AN ANALYSIS OF HYDROLOGIC SIMULATION AND GROUNDWATER WITHDRAWAL PATTERNS IN EASTERN LANSING, MICHIGAN

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ABSTRACT

AN ANALYSIS OF HYDROLOGIC SIMULATION AND GROUNDWATER WITHDRAWAL PATTERNS IN EASTERN LANSING, MICHIGAN

By

Ronald L. Van Til

Piezometric surface values for 42 Saginaw Formation wells in the eastern Lansing area were used to analyze piezometric simulations projected by the Wheeler-Vanlier electric analog model. Following hydrologic analysis, yearly and seasonal groundwater withdrawal patterns for 1975-1976 were mapped and correlated with the 1976 piezometric surface.

Significant differences between actual and analog-projected piezometric conditions from 1964-1976 remained unexplained within the existing model design. Consequently, the model was considered unreliable for future piezometric simulation and further investigation was recommended.

Actual groundwater withdrawal patterns for 1975-1976 indicated proportionally larger and more evenly distributed withdrawals throughout Michigan State University than in East Lansing and Meridian Township, with

localized piezometric declines in areas of concentrated pumpage in central East Lansing and north central Meridian Township and more uniform piezometric declines throughout Michigan State University. Actual withdrawal procedures for 1975-1976 were shown to reflect both hydrologic and jurisdictional circumstances throughout the eastern Lansing area.

AN ANALYSIS OF HYDROLOGIC SIMULATION AND GROUNDWATER WITHDRAWAL PATTERNS IN EASTERN LANSING, MICHIGAN

By

Ronald L. Van Til

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To

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and

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INTRODUCTION

The upper subsurface bedrock of Michigan's central lower Peninsula is characterized by a complex association of lithologic units of Pennsylvanian age known collectively as the Saginaw Formation. Composed primarily of alternating beds of differentially permeable sandstone and shale with thin interbedded strata of limestone and coal, the Saginaw Formation is the primary hydrologic system underlying the lower central Michigan region. In the Lansing Metropolitan area, the Saginaw Formation serves as the principal source of municipal and institutional water supply.

Although lithologic characteristics have been determined for the Saginaw Formation, initial hydrologic investigations have provided only a generalized view of the Saginaw Formation as an artesian system. An analytical approach was therefore utilized in 1967 in an attempt to determine specific hydrologic characteristics and more exact aquifer response to variance in patterns of municipal and institutional groundwater withdrawal.

Using existing hydrologic data, an electric analog model was constructed by Wheeler (1967) and further refined by Vanlier and Wheeler (1968) to simulate known past aquifer piezometric conditions in the greater Lansing area. Following adjustment and subsequent agreement between model projections and documented past hydrologic conditions, model simulation accuracy was assumed. Projections of future aquifer piezometric response to anticipated groundwater withdrawals were then made in an attempt to forecast future hydrologic conditions throughout the area.

Completion of the electric analog model provided a more-detailed understanding of the specific hydrologic characteristics of the Lansing aquifer system. Model projections of aquifer response to anticipated future aquifer withdrawals further suggested considerable variance in the distribution and configuration of future groundwater reserves. Significant among the 1967 model-analysis projections was the delineation of the eastern portion of the Lansing Metropolitan area as an area of potential maximum groundwater decline. Rapid expansion of the aquifer's cone of depression was hypothesized throughout the area in response to anticipated increased groundwater withdrawals by the City of East Lansing, Meridian Township, and Michigan State University.

The need for a more precise understanding of projected aquifer response in the eastern Lansing Metropolitan area has been demonstrated by the continued decrease since 1967 in available groundwater supplies and substantial projected increases in future groundwater withdrawals. Recorded 1964-1976 piezometric surface values further indicate less extreme piezometric declines than projected by the Wheeler-Vanlier analog model. A research project was therefore designed to analyze the predictive accuracy of analog model simulation and the patterns of municipal and institutional groundwater withdrawal for East Lansing, Meridian Township, and Michigan State University.

The primary investigative hypothesis formulated for the study was that differences between actual and model-projected piezometric declines from 1964-1976 would exceed the model-stated predictive accuracy range of ± 10 feet. To test the hypothesis, an initial comparison was made between analog-projected and actual piezometric pressure surfaces for the years 1975 and 1976. Following analysis of analog piezometric simulation, yearly and seasonal groundwater withdrawal patterns were determined for East Lansing, Meridian Township, and Michigan State University. Finally, an assessment was made of the combined effect of groundwater withdrawals on area hydrology.

REVIEW OF LITERATURE

Prior hydrologic investigation of the Saginaw Formation in the Lansing Metropolitan area has emphasized the importance of a regional artesian aquifer system as a primary source of domestic and industrial water supply. Hydrologic investigations have been undertaken by Stuart (1945), Mencenberg (1963), Firouzian (1963), Carroll (1963), Wheeler (1967), Vanlier and Wheeler (1968), and Wood (1969).

The first comprehensive investigation of the groundwater hydrology of the Saginaw Formation in the Lansing area was undertaken in 1945 by W. T. Stuart. Saginaw Formation sandstones were described as predominately well rounded and well sorted quartz grains lightly cemented together to form interstices equivalent or larger than the grain sizes themselves. The connecting passages between grains were identified as generally parallel to the bedding planes, with considerable vertical connection within beds and restricted connection between beds.

The sandstones of the formation were included within the low to medium permeability range, with higher overall transmissibility values as a result of substantial sandstone thickness. Divergent transmissibility and storage values were attributed to variations in sandstone type and manner of sedimentation, with average transmissibility and storage values calculated as 23,000 gpd per foot and .000382, respectively.

The overall groundwater flow into the area of diversion was estimated as between five to nine million gallons per day, with maximum flow from the south and minimum flows from the east and north. Although direct and solution channel recharge were specified, downward and lateral percolation in areas of contact between formation sandstones and overlying glacial deposits was hypothesized as the greatest probable source of aquifer recharge.

Stuart concluded that conditions of groundwater equilibrium in the Lansing area prior to 1935 had been followed by a decline from 1935-1945 in area groundwater levels as a direct consequence of increased municipal and industrial pumpage. The total area influenced by groundwater withdrawals in 1945 was estimated as forty-eight square miles.

Stratigraphic characteristics of the Saginaw Formation in the Lansing area were correlated in 1963 by F. Mencenberg. The Saginaw Formation was broadly described as consisting principally of alternating sandstones and shales deposited in terrestrial and marine environments during the Pennsylvanian Period, with extensive and generally continuous basal sandstones and incontinuous cyclical strata formations.

The Saginaw group was defined hydrologically as an artesian system, with occasional elevated or perched water tables associated with discontinuous and unrelated clay lenses in the overlying glacial drift. The generation of artesian pressures within the aquifer was attributed to the presence of confining shaley aquicludes, basinward formation dip, and general surface topography.

An electrical resistivity study of the Saginaw Formation in the Lansing area was conducted in 1963 by J. Carroll. Lithologic profiles were constructed along a southeast to northwest traverse in the Lansing-East Lansing area and an east-west traverse in southern Lansing in an attempt to discern the lithologic characteristics of the Saginaw Formation and the composite thickness of the overlying glacial deposits. Resistivity measurements were found to approximate actual well profile data for glacial deposits, although inaccuracies were encountered in the analysis of deeper bedrock formations.

Hydrologic characteristics of the Saginaw Formation in the Lansing area were investigated in 1963 by A. Firouzian. Average transmissibility for the Saginaw Formation using flow-net analysis was estimated as 23,628 gpd per foot, while direct and indirect recharge were estimated as three million gallons a day and twenty-eight million gallons a day, respectively. Wide areal variations in transmissibility and recharge values were noted.

A decline in the piezometric surface of as much as ninety feet in the Lansing area was related by Firouzian to increased aquifer pumpage from 1945-1963, with the deepest cones of depression over areas of maximum pumpage. The area of effective recharge was extended to one hundred and twenty square miles, or 2.5 times the original recharge area estimated by Stuart in 1945. A comparison of actual pumpage and estimated aquifer recharge values led Firouzian to conclude that the Lansing artesian aquifer was in a state of near-equilibrium in 1963.

An analytical approach to the investigation of the hydrology of the Saginaw Formation was developed in 1967 by M. Wheeler. Idealized assumptions inherent in earlier theoretical studies were minimized through the utilization of an electric analog model designed to simulate actual aquifer conditions.

Leakage through the upper confining beds of the aquifer was identified as the primary source of aquifer recharge in the Lansing area. Leakage was described as nearly uniform and responsible for a reduction in horizontal groundwater movement through the aquifer, thereby lessening the overall importance of transmissibility. The artesian storage coefficient was found to have no effect on long-term drawdowns and the water-table storage coefficient of a small dewatered portion of the aquifer only a small effect.

Increased importance was given by Wheeler to the storage coefficient of overlying glacial drift, as additional groundwater withdrawals were found to have increased leakage from overlying glacial deposits to the aquifer, thereby significantly lowering water levels in the drift. Area river courses were further identified as important but generally finite sources of aquifer recharge. Localized high recharge areas hydrologically associated with the Mason Esker were identified in northern and southern Lansing.

Additional analyses of Saginaw Formation analog simulation in the Lansing Metropolitan area were undertaken in 1968 by K. E. Vanlier and M. Wheeler. A series of future analog piezometric projections were developed to illustrate the importance of analog model application in area groundwater planning and development. Model projections indicated a continuation of the decline in the overall cone of depression in the Lansing Metropolitan area through 1985. In addition, groundwater declines were hypothesized to increase most rapidly in depth and extent in eastern Lansing from 1968-1975 in response to substantial expected increases in withdrawals from East Lansing, Meridian Township, and Michigan State University.

Similar though less severe groundwater declines were projected for the southern and western Lansing area.

Although groundwater supplies were termed adequate until 1985 by Vanlier and Wheeler, the need for water management and development programs was suggested for post-1985 area water demands. Additional alternatives for future groundwater development were outlined, including more extensive use of glacial aquifers, artificial aquifer recharge, diversion of high streamflow, development of more-distant well fields, and importation of water from the Great Lakes.

The groundwater geochemistry of the Saginaw Formation in the Upper Grand River Basin was investigated in 1969 by W. Wood. Glacial drift and soils were found to contribute substantially more dissolved solids to Saginaw Formation groundwater than atmospheric precipitation, water migration from adjacent formations, or mineral solution within the formation. Lower dissolved solids concentrations in the Saginaw Formation were attributed to processes of osmosis and ultrafiltration of groundwater by shale members of the formation.

Although a state of dynamic ion filtration equilibrium was suggested in hydrologically undeveloped areas of the Upper Grand River Basin, with the continuous removal of dissolved solids concentrations by local cell flow and lateral groundwater movement, the likelihood of increased dissolved solids concentrations was hypothesized in areas of high aquifer pumpage. The probability of increased dissolved solids concentrations was recognized in the Lansing Metropolitan area, with possible consequent decreased groundwater recharge to the Saginaw Formation from overlying glacial deposits.

METHODS

Groundwater Hydrologic Principles

Fundamental principles of groundwater hydrology for the Saginaw Formation are based on concepts of porosity, permeability, transmissibility, and storage as they occur in an artesian aquifer system.

An aquifer can be defined as a hydrologic unit capable of storing and transmitting water in appreciable quantities. In the presence of underlying and overlying impermeable or semi-permeable strata, an aquifer is confined and made artesian. Subsurface aquifer water movement is a direct function of the number, size, shape, arrangement, and interconnection of rock pore spaces, or interstices, and the overall hydraulic gradient.

The extent and nature of subsurface water movement within an artesian aquifer is determined primarily by overall values of porosity and permeability. Porosity can be described as the comparison of interstitial volume to overall rock volume, typically expressed as a percentage. Permeability is described as an expression of water movement or transmission through an aquifer, as determined by overall interstitial arrangement and interconnection and the occurrence of structural faults, cracks, or joints.

The coefficient of permeability is expressed quantitatively as the rate of flow in gallons per day through a cross-sectional area of the aquifer one square foot under a hydraulic gradient of one foot per foot.

Aquifer transmissibility represents an overall expression of the permeability of an aquifer. Transmissibility is defined quantitatively as the flow of water in gallons through a cross-sectional area one foot wide and extending the entire saturated thickness of the aquifer under a hydraulic gradient of one hundred percent. The coefficient of storage represents the value of water released from or taken into storage per unit aquifer area per unit head, or pressure, change.

Under natural conditions, water levels within an artesian aquifer fluctuate within an equilibrium range in response to natural processes of recharge and discharge. A piezometric, or imaginary pressure surface is formed at some level above the confined artesian system. This surface is defined as the level to which confined artesian groundwater would rise in a well tapping the aquifer formation.

The piezometric surface serves as an indication of both the general configuration and extent of groundwater supplies below. When artificial groundwater withdrawals are initiated, the piezometric surface is lowered in the vicinity of the wells and a cone of depression is formed. If continued artifical discharge exceeds natural processes of recharge, both the groundwater levels and the piezometric surface in the affected area are lowered and widened. At any given time, therefore, the elevation and configuration of the piezometric surface serves as an indication of overall aquifer conditions.

The amount of groundwater which can be withdrawn from an artesian aquifer is dependent on the overall capacity of the aquifer formation and the nature and extent of artificial discharge. Groundwater pumpage in excess of total natural recharge may substantially lower and eventually deplete groundwater reserves by creating a continual state of groundwater disequilibrium.

Analog Simulation of Groundwater Hydrology

The hydrologic functions of the Saginaw Formation artesian aquifer were simulated through the use of an electric analog model developed by M. Wheeler in 1967 and further refined by Vanlier and Wheeler in 1968.

An electric analog model simulates hydrologic functions and piezometric response by directing an electrical current through a network of capacitors and resistors arranged in a representative fashion. In model design, resistors are used to simulate aquifer transmissibility or permeability, while capacitors are used to simulate aquifer storage capacity. Once adjusted, the movement and storage of electrical current in the model network is considered analogous to hydrologic changes in the aquifer system. Both hydrologic characteristics and piezometric response to various past or future pumpage or discharge schemes can then be determined in greatly reduced time.

Design of the analog simulation model for the Saginaw Formation in the Lansing Metropolitan area was accomplished through successive analyses. An initial conceptual model of the aquifer was developed using transmissibility data collected in 1945 by W. T. Stuart. Where unavailable, values of aquifer transmissibility were estimated on the basis of sandstone thickness and average permeability. Using these data, low transmissibility zones surrounding the Lansing Metropolitan area were identified and used to delineate natural aquifer boundaries.

Following definition of a discrete aquifer, an analysis of the model in steady-state was undertaken to determine aquifer hydrologic conditions prior to development. Hydrologic data for 1900 and initial model analyses were used to determine preliminary estimates of natural recharge and discharge values. Although initially overestimated, general recharge or leakage rates were subsequently determined for area river segments and eleven regions within the Lansing Metropolitan area. Completion of steady-state analysis thereby provided a more specific understanding of aquifer recharge-discharge functions and potential leakage from overlying glacial deposits.

Following steady-state analysis, time-dependent variables were introduced for transient model analysis. A condition of aquifer equilibrium was assumed for 1935 in response to the reported stabilization of the artesian piezometric surface to 1935 groundwater withdrawals. As a result, 1935 conditions were used as a reference base for additional transient analyses. Groundwater pumpage values were determined for all production wells in the Lansing Metropolitan area and grouped into a series of pumpage centers to facilitate analysis. Division of groundwater withdrawal rates into step-functions further simplified analysis with arbitrarily identified time periods between 1935-1964.

Following the completion of actual 1945 and 1964 piezometric surface maps from existing hydrologic data, groundwater withdrawals for 1935-1945 were imposed on the analog simulation model. Analyses indicated a significant difference between model-projected and actual aquifer piezometric drawdowns. Significant movement of groundwater from the overlying glacial material into the aquifer system was subsequently identified, suggesting the increased importance of the groundwater storage capacity of area glacial deposits. The identification of areas of high glacial-material recharge associated with the Mason Esker in northeastern Lansing led to further modification of model recharge values. Following additional minor revisions, the analog simulation model was considered representative of the Saginaw Formation aquifer system in 1964.

The completed analog model was considered a significant predictive tool in forecasting future piezometric surface response to groundwater withdrawals in the Lansing Metropolitan area. Caution was emphasized, however, in the extension of model analyses based on the developed condition of the aquifer in 1964. Additional errors identified as inherent in the analog model included the possible inaccuracy of electrical components, basic hydrologic assumptions of aquifer equilibrium and storage, and previously recorded hydrologic data. Within these limitations, projections of future aquifer piezometric response to anticipated area groundwater withdrawals were expected to be accurate within ± 10 feet.

Data Collection and Analysis

Hydrologic data for the period 1975-1976 were collected for the analysis of analog piezometric simulation and patterns of municipal groundwater withdrawal in the eastern Lansing study area.

Forty-four municipal and institutional well sites for East Lansing, Meridian Township, and Michigan State University were used for hydrologic analysis (Figure 1). Twenty-five municipal production wells are operated by

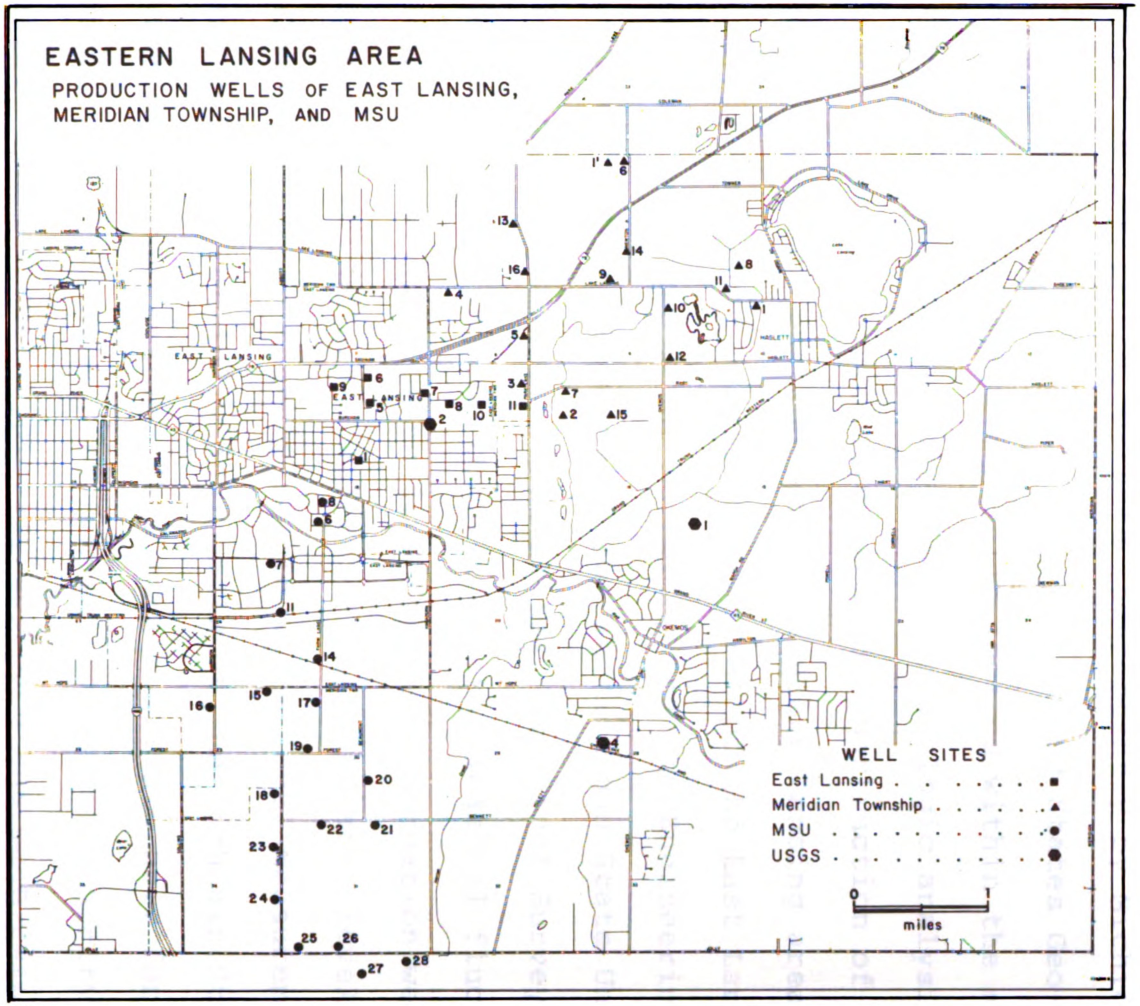

Figure 1.--Eastern Lansing area production wells of East Lansing, Meridian Township, and Michigan State University.

the East Lansing-Meridian Water and Sewer Authority, following joint incorporation of the individual water systems of East Lansing and Meridian Township in 1969. Nineteen production wells are operated independently by Michigan State University. Four additional United States Geological Survey observation wells located within the study area were utilized as controls for hydrologic analysis.

Specific hydrologic data for construction of the 1976 piezometric surface for the eastern Lansing area were obtained from hydrologic records of the East Lansing-Meridian Water and Sewer Authority and the Engineering Department of the Physical Plant at Michigan State University. An analysis of United States Geological Survey hydrographs for Ingham County indicated seasonal fluctuations of between three to five feet in observation wells, suggesting the original selection of mean water-level values. Although monthly static water level measurements were recorded for individual wells of the Michigan State University water system, data were available only for February 1976 for the East Lansing-Meridian Authority wells. Since values typically approach the mean during the late fall-winter period, and given the unavailability of complete monthly data, February static water-level values were accepted as representative for the purposes of the study.

All static water-level measurements were recorded by the Engineering Department of Michigan State University and the East Lansing-Meridian Water and Sewer Authority using an electric probe to measure water elevations following a minimum twenty-four hour well shutdown. Whenever possible, adjacent wells were shut down to minimize or eliminate the effects of pumpage drawdowns. Despite recording precautions, the possibility of interference from adjacent wells is recognized as a possible source of study error.

Following collection of static water-level data for each of the forty-four study area well sites and four United States Geological Survey observation wells, individual piezometric surface values were calculated by subtracting static water levels from recorded well-site ground elevations. The resulting piezometric surface values, expressed in elevations above mean sea level, were then contoured to produce a 1976 piezometric surface map of the eastern Lansing study area.

Comparative piezometric measurements were taken from all study area well sites on the 1975 analog-projected and 1976 actual piezometric maps to determine the predictive accuracy of the electric analog model. Piezometric value differences for each well site were determined, then evaluated within an expected model accuracy range of ± 10 feet. Although 1976 actual piezometric values represent an additional two months' pumpage, minimal allowances were accepted to allow use of the most current hydrologic data available.

Additional hydrologic data were collected to determine the specific patterns of municipal groundwater withdrawal in the eastern Lansing area for 1975 and 1976. Monthly pumpage data for the two-year study period were obtained from the East Lansing-Meridian Water and Sewer Authority and the Engineering Department of the Physical Plant at Michigan State University. Although an original three-year analysis period had been chosen, complete monthly data were unavailable for all East Lansing-Meridian Authority production wells. Groundwater pumpage data were therefore collected for the 1975-1976 two-year period.

Monthly groundwater pumpage was measured by metered flow at individual well sites throughout the Michigan State University well system. Pumpage from the East Lansing-Meridian Authority water system was centrally measured and recorded as time-flow at the Authority water treatment plant. Time-flow values for each well were subsequently converted into gallon pumpage values. Inaccuracies in time-flow measurement and subsequent conversion are estimated as less than five percent.

Total 1975-1976 groundwater pumpage values were initially compiled for individual well sites to determine the variance of total groundwater withdrawals over the study area. Total pumpage values were determined by totaling monthly withdrawals for 1975 and 1976 for individual well sites. Seasonal pumpage over the 1975-1976 period was then determined for each well site by totaling pumpage for the December-February, March-May, June-August, and September-November periods. Both total yearly and seasonal pumpage values were expressed in total rather than mean gallons. Following compilation, total yearly and seasonal withdrawals were then mapped in a series of area groundwater maps for analysis.

PRESENTATION OF FINDINGS

Eastern Lansing Piezometric Conditions

Comparison of actual and analog-projected piezometric values in the eastern Lansing area indicates substantial differences between the 1976 actual and the 1975 projected piezometric surface (Table 1). Measured piezometric values indicate an average model overprojection of 82.9 feet for the entire eastern Lansing area, with considerable variation in accuracy throughout the representative jurisdictional areas of East Lansing, Meridian Township, and Michigan State University.

Maximum differences between actual and analog-projected piezometric values are evident throughout East Lansing and Michigan State University, with less extreme differences throughout Meridian Township. Model-projected average piezometric declines for East Lansing and Michigan State University from 1964-1975 were overprojected 96 feet and 95.4 feet, respectively. Throughout Meridian Township, piezometric surface declines were overprojected an average of 64.4 feet.

Actual piezometric surface declines from 1964-1976 indicate considerably less-pronounced piezometric response throughout the eastern Lansing area (Table 2).

TABLE 1.--1975 analog-projected and 1976 actual piezometric values for the eastern Lansing area.

Well	1975 Analog-projected Piezometric Values (ft above mean sea level)	1976 Actual Piezometric Values (ft above mean sea level)	Net Difference (ft)
EL-1	--	--	--
EL-5	690	765	+ 75
EL-6	--	--	--
EL-7	690	779	+ 89
EL-8	691	793	+102
EL-9	700	780	+ 80
EL-10	696	807	+111
EL-11	715	834	+119
MT-1	797	807	+ 10
MT-1'	792	836	+ 44
MT-2	726	834	+108
MT-3	718	811	+ 93
MT-4	735	805	+ 70
MT-5	730	813	+ 83
MT-6	794	837	+ 43
MT-7	730	834	+104
MT-8	796	838	+ 42
MT-9	768	850	+ 82
MT-10	771	829	+ 58
MT-11	790	833	+ 43
MT-12	771	832	+ 61
MT-13	775	823	+ 48
MT-14	777	832	+ 55
MT-15	750	838	+ 88
MT-16	755	917	+ 62
MSU-6	692	773	+ 81
MSU-7	688	783	+ 95
MSU-8	690	785	+ 95
MSU-11	698	773	+ 75
MSU-14	692	778	+ 86
MSU-15	690	785	+ 95
MSU-16	695	773	+ 78
MSU-17	690	772	+ 82
MSU-18	692	801	+109
MSU-19	690	786	+ 96
MSU-20	693	807	+114
MSU-21	698	812	+114
MSU-22	695	794	+ 99
MSU-23	700	798	+ 98
MSU-24	719	828	+109

TABLE 1.--Continued.

Well	1975 Analog-projected Piezometric Values (ft above mean sea level)	1976 Actual Piezometric Values (ft above mean sea level)	Net Difference (ft)
MSU-25	735	829	+ 94
MSU-26	730	826	+ 96
MSU-27	735	832	+ 97
MSU-28	730	830	+100

<u>Average Net Difference</u>

East Lansing = +96.0'
Meridian Township = +64.4'
Michigan State University = +95.4'
Eastern Lansing Area = +82.9'

TABLE 2.--1964 and 1976 actual piezometric values for the eastern Lansing area.

Well	1964 Actual Piezometric Values (ft above mean sea level)	1976 Actual Piezometric Values (ft above mean sea level)	Net Difference (ft)
EL-1	--	--	--
EL-5	770	765	- 5
EL-6	--	--	--
EL-7	788	779	- 9
EL-8	795	793	- 2
EL-9	780	780	0
EL-10	801	807	+ 6
EL-11	805	834	+29
MT-1	828	807	-21
MT-1'	821	836	+15
MT-2	809	834	+25
MT-3	804	811	+ 7
MT-4	799	805	+ 6
MT-5	805	813	+ 8
MT-6	822	837	+15
MT-7	808	834	+26
MT-8	829	838	+ 9
MT-9	815	850	+35
MT-10	819	829	+10
MT-11	826	833	+ 7
MT-12	819	832	+13
MT-13	809	823	+14
MT-14	817	832	+15
MT-15	814	838	+24
MT-16	808	817	+ 9
MSU-6	781	773	- 8
MSU-7	775	783	+ 8
MSU-8	781	785	+ 4
MSU-11	776	773	- 3
MSU-14	779	778	- 1
MSU-15	779	785	+ 6
MSU-16	785	773	-12
MSU-17	784	772	-12
MSU-18	805	801	- 4
MSU-19	797	786	-11
MSU-20	811	807	- 4
MSU-21	821	812	- 9
MSU-22	815	794	-21
MSU-23	820	798	-22

TABLE 2.--Continued.

Well	1964 Actual Piezometric Values (ft above mean sea level)	1976 Actual Piezometric Values (ft above mean sea level)	Net Difference (ft)
MSU-24	826	828	+ 2
MSU-25	834	829	- 5
MSU-26	835	826	- 9
MSU-27	837	832	- 5
MSU-28	838	830	- 8

<u>Average Net Difference</u>

East Lansing = + 3.2'
Meridian Township = +12.8'
Michigan State University = - 6.0'
Eastern Lansing Area = + 2.9'

Comparative 1964 and 1976 actual piezometric values indicate an average elevation of 2.9 feet in the piezometric surface from 1964-1976, with considerable variation in piezometric response throughout East Lansing, Meridian Township, and Michigan State University. Average piezometric surface elevations of 3.2 feet and 12.8 feet, respectively, were recorded for East Lansing and Meridian Township; however, an average piezometric decline of 6 feet was indicated throughout Michigan State University.

1975 Analog-Projected Piezometric Surface

The 1975 analog-projected piezometric surface for the eastern Lansing area represents a continuation of piezometric response to developed hydrologic conditions of the Saginaw aquifer in 1964 (Figure 2). Anticipated groundwater withdrawal rates for East Lansing, Meridian Township, and Michigan State University for the 1965-1975 period were imposed on the model in an attempt to accurately forecast piezometric response over an eleven-year period.

The projected enlargement of the cone of depression in the eastern Lansing area from 1964-1975 represents an eastern extension of the overall cone of depression of the Lansing Metropolitan area. Analog-projected piezometric response to anticipated groundwater pumpage by East Lansing, Meridian Township, and Michigan State

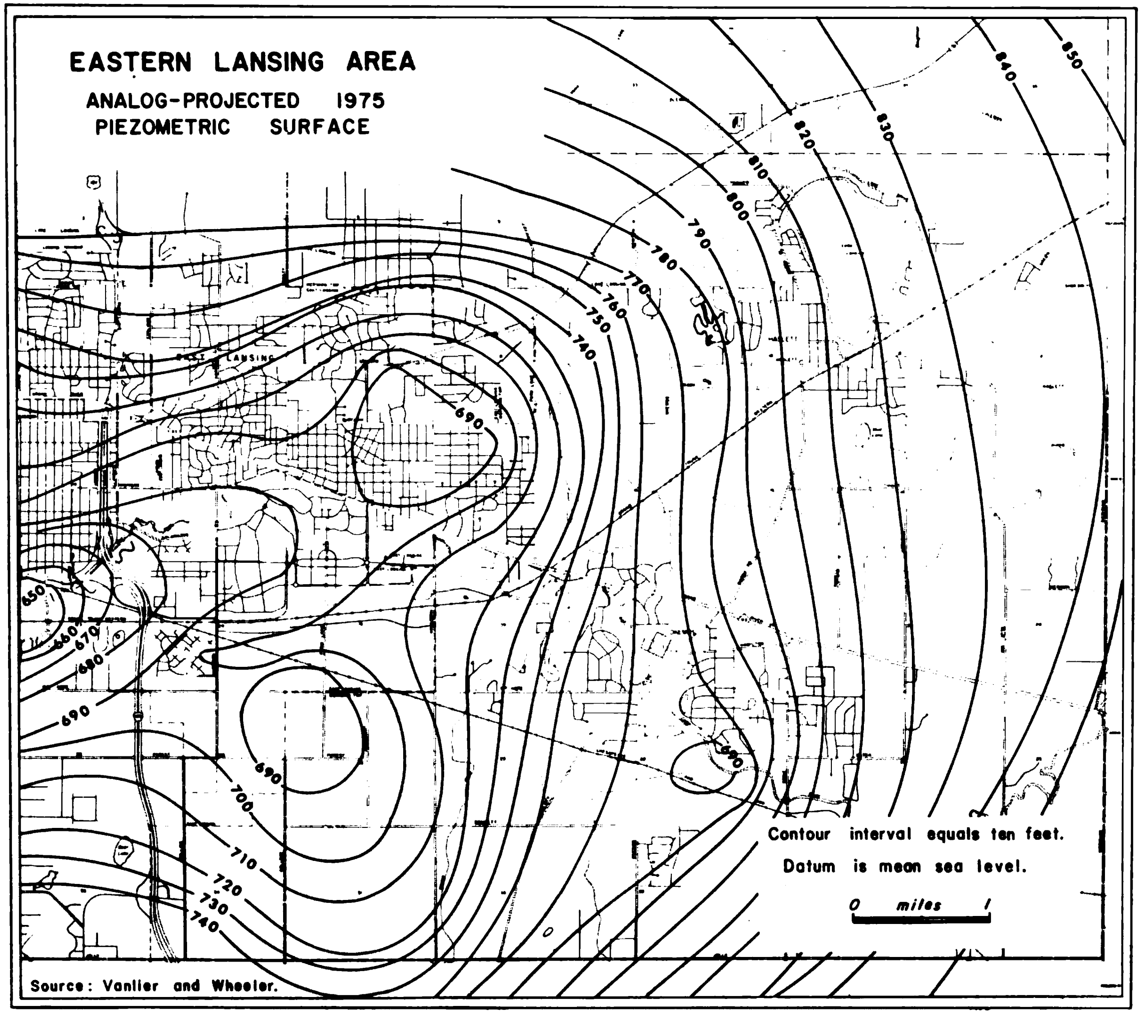

Figure 2.--Eastern Lansing area analog-projected 1975 piezometric surface.

University was expected to produce an average piezometric decline of 90 feet. A similarly-sized though less severe cone of depression was also projected throughout the western and central portions of the eastern Lansing area.

The configuration of the 1975 analog-projected piezometric surface indicates maximum piezometric declines in central East Lansing, central Michigan State University, and south central Meridian Township. An enlarged double piezometric depression in the western portion of the eastern Lansing area suggests an apparent association between the piezometric depressions of central East Lansing and central Michigan State University. Piezometric surface values of 690 feet for both piezometric lows increase northward, southward, and eastward, with piezometric decreases westward toward central Lansing.

A less extensive piezometric depression is projected near the city of Okemos in south central Meridian Township. Piezometric values of 760 feet increase rapidly southward and eastward, with similar though more gradual increases to the north. Piezometric values decrease westward from south central Meridian Township toward central East Lansing and central Michigan State University. The configuration and elevation of the piezometric surface suggest no direct association between the Meridian Township depression and the two larger depressions of East Lansing and Michigan State University.

1976 Actual Piezometric Surface

The 1976 actual piezometric surface for the eastern Lansing area represents the actual response of the Saginaw aquifer to hydrologic conditions from 1964-1976 (Figure 3). Piezometric values from 42 production wells and 3 United States Geological Survey observation wells were used to determine the configuration of the piezometric surface in East Lansing, Meridian Township, and Michigan State University.

The enlargement of the cone of depression in the eastern Lansing area represents the actual eastern extension of the overall cone of depression for the Lansing Metropolitan area from 1964-1976. Comparative piezometric values for 1964 and 1976 indicate an average 2.9 foot rise in elevation of the piezometric surface. Considerable variance in piezometric values is evident throughout the eastern Lansing area, with net piezometric differences ranging from + 35 feet to - 22 feet.

The 1976 actual piezometric surface indicates piezometric lows in central East Lansing and northwestern Meridian Township. An extension of the Lansing piezometric depression is evident in northwestern Michigan State University, although reduced piezometric values are less apparent throughout southern Michigan State University. Variations in the 1976 actual piezometric surface

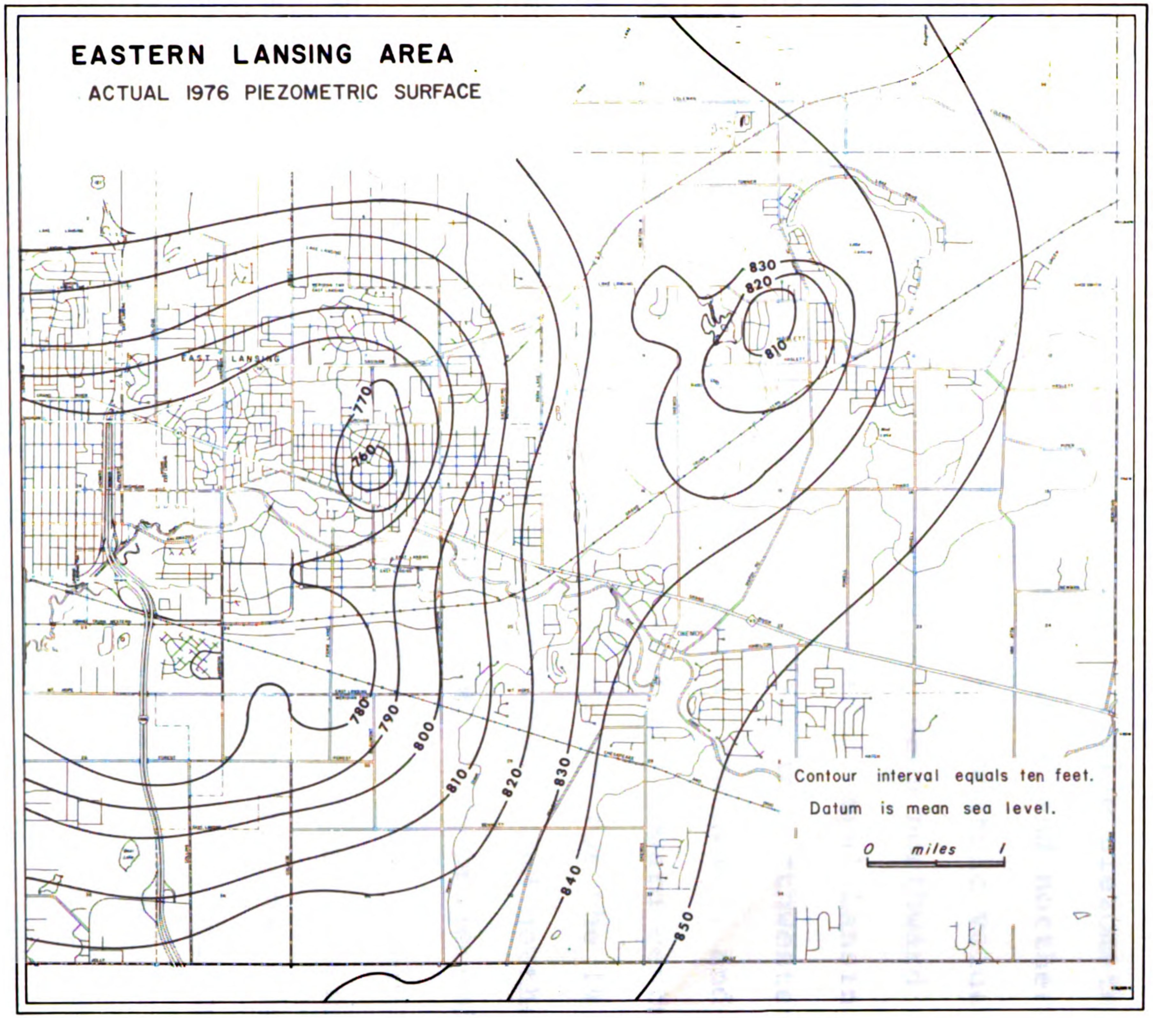

Figure 3.--Eastern Lansing area actual 1976 piezometric surface.

indicate significant differences between actual and analog-projected piezometric conditions.

The northward shift of 1976 actual piezometric depressions suggests an increased relative piezometric response throughout central East Lansing and northern Meridian Township from 1964-1976. Piezometric values of 760 feet in central East Lansing increase northward and southward and decline westward toward central Lansing. Minimum piezometric values of 830 feet in northwestern Meridian Township increase northward, southward, and eastward, with declining values westward toward central East Lansing. Average piezometric values for the 1976 actual piezometric surface in East Lansing and northern Meridian Township are 72.6 feet higher than projected.

Extensive piezometric response is also indicated throughout the southern portion of the eastern Lansing area. Piezometric values increase southward from the central East Lansing and northwestern Meridian Township lows, with an apparent alteration of the piezometric surface throughout central and southern Michigan State University. Average values for the 1976 actual piezometric surface throughout Michigan State University are 95.4 feet higher than projected. Reduced piezometric values projected for south central Meridian Township are not evident in the 1976 actual piezometric surface.

Eastern Lansing Groundwater Withdrawal Patterns

Groundwater withdrawal patterns for the eastern Lansing area in 1975 and 1976 indicate maximum groundwater withdrawals from Michigan State University, with substantial though less extensive pumpage throughout East Lansing and Meridian Township (Tables 3 and 4). Groundwater withdrawal values for 1975 and 1976 indicate proportional withdrawals of 57 percent for Michigan State University and 43 percent for East Lansing and Meridian Township.

Variance in the distribution and magnitude of groundwater withdrawals is evidenced throughout the eastern Lansing area, with generally uniform pumpage throughout the Michigan State University water system and less systematic withdrawal throughout the East Lansing-Meridian Water and Sewer Authority water system. East Lansing-Meridian Authority pumpage values range from 4,344,300 gallons to 467,897,200 gallons and are unevenly distributed throughout East Lansing and Meridian Township. Michigan State University withdrawals range from 11,035,000 gallons to 325,033,000 gallons and are more evenly distributed throughout Michigan State University.

Seasonal groundwater withdrawals throughout the eastern Lansing area indicate nearly uniform pumpage for fall, winter, and spring, with slightly increased

TABLE 3.--Production well total groundwater withdrawals for 1975 and 1976 for East Lansing, Meridian Township, and Michigan State University.

Well	1975 Total Withdrawals (gallons)	1976 Total Withdrawals (gallons)	1975 & 1976 Total Withdrawals (gallons)
EL-1	239,956,900	227,940,300	467,897,200
EL-5	115,249,000	133,891,500	249,140,500
EL-6	100,191,400	142,939,300	243,130,700
EL-7	62,753,400	42,938,600	137,692,000
EL-8	7,045,700	74,388,100	81,433,800
EL-9	93,065,700	107,891,900	200,957,600
EL-10	88,087,900	55,347,700	143,435,600
EL-11	96,770,000	48,734,200	145,504,200
MT-1	23,686,000	78,145,600	101,831,600
MT-1'	84,849,400	64,425,100	149,274,500
MT-2	40,705,700	44,148,000	84,853,700
MT-3	23,286,600	22,157,600	45,444,200
MT-4	0	0	0
MT-5	2,598,600	3,564,900	6,163,500
MT-6	12,702,700	16,198,400	28,901,100
MT-7	67,461,300	84,932,200	152,393,500
MT-8	38,979,200	50,450,200	89,429,400
MT-9	15,600	10,276,600	10,292,200
MT-10	1,756,800	2,587,500	4,344,300
MT-11	145,932,900	180,203,300	326,136,200
MT-12	687,500	3,713,200	4,400,700
MT-13	0	0	0
MT-14	14,885,500	26,941,700	41,827,200
MT-15	0	0	0
MT-16	0	0	0
MSU-6	0	0	0
MSU-7	5,500,000	5,535,000	11,035,000
MSU-8	96,489,000	86,704,000	183,193,000
MSU-11	70,993,000	59,000,000	129,993,000
MSU-14	0	29,000	29,000
MSU-15	126,640,000	139,697,000	266,337,000
MSU-16	123,119,000	94,833,000	217,952,000
MSU-17	109,332,000	104,188,000	213,520,000
MSU-18	107,732,000	96,775,000	204,507,000
MSU-19	144,831,000	127,363,000	272,194,000
MSU-20	101,563,000	96,223,000	197,786,000
MSU-21	115,762,000	117,915,000	233,677,000
MSU-22	85,506,000	96,157,000	181,663,000
MSU-23	108,748,000	89,761,000	198,184,000
MSU-24	109,004,000	117,180,000	226,184,000

TABLE 3.--Continued.

Well	1975 Total Withdrawals (gallons)	1976 Total Withdrawals (gallons)	1975 & 1976 Total Withdrawals (gallons)
MSU-25	97,525,000	89,668,000	187,193,000
MSU-26	98,572,000	83,736,000	182,308,000
MSU-27	161,212,000	158,038,000	319,250,000
MSU-28	157,661,000	167,372,000	325,033,000

TABLE 4.--Water system total groundwater withdrawals for 1975 and 1976 for East Lansing-Meridian Township and Michigan State University.

	1975 Total Withdrawals (gallons)	1976 Total Withdrawals (gallons)	1975 & 1976 Total Withdrawals (gallons)
EL-MT	1,260,667,800	1,453,815,900	2,714,483,700 (43.3%)
MSU	1,820,189,000	1,730,174,000	3,550,363,000 (56.7%)
Total	3,080,856,800	3,183,989,900	6,264,846,700 (100%)

withdrawals during the summer (Tables 5 and 6). Respective seasonal withdrawal values of 25.4 percent, 23 percent, and 23.6 percent were recorded for the fall, winter, and spring periods. The remaining 27.9 percent of groundwater withdrawals were recorded in summer.

Comparative seasonal withdrawal values for the individual water systems of Michigan State University and the East Lansing-Meridian Water and Sewer Authority indicate more pronounced summer withdrawals throughout East Lansing and Meridian Township. Increased East Lansing-Meridian pumpage of 31.3 percent suggests a moderate seasonal imbalance in the East Lansing-Meridian groundwater withdrawal pattern. Nearly uniform seasonal withdrawal values are indicated for Michigan State University, with minimal pumpage throughout northern Michigan State University and increased withdrawals throughout central and southern Michigan State University.

Total Groundwater Withdrawals: 1975 and 1976

Combined groundwater withdrawals for 1975 and 1976 represent total production well pumpage for the eastern Lansing area over a two-year period (Figure 4). Individual withdrawals for the 44 municipal and institutional wells of East Lansing, Meridian Township, and Michigan State University were compiled to determine the

TABLE 5.--Production well seasonal groundwater withdrawals for 1975 and 1976 for East Lansing, Meridian Township, and Michigan State University.

Well	Dec-Feb. Total Withdrawals (gallons)	Mar-May Total Withdrawals (gallons)	June-Aug. Total Withdrawals (gallons)	Sept-Nov. Total Withdrawals (gallons)
EL-1	119,388,100	120,419,200	133,590,600	104,335,400
EL-5	53,933,900	66,955,000	58,522,000	65,082,600
EL-6	48,172,700	55,688,600	70,803,800	68,211,400
EL-7	36,836,800	31,417,900	36,263,300	35,350,100
EL-8	24,946,500	19,145,100	20,152,800	16,255,000
EL-9	63,332,800	33,294,300	54,827,300	50,546,400
EL-10	40,014,000	24,644,700	44,564,500	37,827,700
EL-11	48,540,600	29,003,500	41,318,100	33,215,400
MT-1	39,665,900	19,307,400	17,298,000	26,100,400
MT-1'	29,412,200	4,677,000	46,849,400	62,418,000
MT-2	16,324,900	14,577,200	33,893,600	18,984,200
MT-3	2,668,800	2,216,400	26,815,600	11,474,200
MT-4	0	0	0	0
MT-5	283,400	187,000	2,701,100	0
MT-6	1,274,400	552,900	14,590,900	9,350,700
MT-7	25,143,100	9,539,300	71,492,300	39,800,600
MT-8	2,379,700	6,243,100	51,670,900	28,427,600
MT-9	15,600	0	0	8,326,600
MT-10	763,200	0	993,600	0
MT-11	56,306,900	117,703,200	97,996,200	67,467,800
MT-12	0	0	0	0
MT-13	0	0	0	0
MT-14	281,800	0	24,534,600	14,696,900
MT-15	0	0	0	0
MT-16	0	0	0	0
MSU-6	0	0	0	0
MSU-7	5,551,000	5,385,000	866,000	1,443,000
MSU-8	48,541,000	48,682,000	42,979,000	46,114,000
MSU-11	26,194,000	37,720,000	32,788,000	34,172,000
MSU-14	0	0	0	0
MSU-15	58,810,000	74,590,000	60,945,000	74,494,000
MSU-16	52,668,000	41,719,000	64,034,000	64,870,000
MSU-17	60,691,000	45,720,000	56,482,000	52,696,000
MSU-18	40,008,000	56,217,000	62,906,000	46,178,000
MSU-19	67,071,000	72,742,000	65,173,000	68,603,000
MSU-20	47,124,000	52,816,000	50,655,000	50,555,000
MSU-21	60,817,000	71,058,000	43,465,000	58,887,000
MSU-22	34,028,000	48,494,000	49,569,000	48,189,000
MSU-23	49,083,000	50,256,000	54,403,000	43,461,000

TABLE 5.--Continued.

Well	Dec.-Feb. Total Withdrawals (gallons)	Mar-May Total Withdrawals (gallons)	June-Aug. Total Withdrawals (gallons)	Sept-Nov. Total Withdrawals (gallons)
MSU-24	46,634,000	60,760,000	56,666,000	58,930,000
MSU-25	48,010,000	53,644,000	47,002,000	45,474,000
MSU-26	29,771,000	45,538,000	56,188,000	46,628,000
MSU-27	85,319,000	81,393,000	81,362,000	74,138,000
MSU-28	78,815,000	81,909,000	77,667,000	84,145,000

TABLE 6.--Water system seasonal groundwater withdrawals for 1975 and 1976 for East Lansing-Meridian Township and Michigan State University.

Water System	Dec-Feb. Total Withdrawals (gallons)	Mar-May Total Withdrawals (gallons)	June-Aug. Total Withdrawals (gallons)	Sept-Nov. Total Withdrawals (gallons)
EL-MT	609,685,300	555,541,800	849,058,600	699,048,600
MSU	839,135,000	928,643,000	903,150,000	899,006,000
Total	1,448,820,300	1,484,184,800	1,752,208,600	1,598,054,600

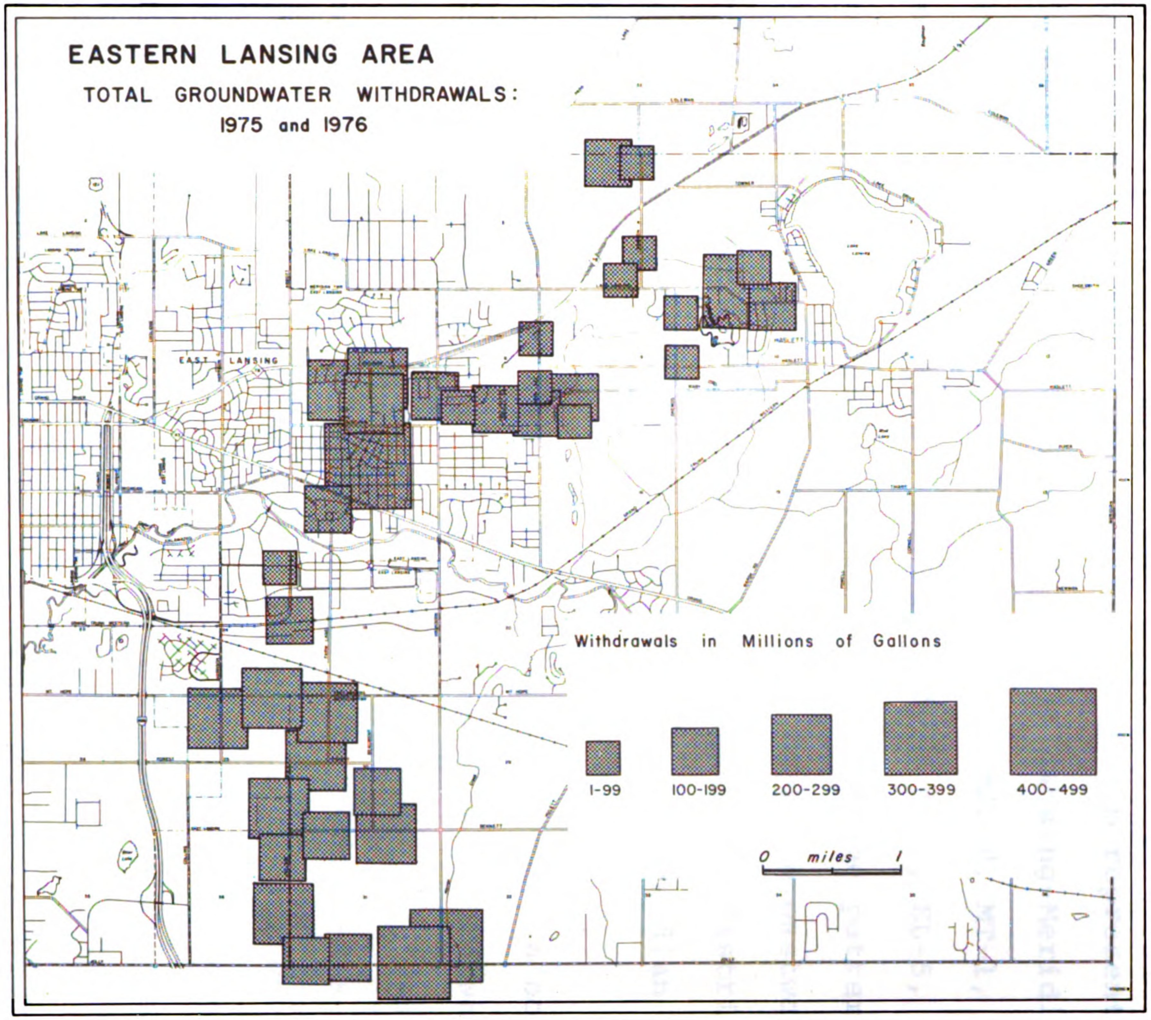

Figure 4.--Eastern Lansing area total groundwater withdrawals: 1975 and 1976.

distribution and extent of withdrawals throughout the eastern Lansing area.

Areas of concentrated pumpage in central East Lansing and north central Meridian Township represent disproportionate withdrawals from East Lansing-Meridian Authority wells EL-1, EL-5, EL-6, EL-9, MSU-8, MT-1, MT-8, and MT-11. Substantial withdrawals from EL-1, EL-5, EL-6, and MSU-8 are evident in the clustered pumpage pattern in central East Lansing. Pumpage values decrease eastward of central East Lansing and are more uniformly distributed throughout eastern East Lansing and western Meridian Township.

A second groundwater withdrawal cluster in north central Meridian Township includes combined withdrawals from MT-1, MT-8, and MT-11. Although pumpage is less extensive for MT-1 and MT-8, substantial withdrawals from MT-11 form a localized pumpage concentration smaller in magnitude than the concentration for central East Lansing. Minimum withdrawals from 0-28,901,100 gallons were recorded in northwestern Meridian Township from East Lansing-Meridian Authority wells MT-4, MT-5, MT-6, MT-9, MT-10, MT-12, MT-13, MT-15, and MT-16.

Total withdrawals throughout central and southern Michigan State University indicate a nearly uniform groundwater withdrawal pattern. Systematic pumpage evident throughout the Michigan State University water system includes nearly uniform withdrawals from MSU-8, MSU-11,

MSU-15, MSU-16, MSU-17, MSU-18, MSU-19, MSU-20, MSU-21, MSU-22, MSU-23, MSU-24, MSU-25, and MSU-26. Moderately increased pumpage values were recorded in southern Michigan State University for MSU-27 and MSU-28.

Minimum pumpage throughout northern Michigan State University includes slightly decreased withdrawals from MSU-8 and MSU-11. Inconsequential withdrawals are recorded for MSU-6 and MSU-14, with both wells unutilized for production in 1975 and 1976. Moderate groundwater withdrawals from MSU-8 in the northern portion of Michigan State University appear more closely associated with the central East Lansing well cluster.

Seasonal Groundwater Withdrawals: 1975 and 1976

Seasonal groundwater withdrawals for 1975 and 1976 represent production well pumpage for the December-February, March-May, June-August, and September-November periods. The distribution and magnitude of seasonal withdrawals for the eastern Lansing area are indicated in Figure 5, Figure 6, Figure 7, and Figure 8.

Seasonal patterns of groundwater withdrawal remain nearly uniform throughout the year, with moderate seasonal differences in pumpage for individual wells in East Lansing, Meridian Township, and Michigan State University. Areas of concentrated withdrawals in central East Lansing

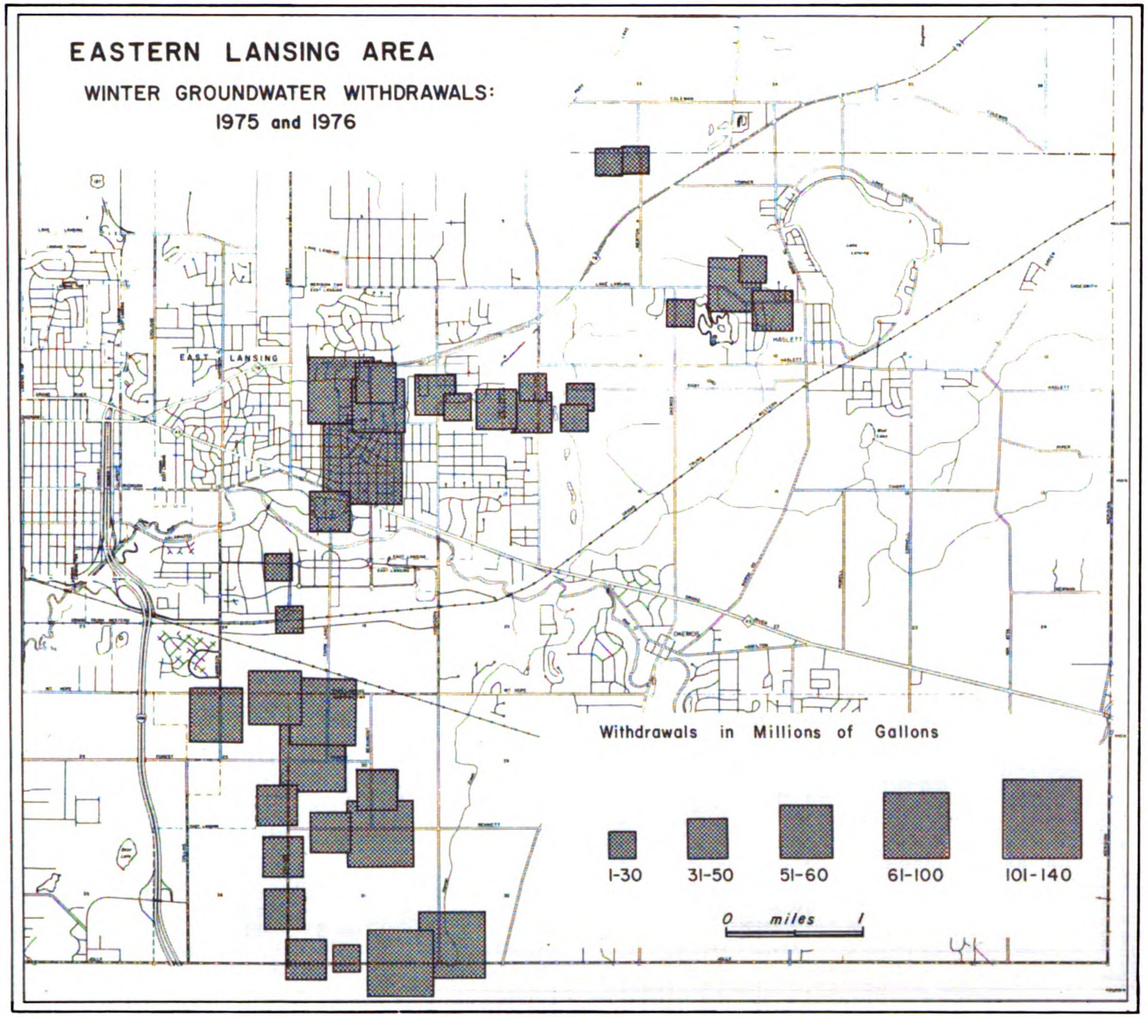

Figure 5.--Eastern Lansing area winter groundwater withdrawals: 1975 and 1976.

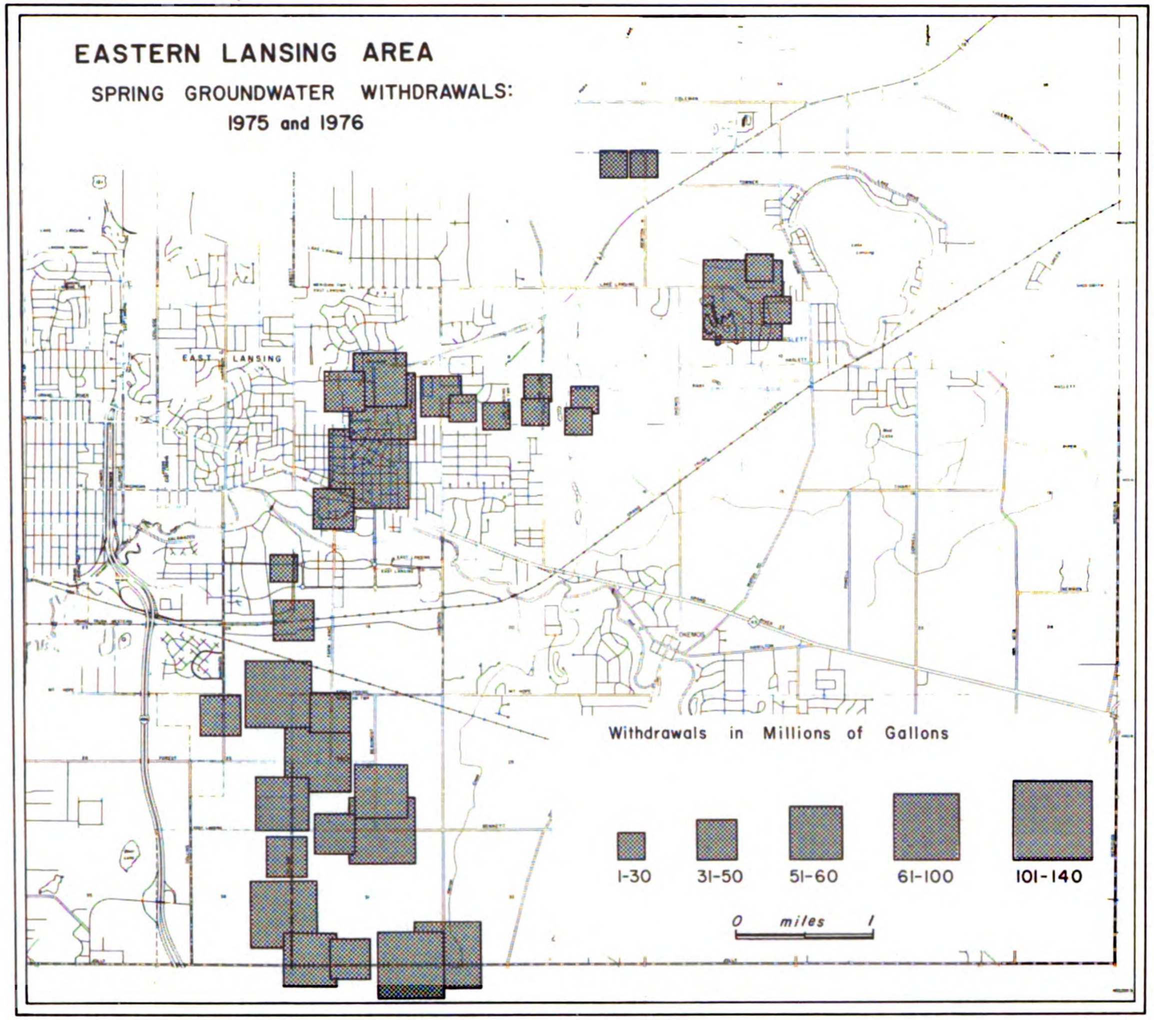

Figure 6.--Eastern Lansing area spring groundwater withdrawals: 1975 and 1976.

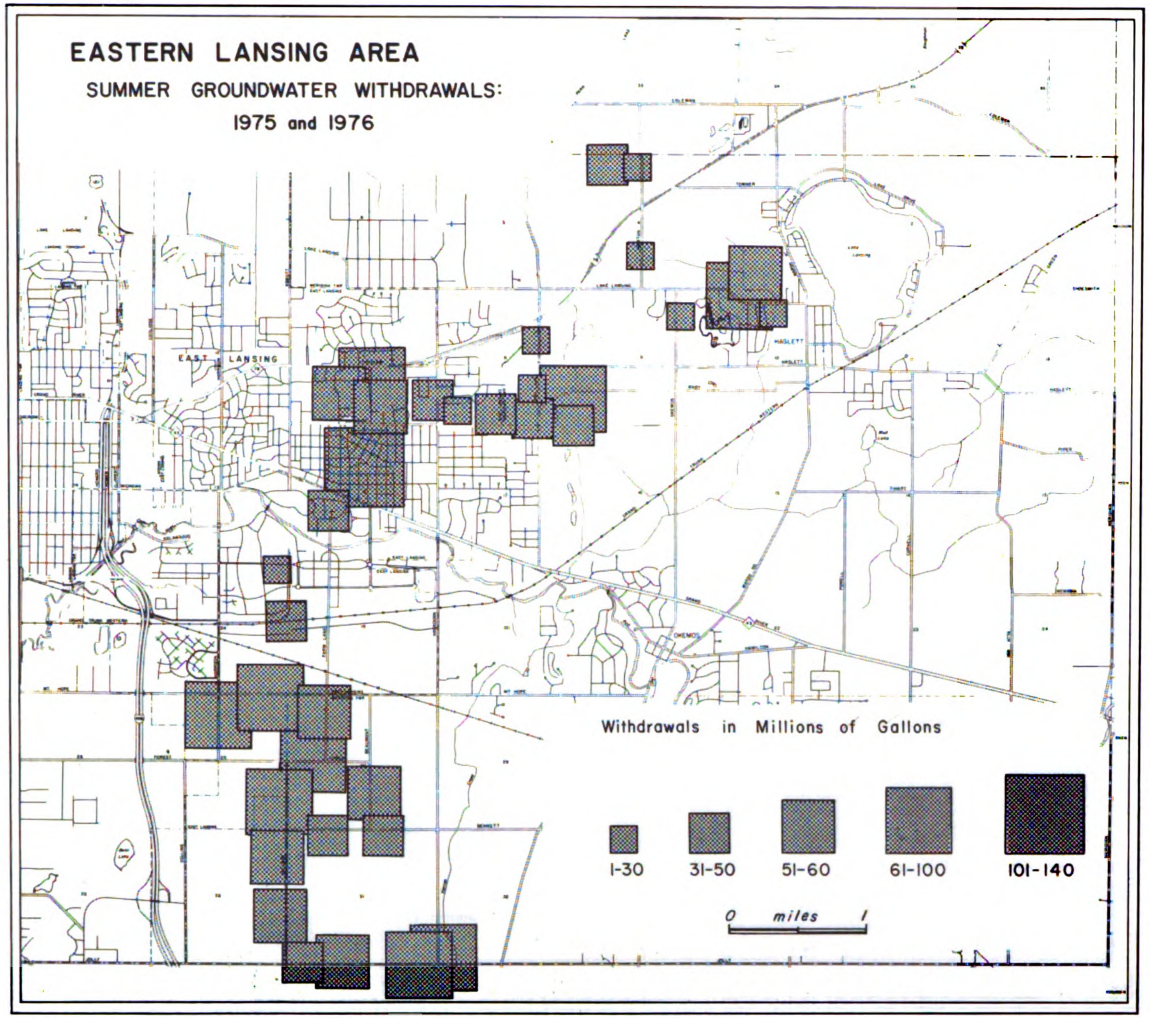

Figure 7.--Eastern Lansing area summer groundwater withdrawals: 1975 and 1976.

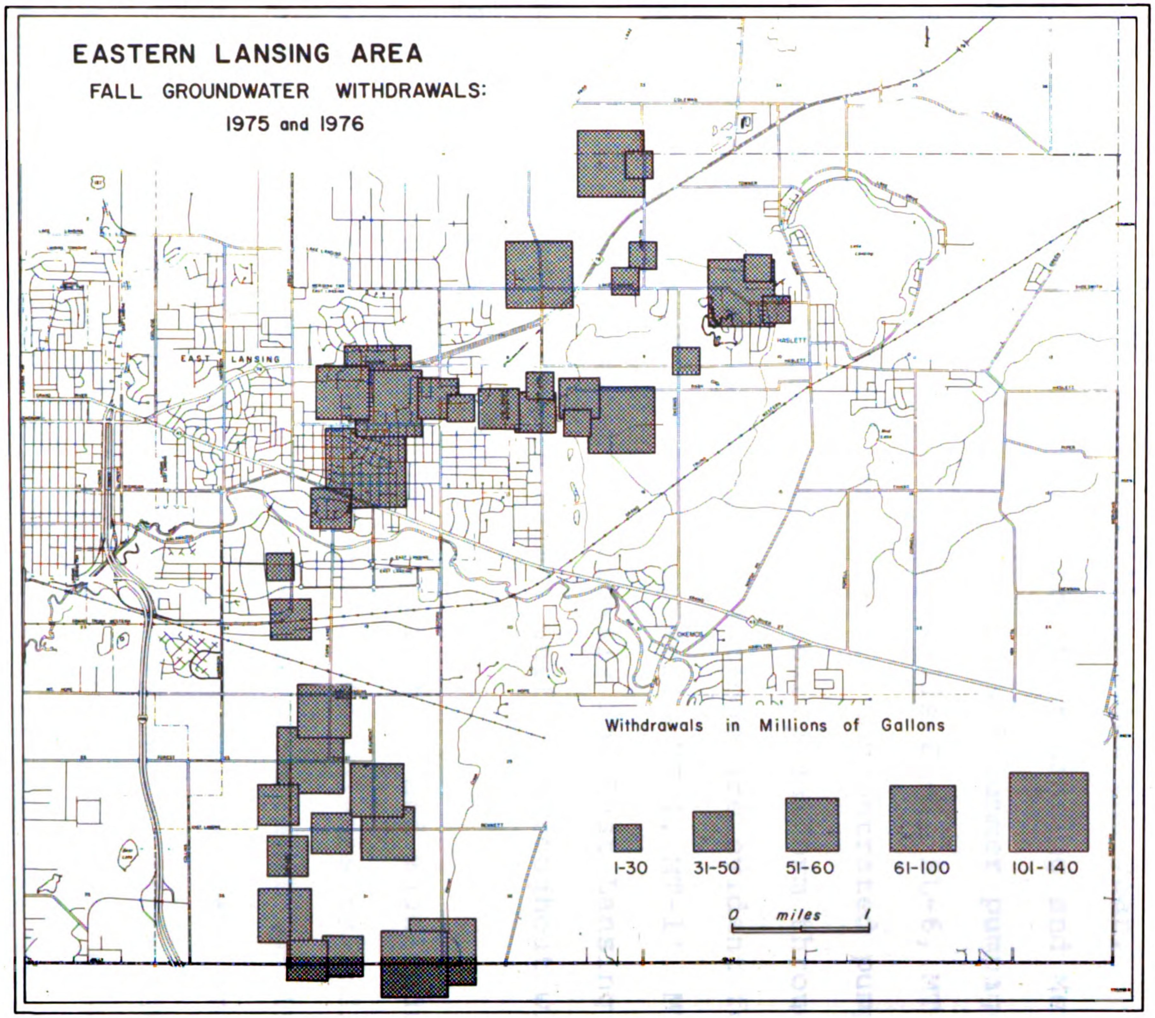

Figure 8.--Eastern Lansing area fall groundwater withdrawals: 1975 and 1976.

and north central Meridian Township exhibit moderate seasonal fluctuations. The nearly-uniform distribution of groundwater withdrawals throughout Michigan State University remains unchanged throughout the year.

Seasonal withdrawals for East Lansing and Meridian Township indicate moderately increased summer pumpage from East Lansing-Meridian Authority wells EL-1, EL-6, MT-2, MT-3, MT-6, MT-7, MT-8, and MT-14. Concentrated pumpage in central East Lansing remains nearly uniform throughout the year, although seasonal variations are evident for north central Meridian Township wells MT-1, MT-1', MT-8, and MT-11. Groundwater withdrawals for East Lansing and Meridian Township remain nearly uniform throughout winter, spring, and fall.

The nearly uniform distribution and magnitude of withdrawals throughout Michigan State University indicate a systematic pattern of groundwater withdrawal for 1975 and 1976. Minimal variations in seasonal pumpage occur throughout Michigan State University, with nearly equivalent pumpage from MSU-8, MSU-11, MSU-15, MSU-16, MSU-17, MSU-18, MSU-19, MSU-20, MSU-21, MSU-22, MSU-23, MSU-24, MSU-25, MSU-26, MSU-27, and MSU-28.

DISCUSSION OF FINDINGS

Analog Model Simulation Accuracy

The degree of analog simulation inaccuracy evident throughout the eastern Lansing area represents an initial basis for model evaluation. Although discrepancies between actual and analog-projected piezometric values indicate extensive overprojection of piezometric response from 1964-1976, projected response may be consistent with originally programmed withdrawal and recharge data. A re-examination of basic model assumptions, programmed value inputs, and possible anomalous climatic or hydrologic conditions from 1964-1975 was therefore undertaken in an attempt to explain piezometric differences within existing model design.

Normally, excessive piezometric response can be expected as a consequence of three factors: (1) overestimated 1964-1975 withdrawal rates used in model analyses, (2) increased aquifer recharge extensive enough to offset withdrawal-induced declines, or (3) changes in the relative importance or interrelationships of fundamental hydrologic variables. Although incorrectly forecasted withdrawal or precipitation recharge rates can be attributed to human error as transient program inputs, changes in the relative importance or interaction of hydrologic variables would suggest fundamental deficiencies in model design.

Following examination of specific rates of ground-water withdrawal and estimated precipitation recharge from 1964-1975, adjustments were made to determine the estimated effect of incorrectly forecasted model values on projected piezometric declines. Readjusted value differences were then deducted and model projections re-evaluated. Final assessment of the overall accuracy of future piezometric simulation was based on a model-stated predictive expectancy range of ± 10 feet.

Analog-Projected and Actual Withdrawal Rates

Projected withdrawal rates used in model analyses were determined by estimating the expected increase in average daily withdrawal from 1965-1975 from East Lansing, Meridian Township, and Michigan State University. Additional withdrawal centers expected by 1975 were similarly imposed on the model to simulate the future configuration of withdrawals throughout the eastern Lansing area. Actual withdrawal rates from 1965-1975 represent actual yearly pumpage subsequently recorded for each of the respective water systems.

Comparative average withdrawal rates indicate a 33 percent overestimation of expected groundwater withdrawals from 1965-1975 (Table 7). Projected withdrawal rates were overestimated 4.33 mgd throughout the eastern Lansing area, with respective overprojections of 2.11 mgd and 2.22 mgd for East Lansing-Meridian Township and Michigan State University. Further differences were indicated between the actual and projected configuration of withdrawal centers. Expected withdrawal centers in northeastern East Lansing and south central Meridian Township were subsequently developed throughout north central and northwestern Meridian Township. Withdrawal centers were accurately projected throughout southern Michigan State University.

Differences in the actual and projected magnitude and configuration of groundwater withdrawals provide a preliminary basis for model re-evaluation. Approximately one third of the overprojected piezometric declines can be explained by assuming that projected groundwater declines are a direct function of groundwater withdrawal rates used in model analyses. Since actual piezometric declines generally decrease over a successively enlarged area and are susceptible to variations in local recharge, discharge, and lithology, a slightly smaller piezometric accounting is expected.

TABLE 7.--Projected and actual average daily withdrawal rates from 1965-1975 for East Lansing, Meridian Township, East Lansing-Meridian Water and Sewer Authority, and Michigan State University.

Year	Projected Withdrawal Rates (million gallons per day)			Actual Withdrawal Rates (million gallons per day)			
	EL	MT	MSU	EL	MT	AUTH	MSU
1965	4.51	1.50	7.03	2.50	0.14		3.80
1966	4.51	1.50	7.03	2.60	0.15		3.80
1967	4.51	1.50	7.03	2.90	0.25		5.10
1968	4.51	1.50	7.03	3.40	0.32		5.40
1969	4.51	1.50	7.03	3.40	0.52		5.40
1970	4.51	1.50	7.03	3.50	0.58		4.90
1971	4.51	1.50	7.03	3.40	0.73		4.60
1972	4.51	1.50	7.03	3.40	0.79		4.70
1973	4.51	1.50	7.03	1.70	0.40	3.70	5.00
1974	4.51	1.50	7.03			4.30	4.90
1975	4.51	1.50	7.03			4.30	4.90
Average	6.01		7.03		3.90		4.81
Total Average	13.04					8.71	

Changes in the configuration of expected withdrawal centers from 1965-1975 are more difficult to assess. Although withdrawal centers were accurately projected for Michigan State University, actual withdrawal centers for East Lansing and Meridian Township were extended over a larger area than was anticipated in model design. Programmed withdrawals were therefore overconcentrated in northeastern East Lansing and not imposed in north central and northwestern Meridian Township.

The effect of overestimated withdrawal rates used in model analyses appears slightly intensified by the projected overconcentration of withdrawal centers in northeastern East Lansing. The combined effect of overestimated and overconcentrated withdrawals produced a more-pronounced piezometric response throughout East Lansing and western Meridian Township (Figure 2). Since reduced actual withdrawals were distributed over a larger, hydrologically less-developed area, a slightly less-extensive piezometric response occurred (Figure 3).

The extent of overprojected piezometric response that can be attributed to inaccurately projected withdrawal centers appears minimal. No apparent reduction in piezometric overprojection is indicated throughout Michigan State University, where withdrawal rates are similarly overestimated but projected in the proper configuration. Reduced piezometric overprojections indicated in north central and northwestern Meridian Township appear to be a consequence of unanticipated East Lansing-Meridian Authority pumpage rather than changes in the expected configuration of groundwater withdrawals.

Precipitation Recharge

Following comparison of actual and projected withdrawals, precipitation data for the eastern Lansing area from 1965-1975 were examined for evidence of increased aquifer recharge (Table 8). Annual and cumulative departures from normal yearly precipitation were determined for the East Lansing Station based on a 1940-1975 average yearly total of 30.37 inches. Yearly precipitation totals were assumed to be evenly distributed throughout the year.

Reductions in precipitation are evident in the eastern Lansing area from 1965-1969, with subsequent precipitation increases from 1970-1975. Cumulative departures from 1965-1969 indicate an initial 7.03 inch decrease in rainfall, followed by a 7.29 inch cumulative precipitation increase from 1970-1975. The cumulative departure of precipitation for the entire 1965-1975 period indicates a .26 inch increase, representing a slight annual increase of .0236 inches.

Variations in precipitation from 1965-1975 suggest minimal increases in precipitation recharge throughout

TABLE 8.--Annual precipitation, annual departure of precipitation, and cumulative departure of precipitation for 1965-1975 for Michigan State University, East Lansing, Michigan.

Year	Annual Precipitation (inches)	Annual Departure of Precipitation (inches)	Cumulative Departure of Precipitation (inches)
1965	30.09	-0.28	-0.28
1966	26.21	-4.16	-4.44
1967	28.84	-1.53	-5.97
1968	31.89	-1.52	-4.45
1969	27.79	-2.58	-7.03
1970	34.67	+4.30	-2.73
1971	24.56	-5.81	-8.54
1972	30.50	+0.13	-8.41
1973	34.79	+4.42	-3.99
1974	28.86	-1.51	-5.50
1975	36.13	+5.76	+0.26

SOURCE: United States Department of Commerce National Oceanic and Atmospheric Administration Environmental Data Service and Michigan Weather Service, 1976. Michigan State University, East Lansing, Michigan.

the eastern Lansing area, although site data are cautiously interpreted and not necessarily indicative of regional climatic patterns. More extensive precipitation increases associated with higher lake levels in the Lake Michigan-Huron Basin from 1968-1971 have been indicated by Buckler (1973) and have been subsequently related by Harman (1977) to a possible shift in the westerlies long wave pattern. Regional cumulative departures therefore suggest the possibility of more-enhanced regional precipitation recharge to the Saginaw aquifer.

The hydrologic effects of variations in precipitation recharge have been examined by Firouzian (1963). Piezometric fluctuations of three selected Saginaw Formation wells in the Lansing area were correlated with annual and cumulative precipitation departures and municipal pumpage from 1946-1962. Although piezometric declines were moderately inhibited during periods of increased rainfall, overall piezometric response remained primarily a function of municipal pumpage. Reductions in the rate of piezometric decline during periods of increased precipitation and stabilized pumpage were less than 15 feet.

By assuming comparable increases in precipitation recharge from 1970-1975, a maximum reduction of 15 feet in piezometric overprojection could be explained in the eastern Lansing area. Although the exact extent of precipitation recharge is unspecified, actual piezometric reductions are believed to be more conservative. Evidence for reduced precipitation-induced piezometric response is indicated in observation well fluctuations in low pumpage areas in Meridian Township and areas of uniform pumpage throughout Michigan State University. Piezometric fluctuations in both areas are generally less than 10 feet. Direct relationships between precipitation and piezometric response are less apparent in areas of increased withdrawal in central East Lansing.

Hydrologic Variables and Model Design

The relative importance and interrelationships of hydrologic variables represent structural elements of model design. Since inaccurately forecasted withdrawal rates and enhanced precipitation recharge collectively account for less than half of model piezometric overprojections, several fundamental aspects of model design were re-examined. Actual experimentation was not undertaken since the model was disassembled several years after completion of the original study.

The relative importance of fundamental hydrologic variables was originally determined by successive model analyses. Initial analyses of hydrologic conditions from 1900-1964 identified leakage through the upper confining beds of the Saginaw Formation as the most important source of aquifer recharge. The decreased importance of transmissibility was suggested following specification of nearly uniform leakage values throughout the Lansing area. Subsequent analyses identified river courses as constant but fixed sources of aquifer recharge and indicated significant reductions in water levels of saturated overlying drift.

Following transient analyses adjustments, hydrologic interrelationships were simulated in completed model circuitry. Although the completed model was considered representative of the developed aquifer in 1964, caution was emphasized by Wheeler in the projection of future piezometric conditions based on developed model design. The possibility of a reordering of hydrologic variables was suggested as a possible consequence of future aquifer development. Consequently, unexpected hydrologic changes were expected to limit the reliability of the model for future piezometric simulation.

Extensive overprojection of piezometric values from 1964-1976 indicates the likelihood of hydrologic changes unanticipated in original model design. Significantly overprojected piezometric declines remain unexplained after adjusting overprojected withdrawal rates and increasing allowances for precipitation recharge. Since the remaining piezometric overprojections exceed the predicted range of model accuracy by approximately

35 feet, model reliability for futute piezometric simulation is severely limited.

Determination of the nature of possible hydrologic changes was considered beyond the scope of the current investigation. Suggestion of increased transmissibility in response to possible aquifer or glacial drift dewatering from 1964-1975 has not been verified by empirical investigation. The potential effect of additional precipitation recharge on lowered water levels in the glacial drift similarly remains unexamined. Final specification of the nature and extent of aquifer transmissibility and glacial recharge are necessary prerequisites for accurate future piezometric simulation and are therefore recommended for future investigation.

Summary

To summarize, piezometric declines projected throughout the eastern Lansing area from 1964-1975 exceed actual declines by approximately 80 feet. Overestimated withdrawal rates used in model analyses appear directly responsible for nearly one third of the overprojected piezometric declines, with piezometric response slightly enhanced or inhibited by moderate changes in the configuration of projected withdrawal centers. The maximum effect of additional precipitation recharge is estimated as 15 feet.

The combined effect of readjusted withdrawal rates and additional precipitation recharge explains less than half of the model piezometric overprojections. Fundamental changes are therefore suspected in the relative importance and interrelationships of hydrologic variables inherent to model design. Although unverified, increased aquifer transmissibility and recharge from overlying glacial drift are suggested as possible bases for reduced actual piezometric response. Accurate future piezometric simulation is dependent on further empirical investigation and appropriate model revision.

Groundwater Withdrawal Patterns

Accurate hydrologic assessment throughout the eastern Lansing area is based largely on specification of the magnitude and configuration of groundwater withdrawals. While increased withdrawals from 1964-1976 have resulted in net piezometric declines in areas of substantially increased or concentrated pumpage, an average 2.9 foot elevation of the piezometric surface is indicated throughout the eastern Lansing area. Changes in the overall configuration of the piezometric surface therefore represent an adjusted aquifer response to the changing pattern of groundwater withdrawal.

Variations in the distribution of groundwater withdrawals reflect jurisdictional as well as hydrologic circumstances. While differences in overall demand and potential water supply impose broad limitations to hydrologic development, legal or jurisdictional limitations often determine actual withdrawal procedures. Since withdrawal procedures throughout East Lansing and Meridian Township differ in several fundamental respects from procedures utilized by Michigan State University, respective withdrawal practices and jurisdictional limitations were examined to determine the effect of nonhydrologic factors on area withdrawal patterns.

East Lansing-Meridian Township

The configuration of production well withdrawals throughout East Lansing and Meridian Township was determined by the East Lansing-Meridian Water and Sewer Authority following joint incorporation in 1969. The independent water systems of East Lansing and Meridian Township were subsequently combined and enlarged in 1973 with the addition of 15 production wells in northeastern and north central Meridian Township. The locations of Authority wells were determined after extensive hydrologic study throughout northeastern East Lansing and Meridian Township.

The groundwater withdrawal pattern since 1973 has been characterized by an uneven distribution of withdrawals throughout East Lansing and Meridian Township.

Disproportionately increased pumpage in central East Lansing and north central Meridian Township contrasts markedly with minimal pumpage throughout northwestern Meridian Township. Moderate pumpage is recorded in eastern East Lansing (Figure 4). The uneven withdrawal pattern persists throughout the year, with moderate increases in overall pumpage evident during the summer.

Extensive variations in groundwater withdrawal are related to several nonhydrologic factors. Although completed in 1973, Authority well MT-15 in northwestern Meridian Township is inoperative and therefore has never been pumped. Mechanical difficulty has similarly prevented significant pumpage from MT-10. Since demand has been adequately supplied by the remaining wells throughout the system, both wells have been designated inoperative and are maintained on a reserve basis.

Withdrawals from Authority wells MT-4, MT-13, and MT-16 were discontinued following local litigation in 1973. A suit filed by citizens of Meridian Township alleged interference by Authority production wells in privately developed areas in northwestern Meridian Township. Authority pumpage was discontinued pending legal decision to avoid significantly lowering water levels in the glacial drift or depleting water supplies tapped by private wells.

Reductions in projected demand for East Lansing and Meridian Township have allowed spatial manipulation of withdrawals to compensate for inoperative or unpumped wells. Municipal water demands throughout the service area have been adequately supplied by withdrawals from selected high-production wells. Consequently, emphasis since 1973 has been almost exclusively on East Lansing wells EL-1, EL-5, EL-6, EL-7, EL-9, EL-10, EL-11, and Meridian Township wells MT-1, MT-1', MT-2, MT-7, MT-8, and MT-11.

Although East Lansing-Meridian high-production wells have been effectively utilized in areas of high aquifer yield, selective pumpage has reinforced the uneven withdrawal pattern throughout East Lansing and Meridian Township. Selective withdrawals have in turn concentrated piezometric response in central East Lansing and north central Meridian Township. The actual configuration of the piezometric surface therefore reflects both hydrologic and jurisdictional withdrawal factors.

Michigan State University

Total withdrawals throughout Michigan State University are proportionally larger than for East Lansing and Meridian Township (Tables 3 and 4). Groundwater withdrawals are more uniformly distributed throughout central and southern Michigan State University, with

reduced pumpage evident in northern Michigan State University. The configuration of groundwater withdrawals is determined by the Engineering Department of the University Physical Plant.

Successive enlargements of the Michigan State University water system since 1964 have included the addition of 8 production wells in central and southern Michigan State University. Production wells are uniformly spaced approximately 2000 feet apart to reduce interference and are systematically pumped within a given withdrawal range. Pumpage from less-productive older wells in the northern portion of the University has been reduced or discontinued.

Although evenly distributed, increased withdrawals throughout Michigan State University have produced an average 6 foot decline in the piezometric surface from 1964-1976. Piezometric depressions, however, are less severe than in central East Lansing, where disproportionately large withdrawals have lowered the piezometric surface to 760 feet (Figure 3). Uniformly distributed withdrawals may therefore inhibit localized depressions while inducing piezometric declines over a larger area.

Summary

To summarize, groundwater withdrawal patterns throughout the eastern Lansing area reflect both hydrologic and jurisdictional circumstances. Jurisdictional considerations appear more prevalent in East Lansing and Meridian Township, where inoperative wells and legal opposition to Authority pumpage have contributed to an uneven pattern of groundwater withdrawal and more severe localized piezometric response. Systematic pumpage throughout Michigan State University appears to have produced a comparable though more uniform piezometric response.

Additional hydrologic factors undoubtedly affect piezometric response throughout the eastern Lansing area. The northward flow of groundwater through the Saginaw Formation could significantly influence piezometric declines northward of high-withdrawal areas. Overall values of transmissibility, in turn, are fundamentally related to Saginaw Formation sandstone thickness and therefore could induce piezometric variations over relatively short distances. Lastly, reductions in aquifer recharge produced by the diversion of runoff from developed eastern Lansing areas could affect overall piezometric conditions over an extended period of time. Further investigation is recommended in these areas to more precisely define hydrologic interrelationships and fluctuations in overall piezometric response.

CONCLUSIONS

Comparison of actual and analog-projected piezometric conditions in the eastern Lansing area from 1964-1976 indicates differences in observed and expected piezometric response that significantly exceed the stated predictive accuracy range of the Wheeler-Vanlier analog model. Extreme piezometric declines apparent in analog future simulations have not occurred in East Lansing, Meridian Township, and Michigan State University. Although considerable variations in actual piezometric response are indicated throughout the eastern Lansing area, the mean elevation of the piezometric surface remains near the 1964 recorded level.

Model evaluation suggests possible changes in the relative importance and interrelationships of hydrologic variables inherent in model design. Although adjustment of inaccurately forecasted withdrawal and precipitation recharge rates used in model analyses reduced piezometric overprojections by approximately half, the remaining projections exceeded the ± 10 foot model simulation accuracy range by more than 30 feet. The model is therefore considered unreliable for future piezometric simulation and further investigation is recommended.

Actual groundwater withdrawal patterns throughout the eastern Lansing area for 1975 and 1976 indicate proportionally larger and more evenly distributed withdrawals throughout Michigan State University than in East Lansing and Meridian Township. While increased summer pumpage is recorded throughout East Lansing and Meridian Township, overall withdrawals for the eastern Lansing area are seasonally balanced. More severe localized piezometric declines are evident in areas of concentrated pumpage in central East Lansing and north central Meridian Township. Systematic pumpage throughout Michigan State University appears to have induced nearly uniform piezometric declines over a larger area.

The configuration of groundwater withdrawals reflects both hydrologic and jurisdictional circumstances. Jurisdictional considerations appear more prevalent in East Lansing and Meridian Township, where inoperative wells and legal opposition to municipal pumpage have contributed to an uneven pattern of groundwater withdrawal and more severe localized piezometric response. Systematic pumpage throughout Michigan State University appears to have induced a comparable though more uniform piezometric response.

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