Address City, Village or Town County	203 Street Address City, Village or Town County					: AM PM	: AM PM		YES NO			YES NO		YES NO	303 Street Address			
		104 Street Address City, Village or Town County	204 Street Address City, Village or Town County					: AM PM	: AM PM		YES NO			YES NO		YES NO	304 Street Address			
		105 Street Address City, Village or Town County	205 Street Address City, Village or Town County					: AM PM	: AM PM		YES NO			YES NO		YES NO	305 Street Address			
		106 Street Address City, Village or Town County	206 Street Address City, Village or Town County					: AM PM	: AM PM		YES NO			YES NO		YES NO	306 Street Address			

COLUMN E TRIP PURPOSE

1. To Place of Work
2. Work-Connected Business
3. Personal Business
4. School
5. Social-Eat Meal
6. Change Travel Mode
7. Serve Passenger
8. Shopping
9. Recreation
0. Home

COLUMN F LAND USE

1. Commercial Retail & Services
2. Commercial Wholesale & Storage
3. Manufacturing-Nondurable
4. Manufacturing-Durable & Extractive
5. Transportation & Utilities
6. Institutional & Government Services
7. Recreation
8. Agricultural & Related
9. Open Lands & Water Areas
0. Residential

COLUMN H MODE OF TRAVEL

1. Auto Driver
2. Auto Passenger
3. Railroad Passenger
4. Bus Passenger
5. School Bus
6. Taxi Passenger
7. Truck Passenger
8. Walked to Work (Bicycle)
9. Worked At Home
10. Motorcycle
11. Air Travel
12. Water Travel

*COLUMN K Ask This Question If The Mode Of Travel Was A Bus Or Railroad Passenger.

COLUMN O TYPE OF PARKING

1. Street Free
2. Street Meter
3. Lot Free
4. Lot Paid
5. Garage Free
6. Garage Paid
7. Service or Repair
8. Residential Property
9. Cruised
0. Not Parked (Passenger Pick-up or Drop-Off)

FORM T5-60 3/72
SOUTHEASTERN WISCONSIN REGIONAL
PLANNING COMMISSION

HIGH SAMPLE RATE AREA
HOME INTERVIEW SURVEY

SAMPLE NUMBER 1 2 3 4 5 6 [| | | | |]   HEAD OF HOUSEHOLD

1. DO YOU RIDE THE BUS ON A MORE OR LESS REGULAR BASIS? (Check One)

☐ Yes ☐ No If "Yes" Is Checked, Ask 1A, 1B, And 1C.

If "No" Is Checked Go To Item Number 2

1A. FOR WHAT KIND OF TRIP?

TRIP PURPOSE TO	ENTER TIMES / WEEK
0. Home	☐☐
1. Place of Work	☐☐
2. Work-Connected Business	☐☐
3. Personal Business	☐☐
4. School	☐☐
5. Social-Eat Meal	☐☐
8. Shopping	☐☐
9. Recreation	☐☐

1B. WHY DO YOU CHOOSE THE BUS OVER OTHER MEANS OF TRAVEL TO GO TO?

PURPOSES Identified In 1A	REASON WHY A BUS WAS CHOSEN	WAS A CAR AVAILABLE? Yes	No
☐	______	☐	☐
☐	______	☐	☐
☐	______	☐	☐
☐	______	☐	☐
☐	______	☐	☐
☐	______	☐	☐
☐	______	☐	☐

1C. DO YOU EXPECT TO CONTINUE TO RIDE THE BUS?

☐ Yes ☐ No If "No," Why Not?

______

GO TO ITEM NUMBER 4

2. HAVE YOU USED PUBLIC TRANSPORTATION ON A MORE OR LESS REGULAR BASIS AT ANY TIME IN THE PAST? (Check One)

☐ Yes ☐ No If "Yes" Is Checked, Ask 2A, 2B, And 2C.

If "No" Is Checked Go To Item Number 3

2A. HOW LONG AGO? ☐☐ MONTHS

2B. FOR WHAT KIND OF TRIPS DID YOU USE THE BUS AT THAT TIME?
Use Trip Purpose Number From 1A.

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

2C. WHAT WERE YOUR MAIN REASONS FOR DISCONTINUING PUBLIC TRANSPORTATION?

______

GO TO ITEM NUMBER 3

3. UNDER WHAT CONDITIONS WOULD YOU CONSIDER BEGINNING OR RESUMING TRAVEL BY PUBLIC TRANSPORTATION?

______

______

(continued)

OTHER HOUSEHOLD MEMBERS

4. ARE THERE OTHER HOUSEHOLD MEMBERS WHO USE THE BUS ON A MORE OR LESS REGULAR BASIS? (Check One)

☐ Yes ☐ No

If "No" Is Checked Do Not Complete Item Number 4A, 4B And 4C.

If "Yes" Is Checked, Ask 4A, 4B, And 4C.

4A. ENTER THE NUMBER OF TRANSIT TRIPS MADE PER WEEK BY EACH PERSON MAKING TRIPS UNDER EACH TRIP PURPOSE CATEGORY.

PERSON NUMBER	TRIP PURPOSE TO								TOTAL TRIPS
	HOME	WORK PLACE	WORK CONN. BUSI.	PERS. BUSI.	SCHOOL	SOCIAL VISIT	SHOP.	REC.	

4B. DID ANY OF THESE HOUSEHOLD MEMBERS HAVE THE CHOICE OF MAKING THE TRIP BY OTHER MODES OF TRAVEL? ENTER FOR EACH PERSON HAVING SUCH A CHOICE, THE NUMBER INDICATING THE MODE OF TRAVEL USED UNDER EACH TRIP PURPOSE CATEGORY.

MODE OF TRAVEL

1. Auto Driver
2. Auto Passenger
3. Taxi Passenger
4. Motorcycle
5. Walk (or bicycle)

PERSON NUMBER	TRIP PURPOSE TO								TOTAL TRIPS
	HOME	WORK PLACE	WORK CONN. BUSI.	PERS. BUSI.	SCHOOL	SOCIAL VISIT	SHOP.	REC.	

4C. FOR THOSE TRIPS WHICH WERE MADE BY BUS, IN PLACE OF OTHER MODES OF TRAVEL, INDICATE THE REASON WHY THE BUS WAS USED.

PERSON NUMBER	REASON

KENOSHA · MILWAUKEE · OZAUKEE · RACINE · WALWORTH · WASHINGTON · WAUKESHA
SOUTHEASTERN
WISCONSIN
REGIONAL
PLANNING
COMMISSION

OLD COURT HOUSE
P. O. BOX 769
WAUKESHA, WISCONSIN
53187
PHONE 547-6721