New Jersey Geological Survey
Open-File Report OF-89-1

# SIMULATED DRAWDOWNS, 1972-1995, IN THE PLEISTOCENE BURIED-VALLEY AQUIFERS IN SOUTHWESTERN ESSEX AND SOUTHEASTERN MORRIS COUNTIES, NEW JERSEY

Department of Environmental Protection - Division of Water Resources

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by
Jeffrey L. Hoffman

New Jersey Department of Environmental Protection
Division of Water Resources
Geological Survey
CN-029
Trenton, New Jersey 08625

1989

## CONVERSION FACTORS

| Multiply inch-pound unit | by | to obtain metric unit |
|---|---|---|
| inch (in) | 25.4 | millimeter (mm) |
| foot (ft) | 0.3048 | meter (m) |
| mile (mi) | 1.609 | kilimeter (km) |
| foot per second (ft/s) | 0.3048 | meter per second (m/s) |
| foot per mile (ft/mi) | 0.189 | meter per kilometer (m/km) |
| million gallons per day (mgd) | 0.04381 | cubic meter per second ($m^3/s$) |
| square foot ($ft^2$) | 0.09290 | square meter ($m^2$) |

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# SIMULATED DRAWDOWNS, 1972-1995, IN THE PLEISTOCENE BURIED-VALLEY AQUIFERS IN SOUTHWESTERN ESSEX AND SOUTHEASTERN MORRIS COUNTIES, NEW JERSEY

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## ABSTRACT

A request for an additional 0.5 million gallons per day (mgd) of ground-water pumpage from the Chatham Pleistocene buried-valley aquifer in southeastern Morris County, New Jersey, necessitated an evaluation of the possible impacts of the new diversion on ground-water levels. A previously developed ground-water drawdown model was updated with 1972 to 1985 pumpage. This model was then used to simulate drawdowns from 1986 to 1995 attributable to additional demands from anticipated population growth and the requested 0.5 mgd additional pumpage.

Population increases in Morris and Essex Counties are assumed to result in a 15-percent increase in ground-water demand for the period 1986 to 1995. The model indicates that in some sections of the study area this pumping increase will result in a total dewatering of the buried-valley aquifer. The simulation indicates that a 15% pumpage increase, where possible, from 1986 to 1995 will create drawdowns from 0.5 to 7.1 feet at 11 observation wells. An additional 0.5 mgd in pumpage in the Chatham buried-valley aquifer will result in an additional 2.5 feet of drawdown 0.5 mile from the pumpage site and 0.4 foot 3.5 miles away.

Comparison of previously developed estimates of sustainable yield with current pumpage rates and total allocations indicates the buried valleys of Northern Millburn, Slough Brook, and Canoe Brook are overpumped. The Southern Millburn buried valley is overallocated but not yet overpumped, whereas the East Hanover and Chatham buried valleys have unallocated ground-water resources. The values for the buried valleys are summarized below:

| Buried valley | 1985 Pumpage (mgd) | Allocations (mgd) | Sustainable yield (mgd) |
|---|---|---|---|
| East Hanover | 4.87 | 10.65 | 13. |
| Northern Millburn | 2.96 | 4.80 | 0.7 |
| Southern Millburn | 10.97 | 18.98 | 14. |
| Chatham | 4.11 | 6.73 | 12. |
| Slough Brook | 0.78 | 1.00 | 0.06 |
| Canoe Brook | 2.62 | 4.00 | 1.3 |

A ground-water model is one tool by which to estimate the effects of any additional allocations. It must be used in conjunction with other decision-making methodologies to weigh the total benefits of an allocation against any detrimental effects or competing water uses. Inaccuracies in this model's formulation and calibration indicate that its results should not be the sole basis for a decision on whether or not to grant a request for additional pumpage.

## INTRODUCTION

Ground-water use in southeastern Morris and southwestern Essex Counties, New Jersey, has grown steadily. Pumpage has increased from roughly 5 million gallons per day (mgd) during 1900-1929 to 26.5 mgd during 1985. The contiguous parts of these counties form the study area, shown in figure 1. Requests for increased withdrawals have, at times, met with opposition from existing ground-water users.

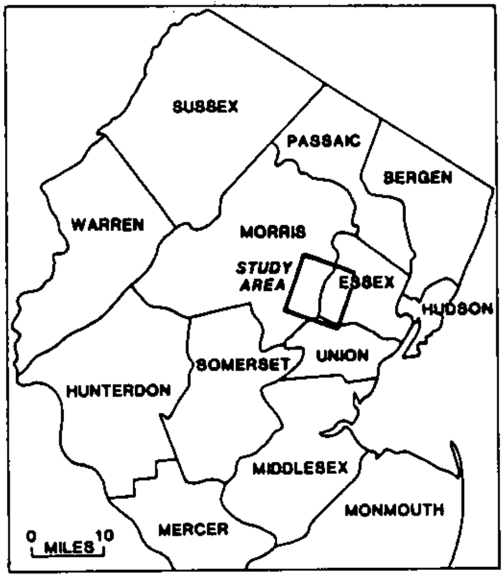

Figure 1. Location of study area

The New Jersey Department of Environmental Protection (NJDEP), Division of Water Resources (DWR) is the regulatory agency charged with managing ground-water resources of the State. Major ground-water users (those wth 100,000 gallons per day of pumpage or more) must receive an allocation permit from the DWR, which sets a maximum monthly pumpage rate along with other limiting criteria. The permits are for a specified length of time. The interference effects which would be caused by new pumpage on established wells is one criterion used in determining whether to allow or limit the location, volume and duration of new pumping.

In 1986 the DWR received a request for a new ground-water diversion from Linpro Florham Park Land Ltd. (Linpro). The application indicated that water would be pumped from the unconsolidated Pleistocene sand and gravel deposit termed the Chatham buried-valley aquifer. This aquifer is one of a network of interconnected buried valleys collectively termed the buried-valley aquifer (fig. 2).

Meisler (1976) defined six buried valleys (fig. 2) in the study area, based partially on the bedrock-contour map of Nichols (1968). Table 1 and figure 3 show, for each buried valley, the 1985 pumpage values and the total allocation for the purveyors included in the study.

As part of the review process, the DWR invited comments from other allocation-permit holders in the area, as well as from interested groups and citizens. The numerous comments received indicated the need to define possible effects of the proposed pumpage on other users. To address the issue, the New Jersey Geological Survey (NJGS), in the role of technical advisor to the

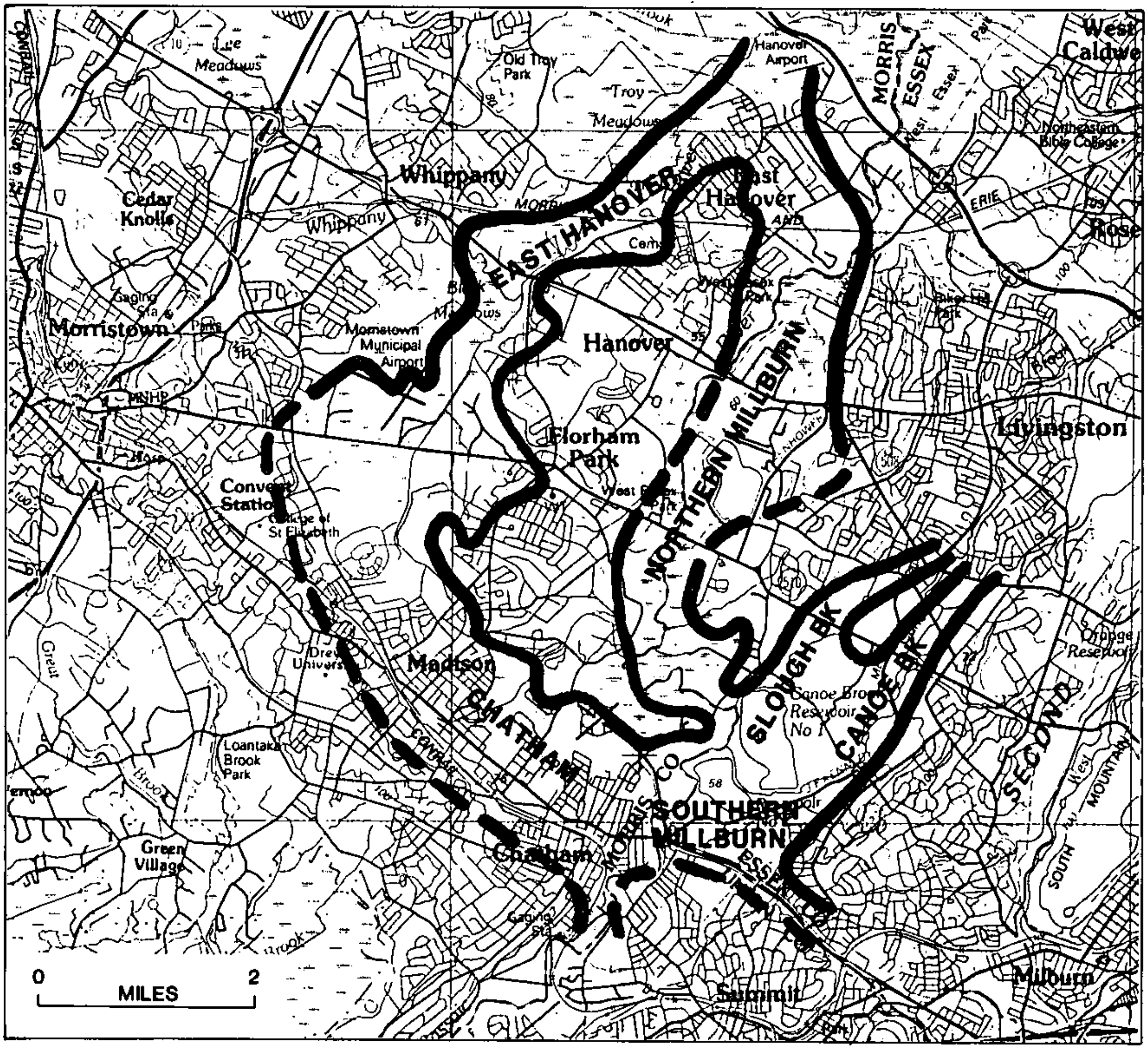

Figure 2. Distribution of buried valleys (modified from Meisler, 1976)

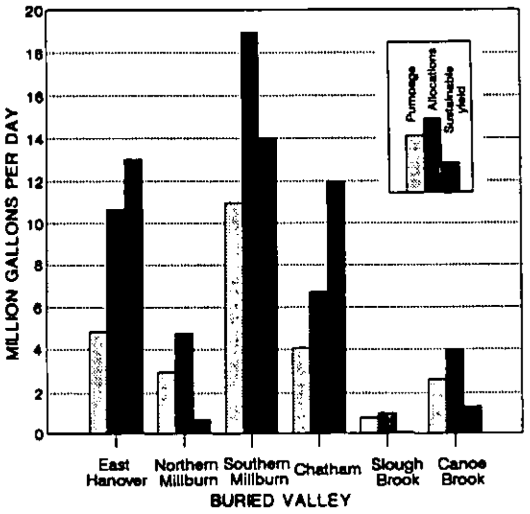

Figure 3. Pumpage, allocations and sustainable yields (1985)

Table 1. 1985 pumpage, allocations, and sustainable yields by buried valley (mgd)

| Buried valley | 1985 Pumpage (mgd) | Allocations (mgd) | Sustainable yield (mgd)[1] |
|---|---|---|---|
| East Hanover | 4.87 | 10.65 | 13. |
| Northern Millburn | 2.96 | 4.80 | 0.7 |
| Southern Millburn | 10.97 | 18.98 | 14. |
| Chatham | 4.11 | 6.73 | 12. |
| Slough Brook | 0.78 | 1.00 | 0.06 |
| Canoe Brook | 2.62 | 4.00 | 1.3 |
| TOTAL | 26.31 | 46.16 | 41. |

[1] As estimated by Meisler (1976). The number of significant figures determined by his results.

DWR, was requested to estimate interference effects.

The United States Geological Survey (USGS) had previously developed a ground-water model of the buried-valley aquifers in the study area (Meisler, 1976). This model produced estimates of the sustainable ground-water yield. Sustainable yield was defined as the amount of water available for pumpage indefinitely with water levels 30 feet above the base of the aquifer. The model was limited by the fact that it did not directly account for the bedrock aquifer underlying the buried-valley aquifers. Additionally, it was calibrated by comparing predicted drawdowns to observed drawdowns. Actual water levels were not closely simulated.

The USGS ground-water model of the area was updated in this study to include 1972 to 1985 pumpage. Predicted drawdowns were then compared to drawdowns measured in observation wells to determine the accuracy of the model.

The updated model then was used to estimate possible impacts of additional pumpage on nearby ground-water levels. A 15-percent increase in ground-water use was assumed, based on estimated population-growth from 1984 to 1995. Drawdowns from 1986 to 1995 in the study area were simulated by first assuming no pumpage at the Linpro site, and then withdrawals of 0.3 and 0.5 million gallons per day. Additionally, estimates were made of drawdowns assuming no pumpage at the Linpro site, but including maximum allowable pumpage elsewhere in the study area.

**Acknowledgements**

I wish to acknowledge the assistance of Harold Meisler of the US Geological Survey, Water Resources Division (Trenton office) in preparing the update of his original model. His suggestions, description of the original work, and the card deck used in his work were invaluable. Additionally, Mary Martin of the same office provided significant suggestions on proper simulation analysis techniques.

## GEOLOGY

Bedrock in the study area consists of shale, siltstone, mudstone, sandstone and basalt of Triassic and Jurassic age (Lyttle and Epstein, 1987; Nichols, 1968). The bedrock is a productive aquifer but was not included in the model in areas where it is overlain by the Pleistocene buried-valley aquifers.

Preglacial stream channels incised into the bedrock are now filled with sand, gravel, silt and clay. Most of these unconsolidated materials were deposited during the most recent glacial episode of the Pleistocene epoch (the Wisconsinan). Some surficial material was deposited in postglacial lakes or by streams. The glacial sand and gravel deposits form the major aquifer in the study area and make up the buried-valley aquifers. The greatest ground-water supply potential generally exists where the buried stream channels are deepest and stratified glacial outwash deposits are thickest.

The depositional history has led to a very heterogeneous unconsolidated aquifer, dominated by semi-confined, water-bearing sand and gravel deposits. Glacial till and fine-grained glacial lake-bed sediments serve as an upper confining unit. The sand and gravel appears to be in hydraulic connection with the underlying bedrock aquifer at places.

## PREVIOUS WORK

Meisler (1976) developed a two-dimensional computer model of ground-water drawdown in the study area's buried-valley aquifer system. His model used Trescott's version of Pinder's two-dimensional finite-difference ground-water model (Trescott, 1973; Pinder, 1970). The current study used the Trescott-Pinder-Larson model, an update of the Trescott model (Trescott and others, 1976).

The model developed by Meisler used a 52 by 52 grid of nodes. The inner 46 by 46 grid used node spacings of either 500 or 1000 feet. The outer 3 nodes on each side used much larger grid spacings, up to 20,000 feet. This larger outer ring was used to insure that the model boundaries were at least 5 miles from the buried-valley aquifers being modeled.

The model assumed that the aquifer was a one-layer system under transient conditions. The buried-valley aquifers were modeled as zones of higher hydraulic conductivity. Nodes outside the buried-valley aquifers were assigned values representative of the bedrock aquifer. At the lateral edges of the model impermeable boundaries were assigned by setting transmissivity and hydraulic conductivity values equal to zero.

The buried-valley aquifers were modeled as being initially semi-confined but with the possibility of converting to water-table conditions if the water level fell below the top of the aquifer. A value of $4.0 \times 10^{-3}$ ft/s was used for the hydraulic conductivity in the Chatham buried-valley aquifer while in all other buried-valley aquifers $3.0 \times 10^{-3}$ ft/s was used. The transmissivity was calculated by multiplying aquifer thickness (derived from published maps or interpreted from available data) by the hydraulic conductivity. A specific storage value of $4 \times 10^{-6}$ ft$^{-1}$ was applied to all nodes which fell in a buried-valley aquifer. The specific storage was multiplied by the thickness of the buried-valley aquifer in each node to give the storage coefficient. A value of 0.16 was used for the specific yield and applied to those buried-valley nodes which experienced water-table conditions.

A semi-confining unit was defined as overlying the buried-valley aquifers. This unit was assigned a thickness ranging from 10 to 80 ft based on available geologic data. The values of hydraulic conductivity used ranged from $7.0 \times 10^{-8}$ ft/s to $4.9 \times 10^{-7}$ ft/s. The hydraulic conductivity assigned to each node was multiplied by the fraction of that node actually covered by a surface-water source. A constant water level of 200 ft was assigned to all water bodies over the semi-confining unit. The code used (Trescott and others, 1976) holds the leakage rate constant if the water level in the aquifer falls below the top of the aquifer.

The bedrock aquifer was assumed to be under water-table conditions at all times. This aquifer is made up of two distinct rock types, sedimentary and igneous. The sedimentary rocks were assigned a transmissivity value of $2.4 \times 10^{-2}$ ft$^2$/s and the igneous rocks a value of $1.8 \times 10^{-2}$ ft$^2$/s in areas not bordering the buried-valley aquifers. In those nodes actually bordering the buried-valley aquifer the transmissivity of sedimentary or igneous rock was set equal to $3.0 \times 10^{-2}$ ft$^2$/s. This higher value was used to provide a transition zone between the bedrock and buried-valley aquifers. The hydraulic conductivity for the bedrock aquifer was calculated by dividing the transmissivity value by 500 ft. A value of 500 ft is used to account for the water-bearing properties of the bedrock aquifer. A value of 0.12 was used for the specific yield of the bedrock aquifer.

A more complete description of the model parameters is given by Meisler (1976).

Meisler used ground-water pumpage for the period 1900-1971 to simulate ground-water levels using a ground-water flow model. A flow model simulates ground-water levels that are compared to observed water levels. When the simulated and observed levels match satisfactorily the model is calibrated. This type of model can be used to determine actual flow paths.

Meisler was unable to satisfactorily reproduce observed water levels. The model was, however, successful in reproducing observed changes in water levels. This type of model is referred to as a drawdown model. Its accuracy is judged by how closely it reproduces water-level changes (drawdowns) in response to pumping changes. A drawdown model can be used to estimate changes in ground-water elevations and predict impacts of increased pumping, but not actual water levels or flow paths.

Total drawdown in a particular well is calculated for any specific time by subtracting the water level at that time from a constant, set base level. The prepumpage (static) water level is often used as this base level. Defining the base level can be somewhat arbitrary. The incremental drawdown is a more convenient measure for computer drawdown models. The incremental drawdown is calculated by subtracting the water level at the end of a pumping period from the water level at the beginning of that period. A positive incremental drawdown indicates a decline in water levels, a negative value indicates a rise in water levels. A drawdown model is calibrated by comparing measured to predicted incremental drawdowns. When these match satisfactorily then the model is considered to accurately reproduce water-level changes during the modeled time period.

The fact that the actual ground-water flow in the study area was not successfully reproduced by Meisler's model indicates that some aspect of the hydrogeology is not accurately represented. The difficulty may lie in the simplified representation of the geology, imperfect characterization of aquifer characteristics, incorrect pumping values, or some other factor. However, Meisler felt that the drawdown model would accurately reproduce changes in water levels caused by increases or decreases in pumpages in the East Hanover and Southern Millburn buried-valley aquifers (Meisler, 1976).

Table 2 (p. 7) shows total drawdowns and incremental drawdowns as simulated by the model using Meisler's data. Drawdowns are shown at the 11 observation wells (fig.4) for which measured drawdowns are available. Because prepumping water levels are not known, the total drawdown and drawdowns for the first pumping period are calculated from an assumed initially flat prepumping potentiometric surface at 200 feet above sea level.

The amount of error in the simulated total drawdown and incrental drawdowns prior to 1952 is unknown due to the lack of observation well data. The assumption of an initially flat piezometric surface probably introduces some error into the simulation; however the amount is unknown. Meisler found an acceptable calibration between available observed water levels and simulated incremental drawdowns.

One problem became apparent when comparing the results of the current study to Meisler's original work (Meisler, 1976). His original values could not be exactly reproduced. Meisler also noticed this (Harold Meisler, USGS, 1986, oral communication). After his original work, he added pumpage for the period 1972-1973. He could not exactly reproduce his original work and was unable to determine the reason.

This problem is highlighted in table 3 (p. 8). This table shows total incremental drawdown for 1953-1971 as simulated by Meisler (1976) and this study for each well. The difference between the simulated incremented drawdowns for each well is shown in the rightmost column. The differences between the simulated incremental drawdowns are less than 1.0 feet in 5 wells, between 1.0 and 2.0 feet in 5 wells and 4.8 feet in one well.

Also shown for each well is the annual absolute difference for both studies. This number is calculated by dividing the difference between the measured and simulated incremental drawdowns by the number of years for which observed water levels are available. This value can be used in comparative statistics between wells because it has been corrected for the actual period of data for each well. At the bottom of the table the average and standard deviation of the annual absolute differences are shown. The original Meisler model showed an average annual absolute error of 0.2 feet over the time period 1953-1971. This study, when updating the same time period, showed an average annual absolute error of 0.4 ft.

The actual incremental drawdowns used by each study are different. This is due to the procedure by which incremental drawdowns were measured from graphs of observed water levels (fig 5, p. 12). This difference is not significant.

## SUSTAINABLE YIELD

Meisler (1976) estimated a sustainable ground-water yield for each buried valley based on the results of his model. The estimates are based on 61 hypothetical wells spread throughout the study area at the deepest parts of the buried valleys. At each of these wells the water level was held constant above the bottom of the aquifer. Meisler then calculated the volume of ground water which would flow to the wells based on these levels. This volume of water was interpreted to be the sustainable yield (the volume of water available indefinitely). Table 1 and figure 3 present the sustainable yields estimated by Meisler.

One major assumption could introduce error into the estimations of sustainable yield. It involves the source of the water pumped from the aquifers. The calculation of sustainable yields assumed that water levels in the buried-valley aquifers were at steady state; that is the ground-water levels were at equilibrium with the 61 hypothetical wells. Under these conditions surface waters (streams and wetlands) are the source of recharge to the wells. This assumption is discussed in more detail below in the section "Limitations of Model."

The sustainable yield results were also based on keeping the water level in the production wells set at 30 feet above the aquifer base. Meisler analyzed the sensitivity of the sustainable yield estimates on the fixed water levels. He

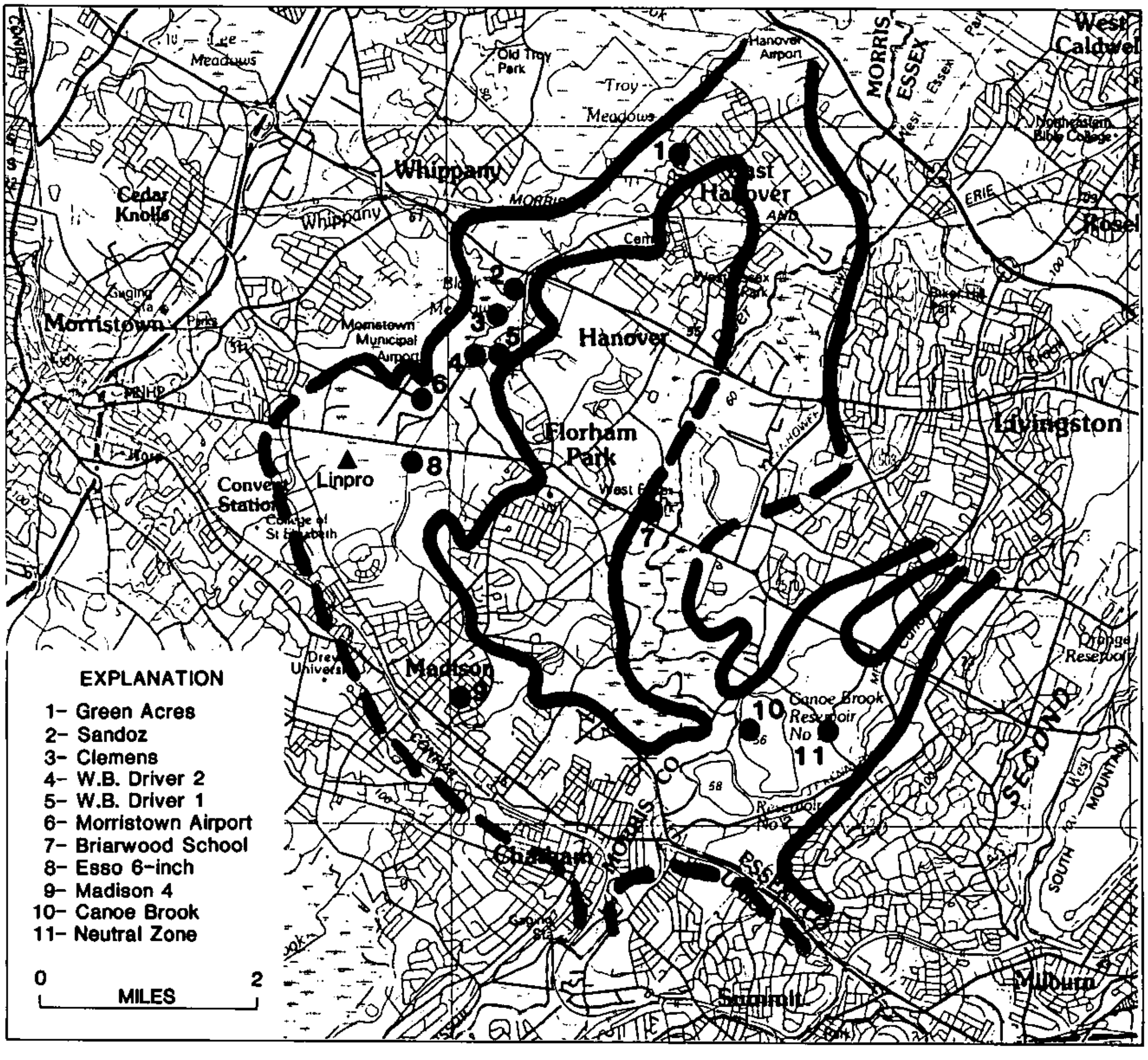

Figure 4. Distribution of observation wells

found that if the levels were lowered to 20 feet above the aquifer base that the sustainable yield would increase by approximately 3%.

## ALLOCATIONS

The Division of Water Resources (DWR) issues allocation permits to ground-water users in New Jersey pumping 100,000 gallons per day or more. The permittees are restricted to a maximum monthly pumping volume, which is referred to as their total monthly allocation. The actual volume pumped is usually smaller than the total monthly allocation except during peak demand periods.

The total allocations for each purveyor were obtained from DWR files. The allocations were converted to an equivalent daily pumpage rate, assigned to each buried valley, and then totaled by buried valley. Table 4 shows the total daily allocation for the ground-water users in the study area. Figure 3 and table 1 list the total daily allocations for the buried-valley aquifers.

## GROUND-WATER WITHDRAWALS, 1972-1985

The earlier ground-water model simulated drawdowns for the period 1900-1971 (Meisler, 1976). Meisler later updated the pumpage for

**Table 2.** Simulated total and incremental drawdowns, 1900-1973[1]

**A) Total drawdowns[2] (ft)**

| | Pumping period | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Observation Well | 1900-1929 | 1930-1945 | 1946-1952 | 1953-1959 | 1960-1965 | 1966-1968 | 1969-1971 | 1972-1973 |
| Green Acres | 0.7 | 1.4 | 2.3 | 3.8 | 6.5 | 6.3 | 8.2 | 8.5 |
| Sandoz | 1.8 | 3.6 | 6.3 | 9.2 | 13.0 | 14.6 | 23.8 | 31.0 |
| Clemens | 1.8 | 3.8 | 6.4 | 9.3 | 13.2 | 14.9 | 24.1 | 31.8 |
| Driver 2 | 2.5 | 5.3 | 8.1 | 11.9 | 17.2 | 19.3 | 29.1 | 35.9 |
| Driver 1 | 3.0 | 6.4 | 9.6 | 14.2 | 20.5 | 23.1 | 31.4 | 36.2 |
| Briarwood School | 7.8 | 15.5 | 23.4 | 30.0 | 36.1 | 40.5 | 46.6 | 47.0 |
| Morristown Airport | 2.3 | 5.1 | 7.2 | 10.1 | 14.5 | 15.8 | 20.0 | 20.9 |
| Esso 6 Inch | 4.0 | 8.2 | 11.6 | 16.6 | 24.8 | 27.4 | 32.6 | 34.0 |
| Neutral Zone | 25.7 | 44.2 | 46.0 | 55.2 | 63.0 | 57.7 | 58.2 | 62.2 |
| Canoe Brook | 17.0 | 26.2 | 32.8 | 44.3 | 55.5 | 53.3 | 56.1 | 58.5 |
| Madison 4 | 9.2 | 17.1 | 22.9 | 30.8 | 41.7 | 43.3 | 48.2 | 48.7 |

**B) Incremental drawdowns[3] (ft)**

| | Pumping period | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Observation Well | 1900-1929 | 1930-1945 | 1946-1952 | 1953 1959 | 1960-1965 | 1966-1968 | 1969-1971 | 1972-1973 |
| Green Acres | 0.7 | 0.7 | 0.9 | 1.5 | 2.7 | -0.2 | 1.9 | 0.3 |
| Sandoz | 1.8 | 1.8 | 2.7 | 2.9 | 3.8 | 1.6 | 9.2 | 7.2 |
| Clemens | 1.8 | 2.0 | 2.6 | 2.9 | 3.9 | 1.7 | 9.2 | 7.7 |
| Driver 2 | 2.5 | 2.8 | 2.8 | 3.8 | 5.3 | 2.1 | 9.8 | 6.8 |
| Driver 1 | 3.0 | 3.4 | 3.2 | 4.6 | 6.3 | 2.6 | 8.3 | 4.8 |
| Briarwood School | 7.8 | 7.7 | 7.9 | 6.6 | 6.1 | 4.4 | 6.1 | 0.4 |
| Morristown Airport | 2.3 | 2.8 | 2.1 | 2.9 | 4.4 | 1.3 | 4.2 | 0.9 |
| Esso 6 Inch | 4.0 | 4.2 | 3.4 | 5.0 | 8.2 | 2.6 | 5.2 | 1.4 |
| Neutral Zone | 25.7 | 18.5 | 1.8 | 9.2 | 7.8 | -5.3 | 0.5 | 4.0 |
| Canoe Brook | 17.0 | 9.2 | 6.6 | 11.5 | 11.2 | -2.2 | 2.8 | 2.4 |
| Madison 4 | 9.2 | 7.9 | 5.8 | 7.9 | 10.9 | 1.6 | 4.9 | 0.5 |

[1] Based on Meisler's (1976) model using data provided by Meisler (Harold Meisler, USGS, written communication, 1986).

[2] Prepumping levels assumed to be 200 feet above sea level.

[3] Positive numbers indicate a decline in water levels. Negative numbers indicate a rise in water levels.

the years 1972-1973 (Harold Meisler, USGS, written communication, 1986). This study adds pumpage for the years 1974-1985 to the model. Pumpage values are based on the quarterly reports from the Division of Water Resources and represent the most reliable estimate of ground-water withdrawals in the area. Summing quarterly pumpage values yielded yearly totals. Missing pumpage values were estimated on the basis of an average of available data. Pumpage for 1985 is shown in table 4 for each user.

Five pumpage periods were established to reflect trends in the pumpage for 1974-1985. These periods are 1974-1976, 1977-1979, 1980, 1981-1984, and 1985. For each pumpage period the yearly totals for each well were averaged to obtain an average annual withdrawal rate. This set of pumpages (table 5) is termed the 100-percent-of-recorded-pumpage values. The average annual pumpage raes were used in the model.

Several well fields covered more than a single cell of the computer model. This required dis-

**Table 3.** Comparsion of incremental drawdowns (ft) from this study and Meisler (1976) for 1953 to 1971

| Well (period of data) | Incremental drawdown | This study | Meisler's study | Difference |
|---|---|---|---|---|
| Green Acres | actual | 0.0 | 1.2 | |
| (1969-1971) | simulated | 1.9 | 1.8 | 0.1 |
| | annual difference | 0.6 | -0.2 | |
| Sandoz | actual | 9.4 | 10.2 | |
| (1969-1971) | simulated | 9.2 | 10.8 | -1.6 |
| | annual difference | 0.1 | -0.2 | |
| Clemens | actual | 10.0 | 11.3 | |
| (1969-1971) | simulated | 9.2 | 11.0 | -1.8 |
| | annual difference | 0.3 | 0.1 | |
| Driver 2 | actual | 13.0 | 13.5 | |
| (1966-1971) | simulated | 11.9 | 11.8 | 0.1 |
| | annual difference | 0.2 | 0.3 | |
| Driver 1 | actual | 11.0 | 10.7 | |
| (1966-1971) | simulated | 10.9 | 10.8 | 0.1 |
| | annual difference | 0.02 | -0.02 | |
| Briarwood School | actual | 7.4 | 6.5 | |
| (1966-1971) | simulated | 10.9 | 6.1 | 4.8 |
| | annual difference | -0.6 | 0.1 | |
| Morristown Airport | actual | 4.7 | 5.5 | |
| (1960-1971) | simulated | 9.9 | 8.8 | 1.1 |
| | annual difference | -0.4 | -0.3 | |
| Esso 6-inch | actual | 3.0 | 5.0 | |
| (1969-1971) | simulated | 5.2 | 4.8 | 0.4 |
| | annual difference | -0.7 | 0.1 | |
| Neutral Zone | actual | 23.8 | 24.0 | |
| (1953-1971) | simulated | 12.2 | 13.6 | -1.4 |
| | annual difference | 0.4 | 0.4 | |
| Canoe Brook | actual | 24.3 | 21.5 | |
| (1953-1971) | simulated | 23.3 | 22.7 | 0.6 |
| | annual difference | 0.1 | -0.1 | |
| Madison 4 | actual | 9.6 | 12.3 | |
| (1960-1971) | simulated | 17.4 | 16.2 | 1.2 |
| | annual difference | -0.6 | -0.3 | |
| Average of annual absolute differences: | | 0.4 | 0.2 | |

tribution of total pumpage from the well field to more than one cell. If the quarterly reports provided pumpage information for individual wells this information was used. Some users, however, reported only the total pumpage for the entire well field. In these cases the average withdrawal rate for the well field was divided by the number of wells in the field to derive an average rate per well. Each cell was assigned pumpage proportional to its number of wells.

## CALIBRATION AND VERIFICATION

Developing and using a ground-water computer model involves four steps: 1) design, 2) calibration, 3) verification, and; 4) projection.

Model design consists of discretizing the study area (dividing it into cells) and assigning to each cell the value of all relevant hydrogeologic parameters. All of the parameters used by Meisler (1976) were also used in the current study.

The second step is calibration. The model is used to simulate water levels (or drawdowns) which are then compared to observed values (fig. 5, p. 12). The hydrogeologic parameters are subsequently modified (within reasonable bounds) until the simulated values satisfactorily match observed data. If a considerable period of observed data is available usually only part of it is used in the calibration step.

Table 4. Withdrawals and total allocations, 1985

| Purveyor | Permit number | Pumpge (mgd) | | Buried valley |
|---|---|---|---|---|
| | | 1985 | Allocation | |
| Southeast Morris County MUA | | | | |
| Black Brook 1, 2; Normandy | 5299 | 2.69 | 4.61 | East Hanover |
| Florham Park Borough | 5214 | 0.86 | 1.75 | East Hanover |
| East Hanover Township | 5072 | 0.92 | 1.69 | East Hanover |
| Sandoz, Inc. | 2118P | 0.39 | 2.40 | East Hanover |
| Suburban Propane | 10015W | 0.01 | 0.10 | East Hanover |
| AMAX Speciality Metals | 10088W | 0.00 | 0.10 | East Hanover |
| Livingston Township | 5074 | 2.96 | 4.80 | Northern Millburn |
| Commonwealth Water Company | | | | |
| Canoe Brook Well Field | 5008 | 4.00 | 7.38 | Southern Millburn |
| Passaic River Well Field | 5008 | 0.96 | 3.00 | Southern Millburn |
| East Orange | | | | |
| Braidburn Well Field | 5041 | 3.19 | 4.20 | Southern Millburn |
| East Orange | | | | |
| Dickinson Well Field | 5041 | 2.79 | 4.20 | Southern Millburn |
| Canoe Brook Country Club | 10162W | 0.02 | 0.10 | Southern Millburn |
| Orange Products Inc. | 10155W | 0.01 | 0.10 | Southern Millburn |
| Chatham Borough | 5046 | 1.12 | 1.61 | Chatham |
| Madison Borough | 5069 | 1.78 | 3.50 | Chatham |
| Exxon Research & Engineering | 2339P | 0.39 | 0.33 | Chatham |
| Morris County Golf Club | 2025P | 0.01 | 0.22 | Chatham |
| Allied Chemical | 2117P | 0.81 | 1.07 | Chatham |
| East Orange | | | | |
| Slough Brook Well Field | 5040 | 0.78 | 1.00 | Slough Brook |
| Canoe Brook Well Field | 5040 | 2.62 | 4.00 | Canoe Brook |
| Total | | 26.31 | | |

**Table 5.** Simulated pumpage, 1972-1985, used in 100-percent-of-recorded-pumpage scenario

| Production well | row | col | 1972-1973[1] | 1974 1976 | 1977 1979 | 1980 | 1981-1984 | 1985 |
|---|---|---|---|---|---|---|---|---|
| 1/12 Commonwealth Canoe Brook | 36 | 39 | 0.54 | 0.47 | 0.33 | 0.49 | 0.51 | 0.43 |
| 1/12 Commonwealth Canoe Brook | 36 | 41 | 0.54 | 0.47 | 0.33 | 0.49 | 0.51 | 0.43 |
| 3/12 Commonwealth Canoe Brook | 36 | 42 | 1.64 | 1.42 | 1.00 | 1.46 | 1.53 | 1.28 |
| 2/12 Commonwealth Canoe Brook | 36 | 43 | 1.10 | 0.95 | 0.67 | 0.98 | 1.02 | 0.85 |
| 3/12 Commonwealth Canoe Brook | 37 | 43 | 1.64 | 1.42 | 1.00 | 1.46 | 1.53 | 1.28 |
| 2/12 Commonwealth Canoe Brook | 38 | 43 | 1.10 | 0.95 | 0.67 | 0.98 | 1.02 | 0.85 |
| Commonwealth Passaic River 51 | 43 | 37 | 0.89 | 0.87 | 0.32 | 0.95 | 0.90 | 0.66 |
| Commonwealth Passaic R. 48,50 | 44 | 38 | 1.78 | 1.74 | 0.64 | 1.90 | 1.79 | 1.32 |
| East Orange Slough Brook | 27 | 41 | 0.13 | 0.11 | 0.19 | 0.13 | 0.24 | 0.18 |
| East Orange Slough Brook | 28 | 41 | 0.13 | 0.11 | 0.19 | 0.13 | 0.24 | 0.18 |
| East Orange Slough Brook | 29 | 41 | 0.13 | 0.11 | 0.19 | 0.13 | 0.24 | 0.18 |
| East Orange Slough Brook | 30 | 46 | 0.00 | 0.11 | 0.19 | 0.13 | 0.24 | 0.18 |
| East Orange Canoe Brook 1 | 30 | 45 | 0.29 | 0.65 | 0.52 | 0.49 | 0.43 | 0.47 |
| East Orange Canoe Brook 2 | 27 | 45 | 0.79 | 0.65 | 0.52 | 0.49 | 0.43 | 0.47 |
| East Orange Canoe Brook 3 | 24 | 45 | 0.75 | 0.65 | 0.52 | 0.49 | 0.43 | 0.47 |
| East Orange Canoe Brook 4 | 22 | 45 | 0.81 | 0.65 | 0.52 | 0.49 | 0.43 | 0.47 |
| East Orange Canoe Brook 5,6 | 19 | 46 | 0.00 | 0.30 | 0.52 | 0.32 | 0.63 | 0.46 |
| East Orange Braidburn 1 | 31 | 30 | 0.85 | 1.01 | 1.06 | 1.15 | 1.24 | 1.03 |
| East Orange Braidburn 2 | 30 | 30 | 0.90 | 1.01 | 1.06 | 1.15 | 1.24 | 1.03 |
| East Orange Braidburn 3 | 29 | 29 | 1.14 | 1.01 | 1.06 | 1.15 | 1.24 | 1.03 |
| East Orange Dickinson 1 | 33 | 31 | 1.16 | 0.92 | 0.93 | 1.02 | 0.98 | 1.00 |
| East Orange Dickinson 2 | 34 | 33 | 0.22 | 0.92 | 0.93 | 1.02 | 0.98 | 1.00 |
| East Orange Dickinson 3 | 32 | 34 | 1.38 | 0.92 | 0.93 | 1.02 | 0.98 | 1.00 |
| Livingston Township 1 | 8 | 38 | 0.14 | 0.11 | 0.08 | 0.07 | 0.09 | 0.00 |
| Livingston Township 2 | 7 | 40 | 0.23 | 0.23 | 0.18 | 0.10 | 0.18 | 0.00 |
| Livingston Township 3 | 9 | 27 | 0.35 | 0.42 | 0.6 | 0.71 | 0.44 | 0.87 |
| Livingston Township 4 | 13 | 42 | 0.28 | 0.19 | 0.31 | 0.31 | 0.19 | 0.22 |
| Livingston Township 5 | 10 | 28 | 0.45 | 0.40 | 0.69 | 0.30 | 0.53 | 0.41 |
| Livingston Township 6 | 14 | 32 | 0.15 | 0.17 | 0.16 | 0.10 | 0.12 | 0.09 |
| Livingston Township 7 | 15 | 27 | 0.36 | 0.31 | 0.25 | 0.18 | 0.20 | 0.10 |
| Livingston Township 8 | 18 | 34 | 0.38 | 0.27 | 0.34 | 0.24 | 0.23 | 0.25 |
| Livingston Township 9 | 14 | 27 | 0.00 | 0.19 | 0.31 | 0.59 | 0.47 | 0.42 |
| Livingston Township 10 | 15 | 41 | 0.00 | 0.17 | 0.12 | 0.02 | 0.10 | 0.14 |
| Livingston Township 11 | 19 | 34 | 0.17 | 0.23 | 0.14 | 0.24 | 0.20 | 0.17 |
| Livingston Township 12 | 19 | 41 | 0.00 | 0.00 | 0.00 | 0.10 | 0.20 | 0.21 |
| Black Brook 1 (SEMCMUA) | 22 | 12 | 0.77 | 0.96 | 0.85 | 0.78 | 1.03 | 1.10 |
| Black Brook 2 (SEMCMUA) | 24 | 12 | 0.77 | 0.81 | 1.11 | 0.74 | 1.21 | 1.47 |
| Normandy (SEMCMUA) | 31 | 6 | 0.03 | 0.03 | 0.03 | 0.00 | 0.07 | 0.11 |
| Florham Park Borough 1 | 29 | 18 | 0.31 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Florham Park Borough 2 | 26 | 17 | 0.48 | 0.30 | 0.34 | 0.36 | 0.35 | 0.29 |
| Florham Park Borough 3 | 26 | 20 | 0.00 | 0.30 | 0.34 | 0.36 | 0.35 | 0.29 |
| Florham Park Borough 4 | 28 | 17 | 0.00 | 0.30 | 0.34 | 0.36 | 0.35 | 0.29 |
| East Hanover Township 1 | 14 | 14 | 0.51 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| East Hanover Township 2 | 16 | 14 | 0.00 | 0.68 | 0.62 | 0.63 | 0.61 | 0.46 |
| East Hanover Township 5 | 5 | 21 | 0.00 | 0.00 | 0.20 | 0.47 | 0.42 | 0.46 |
| Madison Borough A | 45 | 26 | 0.25 | 0.36 | 0.37 | 0.38 | 0.34 | 0.36 |
| Madison Borough B | 45 | 25 | 0.45 | 0.36 | 0.37 | 0.38 | 0.34 | 0.36 |
| Madison Borough C | 40 | 17 | 0.32 | 0.36 | 0.37 | 0.38 | 0.34 | 0.36 |
| Madison Borough D | 41 | 19 | 0.32 | 0.36 | 0.37 | 0.38 | 0.34 | 0.36 |
| Madison Borough E | 45 | 27 | 0.45 | 0.36 | 0.37 | 0.38 | 0.34 | 0.36 |
| Chatham Borough 1,2,3 | 46 | 30 | 0.98 | 0.99 | 0.99 | 1.01 | 0.93 | 1.12 |
| Canoe Brook Country Club | 41 | 43 | 0.00 | 0.02 | 0.02 | 0.04 | 0.02 | 0.02 |
| Exxon Research & Engineering | 35 | 12 | 0.20 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 |
| Morris County Golf Club | 37 | 5 | 0.03 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| Sandoz 1 | 16 | 13 | 0.01 | 0.21 | 0.19 | 0.15 | 0.08 | 0.08 |
| Sandoz 2 | 17 | 14 | 0.08 | 0.21 | 0.19 | 0.15 | 0.08 | 0.08 |
| Sandoz 3 | 18 | 15 | 0.40 | 0.21 | 0.19 | 0.15 | 0.08 | 0.08 |
| Sandoz 4 | 19 | 15 | 0.49 | 0.21 | 0.19 | 0.15 | 0.08 | 0.08 |
| Sandoz 5 | 20 | 13 | 0.62 | 0.21 | 0.19 | 0.15 | 0.08 | 0.08 |
| Pfizer | 6 | 4 | 0.00 | 0.00 | 0.00 | 0.21 | 0.51 | 0.27 |
| Allied Chemical 1,2,4 | 33 | 5 | 0.23 | 0.33 | 0.67 | 0.79 | 0.65 | 0.61 |
| Allied Chemical 10 | 31 | 5 | 0.00 | 0.00 | 0.00 | 0.00 | 0.16 | 0.20 |
| Allied Chemical | 35 | 34 | 0.06 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Surburban Propane | 15 | 8 | 0.01 | 0.00 | 0.00 | 0.00 | 0.01 | 0.01 |
| Amax Specialties Metal Corp. | 23 | 14 | 0.17 | 0.00 | 0.00 | 0.00 | 0.08 | 0.00 |
| Orange Products, Inc. | 34 | 38 | 0.11 | 0.00 | 0.00 | 0.19 | 0.11 | 0.00 |
| Linpro | 34 | 8 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| TOTALS | | | 28.44 | 28.11 | 29.93 | 30.74 | 28.41 | 26.55[2] |

[1] Data from Harold Meisler, U.S. Geological Survey, 1986

[2] Does not equal total 1985 pumpage from table 1 due to rounding

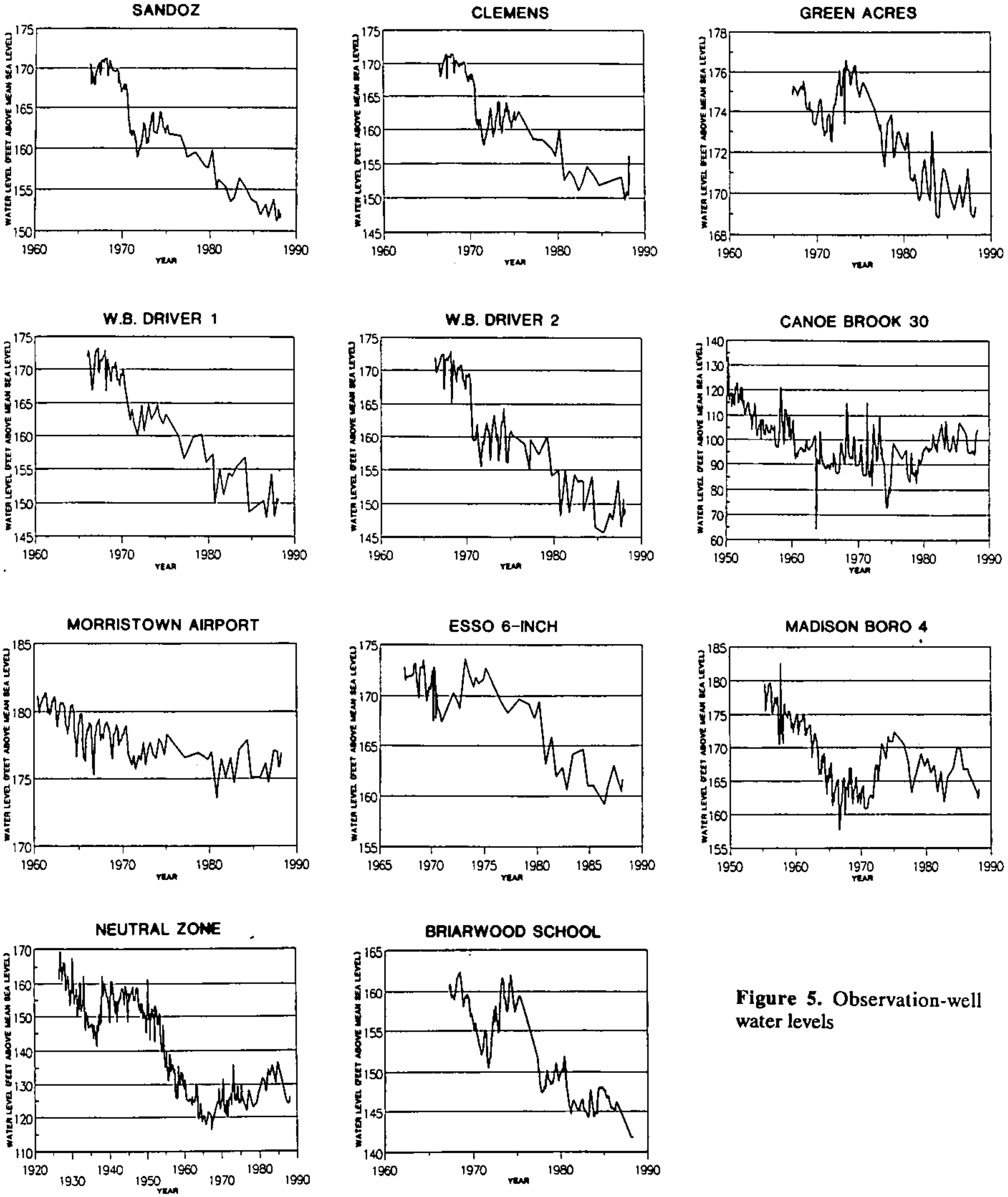

**Figure 5.** Observation-well water levels

Verification consists of using the calibrated model to simulate values for that part of the data not used during the calibration stage. If the historical data record is not long enough to supply sufficient data, the verification step may be bypassed.

The final step, projection, involves using the model to simulate the hydrologic system under anticipated or simulated conditions. For ground-water model this usually entails altering the pumpage values.

Meisler did not have a sufficient historical record of observed water levels to both calibrate and verify his model. He calibrated the model, and then used it to predict sustainable yield from the buried valleys. Meisler modified the physical parameters of his model during calibration to better match the observed drawdowns.

This study began with a verification of Meisler's model. None of the hydrogeological characteristics set by Meisler were altered to provide a closer fit of the observed and predicted drawdowns. Updated pumpage was used to simulate drawdowns which were then compared to observed drawdowns for 5 pumpage periods. Years which had similar total pumpage were grouped together for modeling purposes to decrease computational effort. Drawdowns during each period were simulated based on reported pumpage (table 5). The results obtained using these pumpages are referred to as the "100-percent-of-recorded-pumpage verification scenario."

The accuracy of the this verification scenario was judged by comparing simulated incremental drawdowns to observed drawdowns in 11 observation wells (table 6) in the study area.

Table 7 presents total and incremental drawdown for the 11 observation wells as simulated by the 100-percent-of-recorded-pumpage verification scenario. Table 8 is an analysis of the difference between observed incremental drawdowns and the simulated incremental drawdown for each pumpage period. It presents: 1) observed incremental drawdowns; 2) simulated incremental drawdown, and; 3) the annual absolute difference between the observed and simulated values. Incremental drawdowns are shown only for those wells and pumping periods for which observational data are available. The number of years in each pumping period is shown at the top of the table.

The difference between the observed and simulated values of incremental drawdown was divided by the number of years in each pumping period to yield the annual difference. The annual difference is used to compare the results of pumping periods of varying duration. If the annual difference is negative then the simulated incremental drawdown over that pumping period was greater than the observed value. A positive number indicates the reverse.

The rightmost column indicates, for each well, the average of the absolute values of the annual differences in incremental draw downs. The absolute value is used to indicate total differences. If the absolute annual incremental drawdown values were not used then positive and negative values would cancel out leaving the impression that, on average, the simulated incremental drawdowns were closer to observed values than the data indicate.

The bottom row shows, for each pumping period, the average of the absolute values of the annual differences in incremental drawdowns. Again, the absolute value of the annual differences is used to prevent positive and negative differences from canceling each other out.

Table 8 can be analyzed in three different ways. First, the body of the table can be searched for trends either in a given well or in a given pumping period. Second, the average annual differences can be examined by well (the rightmost column). And third, the average annual differences in a pumping period (the bottom row) can be examined.

Perusing the body of the table doesn't yield any noticeable patterns. The annual differences do not appear to be systematic. The annual differences are not consistently positive or negative, or of similar sizes either in a given well or in a pumping period. Wells which are physically close together (for instance, Driver 1 and Driver 2, or Neutral Zone and Canoe Brook) tend to have annual differences of the same sign but other nearby wells (Clemens and Sandoz, for instance) do not show this correlation.

The rightmost column shows the average of the absolute annual differences for each well. The Clemens well shows the most difference, with an average of 2.0 feet difference between observed and simulated incremental drawdowns. The Green Acres well shows the least difference at 0.6 feet. No pattern is apparent.

**Table 6.** Buried-valley observation wells

| Observation well | Well node location row | column | USGS ID[1] | Buried valley |
|---|---|---|---|---|
| Green Acres | 7 | 19 | 27-0006 | East Hanover |
| Sandoz | 19 | 13 | 27-0005 | East Hanover |
| Clemens | 20 | 12 | 27-0004 | East Hanover |
| W B Driver 2 | 24 | 13 | 27-0003 | East Hanover |
| W BDriver 1 | 25 | 16 | 27-0002 | East Hanover |
| Morristown Airport | 28 | 7 | 27-0015 | East Hanover |
| Briarwood School | 27 | 25 | 27-0012 | Southern Millburn |
| Canoe Brook | 35 | 41 | 13-0013 | Southern Millburn |
| Neutral Zone | 31 | 45 | 13-0014 | Canoe Brook |
| Esso 6-Inch | 31 | 13 | 27-0014 | Chatham |
| Madison 4 | 45 | 26 | 27-0017 | Chatham |

[1] Identification number assigned by U.S. Geological Survey, Water Resources Division, West Trenton

**Table 7.** Simulated total and incremental drawdowns based on 100-percent-of-recorded-pumpage scenario

**A) Total drawdowns[1] (ft)**

| Observation well | Pumping period 1974-1976 | 1977-1979 | 1981-1980 | 1984 | 1985 |
|---|---|---|---|---|---|
| Green Acres | 9.2 | 10.8 | 11.5 | 11.5 | 11.7 |
| Sandoz | 32.6 | 34.1 | 32.3 | 33.2 | 33.2 |
| Clemens | 33.1 | 34.9 | 33.0 | 34.7 | 34.9 |
| Driver 2 | 38.2 | 41.8 | 39.3 | 43.8 | 44.5 |
| Driver 1 | 38.9 | 42.5 | 41.1 | 44.3 | 44.3 |
| Briarwood School | 50.0 | 54.9 | 56.3 | 56.3 | 56.0 |
| Morristown Airport | 23.0 | 26.3 | 26.3 | 28.6 | 29.0 |
| Esso 6-Inch | 36.9 | 40.2 | 40.2 | 41.4 | 41.2 |
| Neutral Zone | 67.6 | 68.5 | 70.4 | 67.7 | 65.1 |
| Canoe Brook | 58.3 | 61.0 | 63.1 | 57.9 | 52.7 |
| Madison 4 | 50.3 | 53.4 | 54.4 | 51.5 | 50.1 |

**B) Incremental drawdowns[2] (ft)**

| Observation well | Pumping period 1974-1976 | 1977-1979 | 1981-1980 | 1984 | 1985 |
|---|---|---|---|---|---|
| Green Acres | 0.7 | 1.6 | 0.7 | 0.0 | 0.2 |
| Sandoz | 1.6 | 1.5 | -1.8 | 0.9 | 0.0 |
| Clemens | 1.3 | 1.8 | -1.9 | 1.7 | 0.2 |
| Driver 2 | 2.3 | 3.6 | -2.5 | 4.5 | 0.7 |
| Driver 1 | 2.7 | 3.6 | -1.4 | 3.2 | 0.0 |
| Briarwood School | 3.0 | 4.9 | 1.4 | 0.0 | -0.3 |
| Morristown Airport | 2.1 | 3.3 | 0.0 | 2.3 | 0.4 |
| Esso 6-Inch | 2.9 | 3.3 | 0.0 | 1.2 | -0.2 |
| Neutral Zone | 5.4 | 0.9 | 1.9 | -2.7 | -2.6 |
| Canoe Brook | -0.2 | 2.7 | 2.1 | -5.2 | -5.2 |
| Madison 4 | 1.6 | 3.1 | 1.0 | -2.9 | -1.4 |

[1] From prepumping conditions to end of pumping period.

[2] Positive numbers indicate a decline in water levels. Negative numbers indicate a rise in water levels.

Table 8. Analysis of difference between actual and simulated incremental drawdowns (ft), 100-percent-of-recorded-pumpage scenario.

| Observation well | Incremental drawdown | 1946-1952 | 1953-1959 | 1960-1965 | 1966-1968 | 1969-1971 | 1972-1973 | 1974-1976 | 1977-1979 | 1980 | 1981-1984 | 1985 | Average of the annual absolute difference for each well |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Years in pumping period | | 7 | 7 | 6 | 3 | 3 | 2 | 3 | 3 | 1 | 4 | 1 | |
| Green Acres | actual | | | | | 0.0 | -1.2 | 2.0 | 1.2 | 1.6 | -0.2 | 1.6 | |
| | simulated | | | | | 1.9 | 0.3 | 0.7 | 1.6 | 0.7 | 0.0 | 0.2 | |
| | annual difference | | | | | -0.6 | -0.8 | 0.4 | -0.1 | 0.9 | -0.1 | 1.4 | 0.6 |
| Sandoz | actual | | | | | 9.4 | -1.6 | 1.4 | 1.8 | 2.6 | 4.8 | 3.6 | |
| | simulated | | | | | 9.2 | 7.2 | 1.6 | 1.5 | -1.8 | 0.9 | 0.0 | |
| | annual difference | | | | | 0.1 | -4.4 | -0.1 | 0.1 | 4.4 | 1.0 | 3.6 | 1.9 |
| Clemens | actual | | | | | 10.0 | -2.0 | 2.6 | 1.8 | 4.4 | 1.2 | | |
| | simulated | | | | | 9.2 | 7.7 | 1.3 | 1.8 | -1.9 | 1.7 | | |
| | annual difference | | | | | 0.3 | -4.8 | 0.4 | 0.0 | 6.3 | -0.1 | | 2.0 |
| Driver 2 | actual | | | | 1.8 | 11.2 | -2.8 | 5.0 | 2.6 | 4.0 | 3.6 | 1.0 | |
| | simulated | | | | 2.1 | 9.8 | 6.8 | 2.3 | 3.6 | -2.5 | 4.5 | 0.7 | |
| | annual difference | | | | -0.1 | 0.5 | -4.8 | 0.9 | -0.3 | 6.5 | -0.2 | 0.3 | 1.7 |
| Driver 1 | actual | | | | 1.8 | 9.2 | -2.8 | 6.0 | 1.6 | 4.4 | 5.8 | | |
| | simulated | | | | 2.6 | 8.3 | 4.8 | 2.7 | 3.6 | -1.4 | 3.2 | | |
| | annual difference | | | | -0.3 | 0.3 | -3.8 | 1.1 | -0.7 | 5.8 | 0.6 | | 1.8 |
| Briarwood School | actual | | | | 1.0 | 6.4 | -4.8 | 4.6 | 7.6 | -0.4 | -1.8 | 2.2 | |
| | simulated | | | | 4.8 | 6.1 | 0.4 | 3.0 | 4.9 | 1.4 | 0.0 | -0.3 | |
| | annual difference | | | | -1.3 | 0.1 | -2.6 | 0.5 | 0.9 | -1.8 | -0.5 | 2.5 | 1.3 |
| Morristown Airport | actual | | | 2.5 | 0.5 | 1.7 | -0.3 | 0.1 | 0.1 | 1.6 | -0.1 | 0.0 | |
| | simulated | | | 4.4 | 1.3 | 4.2 | 0.9 | 2.1 | 3.3 | 0.0 | 2.3 | 0.4 | |
| | annual difference | | | -0.3 | -0.3 | -0.8 | -0.6 | -0.7 | -1.1 | 1.6 | -0.6 | -0.4 | 0.7 |
| Esso 6-inch | actual | | | | | 3.0 | -1.2 | 2.2 | 0.2 | 4.0 | 4.0 | | |
| | simulated | | | | | 5.2 | 1.4 | 2.9 | 3.3 | 0.0 | 1.2 | | |
| | annual difference | | | | | -0.7 | -1.3 | 0.2 | -1.0 | 4.0 | 0.7 | | 1.3 |
| Neutral Zone | actual | 10.0 | 18.4 | 11.4 | -6.0 | 0.0 | -2.0 | 1.4 | -2.2 | -3.2 | -5.8 | | |
| | simulated | 1.8 | 9.2 | 7.8 | -5.3 | 0.5 | 4.0 | 5.4 | 0.9 | 1.9 | -2.7 | | |
| | annual difference | 1.2 | 1.3 | 0.6 | -0.2 | -0.2 | -3.0 | -1.3 | -1.0 | -5.1 | -0.8 | | 1.5 |
| Canoe Brook | actual | | 6.5 | 15.2 | -2.6 | 5.2 | 0.8 | -8.1 | -1.7 | 0.0 | -9.0 | | |
| | simulated | | 11.5 | 11.2 | -2.2 | 2.8 | 2.4 | -0.2 | 2.7 | 2.1 | -5.2 | | |
| | annual difference | | -0.7 | 0.7 | -0.1 | 0.8 | -0.8 | -2.6 | -1.5 | -2.1 | -0.9 | | 1.1 |
| Madison 4 | actual | | | 9.8 | 0.2 | -0.4 | -6.0 | 1.0 | 1.0 | 1.2 | -3.0 | 2.8 | |
| | simulated | | | 10.9 | 1.6 | 4.9 | 0.5 | 1.6 | 3.1 | 1.0 | -2.9 | -1.4 | |
| | annual difference | | | -0.2 | -0.5 | -1.8 | -3.3 | -0.2 | -0.7 | 0.2 | -0.0 | 4.2 | 1.2 |
| Average of the annual absolute difference for each pumping period | | 1.2 | 1.0 | 0.4 | 0.4 | 0.6 | 2.7 | 0.8 | 0.7 | 3.5 | 0.5 | 2.1 | |

The bottom row shows the average of the absolute annual differences for each pumping period. The years up to and including 1971 were used by Meisler in his original model. He later added pumpage for the pumping period 1972-1973. This study added pumpage for 1974-1985.

For the five pumping periods prior to 1972, three had average absolute annual differences of less than or equal to 1.0 feet. The remaining one is based on values in only one well, the Neutral Zone. For the six pumping periods after 1972, three had average values less than 1.0 ft while the remaining three were all over 3.0 ft. This indicates that the simulated values of incremental drawdown, while not significantly different from the observed values during the period 1972-1985, do differ more than those simulated for the period 1946-1971. While the model's ability to match observed incremental drawdown is acceptable for the later time period, it is not as good as was observed by Meisler.

One important note about the average absolute annual differences for each pumping period. The years 1980 and 1985 each were simulated by a single year. This was done to reflect changes in pumping values which were significant enough to warrant treatment as a separate period. The calculated annual absolute differences for these two years were 3.5 and 2.1 feet, respectively. The only other value this large was 2.7 feet for the period 1972- 1973, a two-year pumping period. All other average values were less than or equal to 1.2 feet.

The model appears to have some difficulty matching incremental drawdowns over a short time period. During these shorter periods the transient effects due to changes in pumpage rates are more important. The magnitude of these transient effects are governed to a large extent by the storage capabilities of the system. The fact that the shorter time periods have the greater differences appears to indicate that the values used for storage coefficient in the model may not be as accurate as could be desired.

One reassuring point is that the transient effects, being dependent upon storage values, do not affect the steady-state simulations. The estimates of sustainable yield for the buried-valley aquifers were made under steady-state conditions. Thus any errors associated with imperfect characterizations of the storage in the aquifer systems will not affect the sustainable yield estimates.

One other possible source of error lies in the pumpage values used. If the reported pumpage values are greater or lesser than the amount of ground water actually withdrawn then the predicted incremental drawdowns will be less likely to match observed drawdowns. In an attempt to evaluate the effect of possible errors in reported pumpage, the pumpage values were varied and then used to predict incremental drawdowns.

The reported pumpages are termed the 100-percent-of-recorded-pumpage values because they represent no change from (or 100% of) the values reported to the DWR. These values were reduced by 25 percent, producing the 75-percent-of-recorded-pumpage values, and then increased by 25 percent, the 125-percent recorded-pumpage values. Table 9 presents 1985 pumpage for all three sets of recorded pumpages. The two additional sets of recorded pumpages were used in verification scenarios.

Difficulties were encountered during the 125-percent-of-recorded-pumpage verification scenario. The increase of 25 percent in pumpage caused water levels throughout the eastern part of the study area to fall below the bottom of the aquifer, which halted the simulation. To proceed, all withdrawals in the Commonwealth Canoe Brook, East Orange Slough Brook, East Orange Canoe Brook, East Orange Braidburn, East Orange Dickinson and Livingston wells fields were held to the values used during the 100-percent-of-recorded-pumpage verification scenario.

Tables 10 and 11 present the analysis of the 75-percent-of-recorded-pumpage verification scenario. Tables 12 and 13 show results for the 125-percent recorded-pumpage verification scenario.

Analysis of tables 11 and 12, and comparison to table 8, indicates the pumpage values used in the 100-percent-of-recorded-pumpage verification scenario yielded, on average, the lowest annual differences between observed and simulated incremental drawdowns. The pumpage values used for this scenario do represent the best available estimate of pumpage in the study area.

**Table 9.** 1985 pumpage (mgd) for 100-, 75-, and 125-percent-of-recorded-pumpage scenarios

| Production well | Percent of recorded pumpage<br>100 | 75 | 125 |
|---|---|---|---|
| 1/12 Commonwealth Canoe Brook | 0.33 | 0.25 | 0.33 |
| 1/12 Commonwealth Canoe Brook | 0.33 | 0.25 | 0.33 |
| 3/12 Commonwealth Canoe Brook | 1.00 | 0.75 | 1.00 |
| 2/12 Commonwealth Canoe Brook | 0.67 | 0.50 | 0.67 |
| 3/12 Commonwealth Canoe Brook | 1.00 | 0.75 | 1.00 |
| 2/12 Commonwealth Canoe Brook | 0.67 | 0.50 | 0.67 |
| Commonwealth Passaic River 51 | 0.32 | 0.24 | 0.40 |
| Commonwealth Passaic R. 48,50 | 0.64 | 0.48 | 0.80 |
| East Orange Slough Brook | 0.19 | 0.15 | 0.19 |
| East Orange Slough Brook | 0.19 | 0.15 | 0.19 |
| East Orange Slough Brook | 0.19 | 0.15 | 0.19 |
| East Orange Slough Brook | 0.19 | 0.15 | 0.19 |
| East Orange Canoe Brook 1 | 0.52 | 0.39 | 0.52 |
| East Orange Canoe Brook 2 | 0.52 | 0.39 | 0.52 |
| East Orange Canoe Brook 3 | 0.52 | 0.39 | 0.52 |
| East Orange Canoe Brook 4 | 0.52 | 0.39 | 0.52 |
| East Orange Canoe Brook 5,6 | 0.52 | 0.39 | 0.52 |
| East Orange Braidburn 1 | 1.06 | 0.80 | 1.06 |
| East Orange Braidburn 2 | 1.06 | 0.80 | 1.06 |
| East Orange Braidburn 3 | 1.06 | 0.80 | 1.06 |
| East Orange Dickinson 1 | 0.93 | 0.70 | 0.93 |
| East Orange Dickinson 2 | 0.93 | 0.70 | 0.93 |
| East Orange Dickinson 3 | 0.93 | 0.70 | 0.93 |
| Livingston Township 1 | 0.08 | 0.06 | 0.08 |
| Livingston Township 2 | 0.00 | 0.00 | 0.00 |
| Livingston Township 3 | 0.87 | 0.65 | 0.87 |
| Livingston Township 4 | 0.22 | 0.17 | 0.22 |
| Livingston Township 5 | 0.41 | 0.31 | 0.41 |
| Livingston Township 6 | 0.09 | 0.06 | 0.09 |
| Livingston Township 7 | 0.10 | 0.08 | 0.10 |
| Livingston Township 8 | 0.25 | 0.18 | 0.25 |
| Livingston Township 9 | 0.42 | 0.32 | 0.42 |
| Livingston Township 10 | 0.14 | 0.11 | 0.14 |
| Livingston Township 11 | 0.17 | 0.12 | 0.17 |
| Livingston Township 12 | 0.21 | 0.16 | 0.21 |
| Black Brook 1 (SEMCMUA) | 1.10 | 0.82 | 1.38 |
| Black Brook 2 (SEMCMUA) | 1.47 | 1.10 | 1.84 |
| Normandy (SEMCMUA) | 0.11 | 0.32 | 0.54 |
| Florham Park Borough 1 | 0.00 | 0.00 | 0.00 |
| Florham Park Borough 2 | 0.29 | 0.22 | 0.36 |
| Florham Park Borough 3 | 0.29 | 0.22 | 0.36 |
| Florham Park Borough 4 | 0.29 | 0.22 | 0.36 |
| East Hanover Township 1 | 0.00 | 0.00 | 0.00 |
| East Hanover Township 2 | 0.46 | 0.35 | 0.58 |
| East Hanover Township 5 | 0.46 | 0.35 | 0.58 |
| Madison Borough A | 0.36 | 0.27 | 0.45 |
| Madison Borough B | 0.36 | 0.27 | 0.45 |
| Madison Borough C | 0.36 | 0.27 | 0.45 |
| Madison Borough D | 0.36 | 0.27 | 0.45 |
| Madison Borough E | 0.36 | 0.27 | 0.45 |
| Chatham Borough 1,2,3 | 1.12 | 0.84 | 1.40 |
| Canoe Brook Country Club | 0.02 | 0.01 | 0.02 |
| Exxon Research & Engineering | 0.39 | 0.29 | 0.48 |
| Morris County Golf Club | 0.01 | 0.01 | 0.01 |
| Sandoz 1 | 0.08 | 0.06 | 0.10 |
| Sandoz 2 | 0.08 | 0.06 | 0.10 |
| Sandoz 3 | 0.08 | 0.06 | 0.10 |
| Sandoz 4 | 0.08 | 0.06 | 0.10 |
| Sandoz 5 | 0.08 | 0.06 | 0.10 |
| Pfizer | 0.27 | 0.20 | 0.33 |
| Allied Chemical 1,2,4 | 0.61 | 0.45 | 0.76 |
| Allied Chemical 10 | 0.20 | 0.15 | 0.25 |
| Allied Chemical | 0.01 | 0.01 | 0.02 |
| Surburban Propane | 0.00 | 0.00 | 0.00 |
| Amax Specialties Metal Corp. | 0.00 | 0.00 | 0.01 |
| Orange Products, Inc. | 0.00 | 0.00 | 0.00 |
| Linpro |  | - | - |
| TOTALS | 26.55 | 20.14 | 29.57 |

**Table 10.** Simulated total and incremental drawdowns based on 75-percent-of-recorded-pumpage scenario

**A) Total drawdowns[1] (ft)**

| Observation well | Pumping period | | | | |
|---|---|---|---|---|---|
| | 1974-1976 | 1977-1979 | 1981-1980 | 1984 | 1985 |
| Green Acres | 7.9 | 8.7 | 9.1 | 8.7 | 8.9 |
| Sandoz | 26.3 | 26.4 | 24.8 | 24.7 | 24.7 |
| Clemens | 26.7 | 27.0 | 25.2 | 25.8 | 25.9 |
| Driver 2 | 31.0 | 32.3 | 30.1 | 32.5 | 33.1 |
| Driver 1 | 31.9 | 33.0 | 31.6 | 32.9 | 33.0 |
| Briarwood School | 42.0 | 43.0 | 43.4 | 41.1 | 40.4 |
| Morristown Airport | 19.3 | 20.6 | 20.3 | 21.2 | 22.5 |
| Esso 6-Inch | 30.7 | 31.4 | 31.0 | 30.8 | 30.8 |
| Neutral Zone | 55.3 | 52.6 | 53.4 | 49.5 | 47.3 |
| Canoe Brook | 47.0 | 46.7 | 47.9 | 42.7 | 38.5 |
| Madison 4 | 41.4 | 41.4 | 41.7 | 38.2 | 37.0 |

**B) Incremental drawdowns[2] (ft)**

| Observation well | Pumping period | | | | |
|---|---|---|---|---|---|
| | 1974-1976 | 1977-1979 | 1981-1980 | 1984 | 1985 |
| Green Acres | -0.6 | 0.8 | 0.4 | -0.4 | 0.2 |
| Sandoz | -4.7 | 0.1 | -1.6 | -0.1 | 0.0 |
| Clemens | -5.1 | 0.3 | -1.8 | 0.6 | 0.1 |
| Driver 2 | -4.9 | 1.3 | -2.2 | 2.4 | 0.6 |
| Driver 1 | -4.3 | 1.1 | -1.4 | 1.3 | 0.1 |
| Briarwood School | -5.0 | 1.0 | 0.4 | -2.3 | -0.7 |
| Morristown Airport | -1.6 | 1.3 | -0.3 | 0.9 | 1.3 |
| Esso 6-Inch | -3.3 | 0.7 | -0.4 | -0.2 | 0.0 |
| Neutral Zone | -6.9 | -2.7 | 0.8 | -3.9 | -2.2 |
| Canoe Brook | -11.5 | -0.3 | 1.2 | -5.2 | -4.2 |
| Madison 4 | -7.3 | 0.0 | 0.3 | -3.5 | -1.2 |

[1] From prepumping conditions to end of pumping period.

[2] Positive numbers indicate a fall in water levels. Negative numbers indicate a rise in water levels.

**Table 11.** Analysis of difference between actual and simulated incremental drawdowns (ft), 75-percent-of-recorded-pumpage scenario

| Well | Incremental drawdown | Pumping period<br>1946-1952 | 1953-1959 | 1960-1965 | 1966-1968 | 1969-1971 | 1972-1973 | 1974-1976 | 1977-1979 | 1980 | 1984 | 1985 | Average of the annual absolute difference for each well |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pumping period (no. of years) | | 7 | 7 | 6 | 3 | 3 | 2 | 3 | 3 | 1 | 4 | 1 | |
| Green Acres | actual | | | | | 0.0 | -1.2 | 2.0 | 1.2 | 1.6 | -0.2 | 1.6 | |
| | simulated | | | | | 1.9 | 0.3 | 0.7 | 0.8 | 0.4 | -0.4 | 0.2 | |
| | annual difference | | | | | -0.6 | -0.8 | 0.4 | 0.1 | 1.2 | 0.1 | 1.4 | 0.7 |
| Sandoz | actual | | | | | 9.4 | -1.6 | 1.4 | 1.8 | 2.6 | 4.8 | 3.6 | |
| | simulated | | | | | 9.2 | 7.2 | 1.6 | 0.1 | -1.6 | -0.1 | 0.0 | |
| | annual difference | | | | | 0.1 | -4.4 | -0.1 | 0.6 | 4.2 | 1.2 | 3.6 | 2.3 |
| Clemens | actual | | | | | 10.0 | -2.0 | 2.6 | 1.8 | 4.4 | 1.2 | | |
| | simulated | | | | | 9.2 | 7.7 | -5.1 | 0.3 | -1.8 | 0.6 | | |
| | annual difference | | | | | 0.3 | -4.8 | 2.6 | 0.5 | 6.2 | 0.1 | | 2.4 |
| Driver 2 | actual | | | | 1.8 | 11.2 | -2.8 | 5.0 | 2.6 | 4.0 | 3.6 | 1.0 | |
| | simulated | | | | 2.1 | 9.8 | 6.8 | -4.9 | 1.3 | -2.2 | 2.4 | 0.6 | |
| | annual difference | | | | -0.1 | 0.5 | -4.8 | 3.3 | 0.4 | 6.2 | 0.3 | 0.4 | 2.0 |
| Driver 1 | actual | | | | 1.8 | 9.2 | -2.8 | 6.0 | 1.6 | 4.4 | 5.8 | | |
| | simulated | | | | 2.6 | 8.3 | 4.8 | -4.3 | 1.1 | -1.4 | 1.3 | | |
| | annual difference | | | | -0.3 | 0.3 | -3.8 | 3.4 | 0.2 | 5.8 | 1.1 | | 2.1 |
| Briarwood School | actual | | | | 1.0 | 6.4 | -4.8 | 4.6 | 7.6 | -0.4 | -1.8 | 2.2 | |
| | simulated | | | | 4.8 | 6.1 | 0.4 | -5.0 | 1.0 | 0.4 | -2.3 | -0.7 | |
| | annual difference | | | | -1.3 | 0.1 | -2.6 | 3.2 | 2.2 | -0.8 | 0.1 | 2.9 | 1.6 |
| Morristown Airport | actual | | | 2.5 | 0.5 | 1.7 | -0.3 | 0.1 | 0.1 | 1.6 | -0.1 | 0.0 | |
| | simulated | | | 4.4 | 1.3 | 4.2 | 0.9 | -1.6 | 1.3 | -0.3 | 0.9 | 1.3 | |
| | annual difference | | | -0.3 | -0.3 | -0.8 | -0.6 | 0.6 | -0.4 | 1.9 | -0.3 | -1.3 | 0.7 |
| Esso 6-inch | actual | | | | | 3.0 | -1.2 | 2.2 | 0.2 | 4.0 | 4.0 | | |
| | simulated | | | | | 5.2 | 1.4 | -3.3 | 0.7 | -0.4 | -0.2 | | |
| | annual difference | | | | | 0.7 | -1.3 | 1.8 | -0.2 | 4.4 | 1.1 | | 1.6 |
| Neutral Zone | actual | 10.0 | 18.4 | 11.4 | -6.0 | 0.0 | -2.0 | 1.4 | -2.2 | -3.2 | -5.8 | | |
| | simulated | 1.8 | 9.2 | 7.8 | -5.3 | 0.5 | 4.0 | -6.9 | -2.7 | 0.8 | -3.9 | | |
| | annual difference | 1.2 | 1.3 | 0.6 | -0.2 | -0.2 | -3.0 | 2.8 | 0.2 | -4.0 | -0.5 | | 1.4 |
| Canoe Brook | actual | | 6.5 | 15.2 | -2.6 | 5.2 | 0.8 | -8.1 | -1.7 | 0.0 | -9.0 | | |
| | simulated | | 11.5 | 11.2 | -2.2 | 2.8 | 2.4 | -11.5 | -0.3 | 1.2 | -5.2 | | |
| | annual difference | | -0.7 | 0.7 | -0.1 | 0.8 | -0.8 | 1.1 | -0.5 | -1.2 | -0.9 | | 0.8 |
| Madison 4 | actual | | | 9.8 | 0.2 | -0.4 | -6.0 | 1.0 | 1.0 | 1.2 | -3.0 | 2.8 | |
| | simulated | | | 10.9 | 1.6 | 4.9 | 0.5 | -7.3 | 0.0 | 0.3 | -3.5 | -1.2 | |
| | annual difference | | | -0.2 | -0.5 | -1.8 | -3.3 | 2.8 | 0.3 | 0.9 | 0.1 | 4.0 | 1.5 |
| Average of the annual absolute difference for each pumping period | | 1.2 | 1.0 | 0.4 | 0.4 | 0.6 | 2.7 | 2.2 | 0.5 | 3.3 | 0.5 | 2.3 | |

**Table 12.** Simulated total and incremental drawdowns based on 125-percent-of-recorded-pumpage scenario

**A) Total drawdowns[1] (ft)**

| | Pumping period | | | | |
|---|---|---|---|---|---|
| Observation well | 1974-1976 | 1977-1979 | 1981-1980 | 1984 | 1985 |
| Green Acres | 9.9 | 11.9 | 12.9 | 13.0 | 13.3 |
| Sandoz | 38.3 | 41.3 | 39.6 | 40.8 | 41.0 |
| Clemens | 39.0 | 42.4 | 40.6 | 42.9 | 43.5 |
| Driver 2 | 44.9 | 50.8 | 48.2 | 54.9 | 56.8 |
| Driver 1 | 45.2 | 50.8 | 49.7 | 54.2 | 55.4 |
| Briarwood School | 52.1 | 58.6 | 60.6 | 62.1 | 62.0 |
| Morristown Airport | 26.4 | 31.6 | 32.0 | 35.7 | 38.5 |
| Esso 6-Inch | 42.0 | 47.2 | 47.6 | 50.0 | 50.6 |
| Neutral Zone | 69.5 | 71.9 | 74.4 | 72.4 | 70.0 |
| Canoe Brook | 60.7 | 64.9 | 67.7 | 62.2 | 56.6 |
| Madison 4 | 56.0 | 60.9 | 62.3 | 59.7 | 58.4 |

**B) Incremental drawdowns[2] (ft)**

| | Pumping period | | | | |
|---|---|---|---|---|---|
| Observation well | 1974-1976 | 1977-1979 | 1981-1980 | 1984 | 1985 |
| Green Acres | 1.4 | 2.0 | 1.0 | 0.1 | 0.3 |
| Sandoz | 7.3 | 3.0 | -1.7 | 1.2 | 0.2 |
| Clemens | 7.2 | 3.4 | -1.8 | 2.3 | 0.6 |
| Driver 2 | 9.0 | 5.9 | -2.6 | 6.7 | 1.9 |
| Driver 1 | 9.0 | 5.6 | -1.1 | 4.5 | 1.2 |
| Briarwood School | 5.1 | 6.5 | 2.0 | 1.5 | -0.1 |
| Morristown Airport | 5.5 | 5.2 | 0.4 | 3.7 | 2.8 |
| Esso 6-Inch | 8.0 | 5.2 | 0.4 | 2.4 | 0.6 |
| Neutral Zone | 7.3 | 2.4 | 2.5 | -2.0 | -2.4 |
| Canoe Brook | 2.2 | 4.2 | 2.8 | -5.5 | -5.6 |
| Madison 4 | 7.3 | 4.9 | 1.4 | -2.6 | -1.3 |

[1] From prepumping conditions to end of pumping period.

[2] Positive numbers indicate a fall in water levels. Negative numbers indicate a rise in water levels.

**Table 13.** Analysis of difference between actual and simulated incremental drawdowns (ft), 125-percent-of-recorded-pumpage scenario

| Well | Incremental drawdown | 1946-1952 | 1953-1959 | 1960-1965 | 1966-1968 | 1969-1971 | 1972-1973 | 1974-1976 | 1977-1979 | 1981-1980 | 1984 | 1985 | Average of the annual absolute difference for each well |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  | 7 | 7 | 6 | 3 | 3 | 2 | 3 | 3 | 1 | 4 | 1 |  |
| Green Acres | actual |  |  |  |  | 0.0 | -1.2 | 2.0 | 1.2 | 1.6 | -0.2 | 1.6 |  |
|  | simulated |  |  |  |  | 1.9 | 0.3 | 1.4 | 2.0 | 1.0 | 0.1 | 0.3 |  |
|  | annual difference |  |  |  |  | -0.6 | -0.8 | 0.2 | -0.3 | 0.6 | -0.1 | 1.3 | 0.5 |
| Sandoz | actual |  |  |  |  | 9.4 | -1.6 | 1.4 | 1.8 | 2.6 | 4.8 | 3.6 |  |
|  | simulated |  |  |  |  | 9.2 | 7.2 | 7.3 | 3.0 | -1.7 | 1.2 | 0.2 |  |
|  | annual difference |  |  |  |  | 0.1 | -4.4 | -2.0 | -0.4 | 4.3 | 0.9 | 3.4 | 2.2 |
| Clemens | actual |  |  |  |  | 10.0 | -2.0 | 2.6 | 1.8 | 4.4 | 1.2 |  |  |
|  | simulated |  |  |  |  | 9.2 | 7.7 | 7.2 | 3.4 | -1.8 | 2.3 |  |  |
|  | annual difference |  |  |  |  | 0.3 | -4.8 | -1.5 | -0.5 | 6.2 | -0.3 |  | 2.3 |
| Driver 2 | actual |  |  |  | 1.8 | 11.2 | -2.8 | 5.0 | 2.6 | 4.0 | 3.6 | 1.0 |  |
|  | simulated |  |  |  | 2.1 | 9.8 | 6.8 | 9.0 | 5.9 | -2.6 | 6.7 | 1.9 |  |
|  | annual difference |  |  |  | -0.1 | 0.5 | -4.8 | -1.3 | -1.1 | 6.6 | -0.8 | -0.9 | 2.0 |
| Driver 1 | actual |  |  |  | 1.8 | 9.2 | -2.8 | 6.0 | 1.6 | 4.4 | 5.8 |  |  |
|  | simulated |  |  |  | 2.6 | 8.3 | 4.8 | 9.0 | 5.6 | -1.1 | 4.5 |  |  |
|  | annual difference |  |  |  | -0.3 | 0.3 | -3.8 | -1.0 | -1.3 | 5.5 | 0.3 |  | 1.8 |
| Briarwood School | actual |  |  |  | 1.0 | 6.4 | -4.8 | 4.6 | 7.6 | -0.4 | -1.8 | 2.2 |  |
|  | simulated |  |  |  | 4.8 | 6.1 | 0.4 | 5.1 | 6.5 | 2.0 | 21.5 | -0.1 |  |
|  | annual difference |  |  |  | -1.3 | 0.1 | -2.6 | -0.2 | 0.4 | -2.4 | -5.8 | 2.3 | 1.9 |
| Morristown Airport | actual |  |  | 2.5 | 0.5 | 1.7 | -0.3 | 0.1 | 0.1 | 1.6 | -0.1 | 0.0 |  |
|  | simulated |  |  | 4.4 | 1.3 | 4.2 | 0.9 | 5.5 | 5.2 | 0.4 | 3.7 | 2.8 |  |
|  | annual difference |  |  | -0.3 | -0.3 | -0.8 | -0.6 | -1.8 | -1.7 | 1.2 | -1.0 | -2.8 | 1.2 |
| Esso 6-inch | actual |  |  |  |  | 3.0 | -1.2 | 2.2 | 0.2 | 4.0 | 4.0 |  |  |
|  | simulated |  |  |  |  | 5.2 | 1.4 | 8.0 | 5.2 | 0.4 | 2.4 |  |  |
|  | annual difference |  |  |  |  | -0.7 | -1.3 | -1.9 | -1.7 | 3.6 | 0.4 |  | 1.6 |
| Neutral Zone | actual | 10.0 | 18.4 | 11.4 | -6.0 | 0.0 | -2.0 | 1.4 | -2.2 | -3.2 | -5.8 |  |  |
|  | simulated | 1.8 | 9.2 | 7.8 | -5.3 | 0.5 | 4.0 | 7.3 | 2.4 | 2.5 | -2.0 |  |  |
|  | annual difference | 1.2 | 1.3 | 0.6 | -0.2 | -0.2 | -3.0 | -2.0 | -1.5 | -5.7 | -0.9 |  | 1.7 |
| Canoe Brook | actual |  | 6.5 | 15.2 | -2.6 | 5.2 | 0.8 | -8.1 | -1.7 | 0.0 | -9.0 |  |  |
|  | simulated |  | 11.5 | 11.2 | -2.2 | 2.8 | 2.4 | 2.2 | 4.2 | 2.8 | -5.5 |  |  |
|  | annual difference |  | -0.7 | 0.7 | -0.1 | 0.8 | -0.8 | -3.4 | -2.0 | -2.8 | -0.9 |  | 1.4 |
| Madison 4 | actual |  |  | 9.8 | 0.2 | -0.4 | -6.0 | 1.0 | 1.0 | 1.2 | -3.0 | 2.8 |  |
|  | simulated |  |  | 10.9 | 1.6 | 4.9 | 0.5 | 7.3 | 4.9 | 1.4 | -2.6 | -1.3 |  |
|  | annual difference |  |  | -0.2 | -0.5 | -1.8 | -3.3 | -2.1 | -1.3 | -0.2 | -0.1 | 4.1 | 1.5 |
| Average of the annual absolute difference for each pumping period |  | 1.2 | 1.0 | 0.4 | 0.4 | 0.6 | 2.7 | 1.6 | 1.1 | 3.6 | 1.0 | 2.5 |  |

## PUMPAGE-GROWTH SCENARIOS

The purpose of this phase of the investigation was to predict the effects of additional pumpage on water levels. Additional pumpage was divided into two categories. The first is based on an assumption of growth in the area with a corresponding increase in ground-water use. The second assumes a new allocation at the proposed Linpro site. Four pumpage-growth scenarios were investigated using the ground-water model.

The first pumpage-growth scenario, termed the base-growth scenario, assumed that an allocation was not granted to Linpro. All other pumpage in the study area was increased 15 percent from the values reported for the 1981-1984 pumping period. This increase is based on projected population growth in Morris County (below). It is a conservatively high estimate of population growth as the two largest ground-water users (Commonwealth and East Orange) serve primarily Essex County. The increase was applied at the beginning of the pumpage period 1986-1995. Pumpage is shown as scenario BG in table 14.

| | Population | | Percent |
|---|---|---|---|
| County | July 1, 1984 | July 1, 1995 | change |
| Essex | 841,500 | 794,500 | -5.6 |
| Morris | 417,100 | 479,900 | +15.1 |

Source: NJ Office of Demographic and Economic Analysis, 1985

During the modeling of the base-growth scenario, it was necessary to restrict the Commonwealth Canoe Brook, East Orange Slough Brook, East Orange Canoe Brook, East Orange Braidburn, East Orange Dickinson, Livingston and East Hanover well fields to 1981-1984 pumping rates. The computer model predicted that if the pumpage at these wells was increased by 15 percent the wells would go dry. Additionally, the 15-percent increase was applied only to municipal water purveyors; industrial pumpage was held at its 1981-84 level. Industrial pumpage is assumed not to respond to population changes in the area.

Predicted total and incremental drawdowns for the base-growth scenario at the observation wells are shown in table 15. These values are assumed to indicate the effect of expected increases in pumpage to meet increased demand by current users in the area. Any effect of additional ground-water users in the area was calculated as the difference from this base-growth scenario.

Geonics (1986) reported that Linpro proposed pumping between 0.3 and 0.5 (mgd) from the Chatham buried-valley aquifer. Of this amount, 0.3 mgd was for consumption onsite and an additional 0.2 mgd was for possible transfer to Florham Park Borough. To consider both scenarios, pumpages of 0.3 and 0.5 mgd (table 14) were added to the base-growth scenario.

The first Linpro pumpage-growth scenario assumed that in addition to the pumpage applied to the base-growth scenario, 0.3 mgd was withdrawn from the Linpro site. The second Linpro pumpage-growth scenario assumed that 0.5 mgd was pumped from the Linpro site. Predicted total and incremental drawdowns for these two Linpro pumpage-growth scenarios at the end of the 1986-1995 pumping period are shown in table 15.

Comparing the results of the base-growth and two Linpro pumpage-growth scenarios indicates the estimated effect on water levels of the additional Linpro pumpage. At the Neutral Zone observation well (approximately 3.5 miles from the Linpro site and situated near the Commonwealth Canoe Brook well field) the incremental drawdown calculated by the base-growth scenario is 4.7 feet. If Linpro pumps 0.3 mgd the model predicts an incremental drawdown of 4.9 feet, or an additional 0.2 foot of drawdown. If Linpro pumps 0.5 mgd, then the model predicts 5.1 feet of incremental drawdown at the Neutral Zone well, of which 0.4 foot is attributable to the Linpro pumpage.

At the Esso 6-inch observation well (roughly 0.5 mile from the proposed Linpro pumpage site) the incremental drawdown predicted by the model directly attributable to the Linpro site is 1.5 feet at 0.3-mgd additional pumpage, and 2.5 feet at 0.5-mgd additional pumpage.

As a check on the ground-water resources of the area all pumpage was increased to the maximum allocation amount as shown in table 3. This is the maximum-allocation pumpage-growth scenario. Pumpage at the Commonwealth Canoe Brook well field as well as at all East Orange, Livingston, East Hanover Township and Sandoz wells were held at the 1981-1984 rates. If pumpage at these wells increased while all other pumpage increased to the maximum allocation, then these well fields showed excessive

**Table 14.** Simulated pumpage values (mgd) for pumpage-growth scenarios

| | Growth scenarios | | | |
|---|---|---|---|---|
| Production well | BG[1] | BG + 0.3[2] | BG + 0.5[3] | MA[4] |
| 1/12 Commonwealth Canoe Brook | 0.43 | 0.43 | 0.43 | 0.43 |
| 1/12 Commonwealth Canoe Brook | 0.43 | 0.43 | 0.43 | 0.43 |
| 3/12 Commonwealth Canoe Brook | 1.28 | 1.28 | 1.28 | 1.28 |
| 2/12 Commonwealth Canoe Brook | 0.85 | 0.85 | 0.85 | 0.85 |
| 3/12 Commonwealth Canoe Brook | 1.28 | 1.28 | 1.28 | 1.28 |
| 2/12 Commonwealth Canoe Brook | 0.85 | 0.85 | 0.85 | 0.85 |
| Commonwealth Passaic River 51 | 0.76 | 0.76 | 0.76 | 1.00 |
| Commonwealth Passaic R. 48,50 | 1.52 | 1.52 | 1.52 | 2.00 |
| East Orange Slough Brook | 0.18 | 0.18 | 0.18 | 0.18 |
| East Orange Slough Brook | 0.18 | 0.18 | 0.18 | 0.18 |
| East Orange Slough Brook | 0.18 | 0.18 | 0.18 | 0.18 |
| East Orange Slough Brook | 0.18 | 0.18 | 0.18 | 0.18 |
| East Orange Canoe Brook 1 | 0.47 | 0.47 | 0.47 | 0.47 |
| East Orange Canoe Brook 2 | 0.47 | 0.47 | 0.47 | 0.47 |
| East Orange Canoe Brook 3 | 0.47 | 0.47 | 0.47 | 0.47 |
| East Orange Canoe Brook 4 | 0.47 | 0.47 | 0.47 | 0.47 |
| East Orange Canoe Brook 5,6 | 0.46 | 0.46 | 0.46 | 0.46 |
| East Orange Braidburn 1 | 1.03 | 1.03 | 1.03 | 1.03 |
| East Orange Braidburn 2 | 1.03 | 1.03 | 1.03 | 1.03 |
| East Orange Braidburn 3 | 1.03 | 1.03 | 1.03 | 1.03 |
| East Orange Dickinson 1 | 1.00 | 1.00 | 1.00 | 1.00 |
| East Orange Dickinson 2 | 1.00 | 1.00 | 1.00 | 1.00 |
| East Orange Dickinson 3 | 1.00 | 1.00 | 1.00 | 1.00 |
| Livingston Township 1 | 0.00 | 0.00 | 0.00 | 0.00 |
| Livingston Township 2 | 0.18 | 0.18 | 0.18 | 0.18 |
| Livingston Township 3 | 0.44 | 0.44 | 0.44 | 0.44 |
| Livingston Township 4 | 0.19 | 0.19 | 0.19 | 0.19 |
| Livingston Township 5 | 0.53 | 0.53 | 0.53 | 0.53 |
| Livingston Township 6 | 0.12 | 0.12 | 0.12 | 0.12 |
| Livingston Township 7 | 0.20 | 0.20 | 0.20 | 0.20 |
| Livingston Township 8 | 0.23 | 0.23 | 0.23 | 0.00 |
| Livingston Township 9 | 0.47 | 0.47 | 0.47 | 0.47 |
| Livingston Township 10 | 0.10 | 0.10 | 0.10 | 0.10 |
| Livingston Township 11 | 0.20 | 0.20 | 0.20 | 0.20 |
| Livingston Township 12 | 0.20 | 0.20 | 0.20 | 0.20 |
| Black Brook 1 (SEMCMUA) | 1.19 | 1.19 | 1.19 | 1.60 |
| Black Brook 2 (SEMCMUA) | 1.40 | 1.40 | 1.40 | 1.60 |
| Normandy (SEMCMUA) | 0.08 | 0.08 | 0.08 | 1.60 |
| Florham Park Borough 1 | 0.00 | 0.00 | 0.00 | 0.00 |
| Florham Park Borough 2 | 0.40 | 0.40 | 0.40 | 0.58 |
| Florham Park Borough 3 | 0.40 | 0.40 | 0.40 | 0.58 |
| Florham Park Borough 4 | 0.40 | 0.40 | 0.40 | 0.58 |
| East Hanover Township 1 | 0.00 | 0.00 | 0.00 | 0.00 |
| East Hanover Township 2 | 0.61 | 0.61 | 0.61 | 0.61 |
| East Hanover Township 5 | 0.42 | 0.42 | 0.42 | 0.42 |
| Madison Borough A | 0.39 | 0.39 | 0.39 | 0.70 |
| Madison Borough B | 0.39 | 0.39 | 0.39 | 0.70 |
| Madison Borough C | 0.39 | 0.39 | 0.39 | 0.70 |
| Madison Borough D | 0.39 | 0.39 | 0.39 | 0.70 |
| Madison Borough E | 0.39 | 0.39 | 0.39 | 0.70 |
| Chatham Borough 1,2,3 | 1.07 | 1.07 | 1.07 | 1.75 |
| Canoe Brook Country Club | 0.02 | 0.02 | 0.02 | 0.10 |
| Exxon Research & Engineering | 0.39 | 0.39 | 0.39 | 0.32 |
| Morris County Golf Club | 0.01 | 0.01 | 0.01 | 0.21 |
| Sandoz 1 | 0.08 | 0.08 | 0.08 | 0.08 |
| Sandoz 2 | 0.08 | 0.08 | 0.08 | 0.08 |
| Sandoz 3 | 0.08 | 0.08 | 0.08 | 0.08 |
| Sandoz 4 | 0.08 | 0.08 | 0.08 | 0.08 |
| Sandoz 5 | 0.08 | 0.08 | 0.08 | 0.08 |
| Pfizer | 0.51 | 0.51 | 0.51 | 1.70 |
| Allied Chemical 1,2,4 | 0.65 | 0.65 | 0.65 | 0.80 |
| Allied Chemical 10 | 0.16 | 0.16 | 0.16 | 0.26 |
| Allied Chemical | 0.00 | 0.00 | 0.00 | 0.00 |
| Surburban Propane | 0.01 | 0.01 | 0.01 | 0.10 |
| Amax Specialties Metal Corp. | 0.08 | 0.08 | 0.08 | 0.10 |
| Orange Products, Inc. | 0.11 | 0.11 | 0.11 | 0.10 |
| Linpro | 0.00 | 0.30 | 0.50 | 0.00 |
| TOTALS | 29.61 | 29.91 | 30.11 | 36.76 |

SCENARIO

[1]BG : base growth pumpage + 0.0 mgd Linpro pumpage

[2]BG + 0.3 : base growth pumpage + 0.3 mgd Linpro pumpage

[3]BG + 0.5 : base growth pumpage + 0.5 mgd Linpro pumpage

[4]MA : maximum allocation pumpage + 0.0 mgd Linpro pumpage

The base growth pumpage assumes a 15-percent increase in pumpage over simulated 1981-1984 rates for all ground-water users in the study area except the Commonwealth Canoe Brook well field and all East Orange, Livingston, East Hanover and private industry wells. These users were held at the 1981- 1984 rates.

The maximum-allocation pumpage was applied to all ground- water users except the Commonwealth Canoe Brook well field, and all East Orange, Livingston, East Hanover, and Sandoz wells.

**Table 15.** Simulated total and incremental drawdowns at observation wells from pumpage-growth scenarios.

**A) Total drawdown 1986-1995 (ft)**

| Observation well | 15-percent growth scenarios<br>BG[1] | <br>BG+0.3[2] | <br>BG+0.5[3] | Maximum allocation[4] |
|---|---|---|---|---|
| Green Acres | 12.2 | 12.2 | 12.3 | 13.3 |
| Sandoz | 36.6 | 37.1 | 37.5 | 47.4 |
| Clemens | 38.5 | 39.1 | 39.5 | 51.4 |
| Driver 2 | 49.2 | 50.2 | 50.8 | 72.5 |
| Driver 1 | 49.4 | 50.4 | 51.1 | 71.8 |
| Briarwood School | 59.2 | 59.7 | 60.1 | 67.3 |
| Morristown Airport | 31.9 | 33.4 | 34.4 | 53.7 |
| Esso 6 Inch | 45.5 | 47.0 | 48.0 | 65.1 |
| Neutral Zone | 69.8 | 70.0 | 70.2 | 76.9 |
| Canoe Brook | 59.8 | 60.0 | 60.1 | 67.7 |
| Madison 4 | 55.4 | 56.1 | 56.6 | 74.8 |

**B) Incremental drawdown 1986-1995 (ft)**

| Observation well | 15-percent growth scenarios<br>BG[1] | <br>BG+0.3[2] | <br>BG+0.5[3] | Maximum allocation[4] |
|---|---|---|---|---|
| Green Acres | 0.5 | 0.5 | 0.6 | 1.6 |
| Sandoz | 3.4 | 3.9 | 4.3 | 14.2 |
| Clemens | 3.6 | 4.2 | 4.6 | 16.5 |
| Driver 2 | 4.7 | 5.7 | 6.3 | 28.0 |
| Driver 1 | 5.1 | 6.1 | 6.8 | 27.5 |
| Briarwood School | 3.2 | 3.7 | 4.1 | 11.3 |
| Morristown Airport | 2.9 | 4.4 | 5.4 | 24.7 |
| Esso 6 Inch | 4.3 | 5.8 | 6.8 | 23.9 |
| Neutral Zone | 4.7 | 4.9 | 5.1 | 11.8 |
| Canoe Brook | 7.1 | 7.3 | 7.4 | 15.0 |
| Madison 4 | 5.3 | 6.0 | 6.5 | 24.7 |

Scenarios:

[1]BG : base growth pumpage + 0.0 mgd Linpro pumpage
[2]BG + 0.3 : base growth pumpage + 0.3 mgd Linpro pumpage
[3]BG + 0.5 : base growth pumpage + 0.5 mgd Linpro pumpage
[4]MA : maximum allocation pumpage + 0.0 mgd Linpro pumpage

The base growth pumpage assumes a 15-percent increase in pumpage over simulated 1981-1984 rates for all ground-water users in the study area except the Commonwealth Canoe Brook well field and all East Orange, Livingston, East Hanover and private industry wells. These users were held at the 1981-1984 rates.

The maximum-allocation pumpage was applied to all ground-water users except the Commonwealth Canoe Brook well field, and all East Orange, Livingston, East Hanover, and Sandoz wells.

drawdown and the model predicted that water levels would fall below the bottom of the aquifer. No pumpage was simulated at the proposed Linpro well in the maximum-allocation pumpage-growth scenario.

Under the maximum-allocation pumpage-growth scenario the Neutral Zone well showed 11.8 feet of incremental drawdown and the Esso 6-inch well, 24.7 feet at the end of the period 1986-1995.

## LIMITATIONS OF MODEL

Application and interpretation of a computer model requires many assumptions. These assumptions limit the accuracy and applicability of the model. Four major assumptions affect this model: 1) ground-water flow is limited to two dimensions; 2) Meisler's model was calibrated to a short time period; 3) pumpage must be averaged in space and time to fit the model, and; 4) the streams and wetlands are able to supply an infinite volume of water to the aquifer.

The first limitation involves the hydrogeology of the area. The model simulates the unconsolidated overburden, including the buried-valley aquifer. In the areas between the buried valleys the bedrock aquifer crops out at the surface and this is reflected in the model. The model, though, does not simulate the subsurface extension of the bedrock aquifer beneath the buried-valley aquifer.

Meisler (1976) assumed that under normal, unstressed conditions, ground water flowed upward from the bedrock aquifer into the buried-valley aquifer. This would increase the sustained yield of the buried-valley aquifer.

The underlying bedrock aquifer, though, is the source of water for many wells throughout the area. Ground-water flow may, in places, be downwards, from the overburden into the bedrock. This would decrease the amount of water available as sustainable yield from the buried-valley aquifer. An aquifer test in 1986 at the Linpro site showed that the water level in the buried-valley aquifer was 14 feet higher than the water level in the bedrock (Geonics, 1986). Under these conditions ground water moves downward from the buried-valley aquifer into the bedrock aquifer. During the aquifer test, pumping from the buried-valley aquifer lowered water levels in the bedrock aquifer. Daily fluctuations in water levels were observed in the bedrock aquifer, perhaps caused by nearby pumpage in that aquifer. These fluctuations were also noticeable, but muted, in the buried-valley wells. Clearly, the two aquifers are hydraulically connected.

It is not known whether the bedrock aquifer consistently increases or decreases the sustained yield of an overlying buried-valley aquifer, or if these interactions exert a major influence on water levels. However, the interactions should not be ignored. A more thorough study is needed to define how pumping in one aquifer affects the other. An accurate representation would consider the system as a whole, and predict a sustained yield of the combined bedrock and buried-valley aquifer systems.

The second limitation to the model is the calibration base. Meisler's model was calibrated using a short historical period. Four of the observation wells had 3 years of historical water-level data available, four others 6 years, two had 12 years and two had 19 years. Model parameters were adjusted during Meisler's study to match predicted drawdowns to observed drawdowns in the 12 calibration wells. This was not done during the current study.

The model was subsequently used in the current study to predict drawdowns for the 14-year period 1972-1985. Six pumping periods were used to represent the general increase of pumping during this period. In all but two cases, the model is thus being used to predict drawdowns for an interval greater than the original calibration period. This is undesirable and increases the uncertainty of the model Also, because pumping rates were increasing, this study used higher rates than those used during the original calibration period. This also is undesirable, because all models display greater uncertainty as input parameters extend beyond ranges observed during the calibration period.

The third major assumption deals with how pumpage was represented in the model. Many of the purveyors in the study area report withdrawal data summed for an entire well field for a three-month period. Several of the well fields in this study extend over several nodes. To represent withdrawals, the reported pumpages for each well field were divided by the number of wells in that field, and the average assigned to each well. A more accurate result could be achieved by accurately defining the pumpage for each well. Such well-specific adjustments could alter drawdowns as predicted by the model.

The pumping periods were also approximated. Based on yearly pumpage values, the period 1974-1985 was divided into five shorter intervals. Reported pumpage in each period was averaged for each interval. This average was then used in the model. Thus the model correctly represented the total volume of water withdrawn from the aquifer during each pumping period, but smoothed it out over the period. This assumption results in an average drawdown over the period. Peaks in pumpage and resulting temporary drawdowns are not represented. This approach may account for some of the differences between predicted and actual drawdowns.

The fourth major assumption deals with the source of water to the model. Under steady-state conditions, as was assumed to exist when calculating the sustainable yield, all recharge to the buried-valley aquifers, comes from surface waters: streams and wetlands.

The Passaic River and its tributaries carry more than enough water to recharge the buried-valley aquifers if a direct connection existed between them. The Passaic River at Chatham (in the center of the study area and roughly at the intersections of the Chatham and Southern Millburn buried-valley aquifers) carried an average of 126 million gallons per day during calendar year 1986 (Bauersfeld and others, 1987). This volume is significantly greater than the estimated yields of all of the buried-valley aquifers in the study area.

The estimates of sustainable yield assumed that sufficient water can leak through the semi-confining unit overlying the buried-valley aquifers from the channels of the Passaic River and its tributaries and from wetlands in the area. If the semi-confining unit is more restrictive than assumed by the model, or a significant portion of the wetlands at the surface are drained, then the estimates of sustainable yield may be too high.

During low-water periods, when river flow and the areal extent of wetlands are reduced, the amount of vertical recharge may be diminished. During these times the water available to recharge the buried-valley aquifers may be lower than the predicted amounts.

## OBSERVATIONS ON SUSTAINABLE YIELD AND PERMITTED ALLOCATIONS

Comparison of 1985 pumpage figures with Meisler's estimated sustainable yield (table 1) shows that the Northern Millburn, Slough Brook and Canoe Brook buried valleys are being pumped at rates exceeding the sustainable yield. The results of the 125-percent-of-recorded-pumpage verification scenario support this observation. It was impossible to run the model with any pumpage greater than 1981-1984 levels without simulated water levels in the Commonwealth, East Orange and Livingston well fields falling below the bottom of the aquifer.

According to Meisler (1976), the Northern Millburn, Southern Millburn, Slough Brook, and Canoe Brook buried valleys are overallocated. If all users in these valleys were to pump at their permitted allocation rates the current model predicts that excessive drawdowns would occur, reducing production of water from these buried valleys. Moreover, the allocation for the East Hanover buried valley is close to its estimated sustainable yield.

These conclusions are supported by the results of the maximum-allocation growth-of-pumpage scenario. All well fields held constant in the 125-percent-of-recorded-pumpage verification scenario were also held constant in the maximum-allocation growth scenario. Additionally, trial-and-error adjustments showed that if two users in the East Hanover valley (East Hanover and Sandoz) were to pump their full allocation then one of East Hanover's wells would go dry. This implies that either Meisler's estimate of 13 mgd sustainable yield in the East Hanover buried valley is slightly high, or that the East Hanover and Sandoz well fields are located too close together for each to pump its total allocation.

## CONCLUSIONS

The process of updating pumpage in the Meisler model provided information on possible impacts of a proposed diversion request. This study also provided some insight on the accuracy of Meisler's model and its applicability to situations beyond the original calibration period and conditions. The major conclusions of this study are:

1) Comparison of simulated and observed incremental drawdowns at the observation wells for the period 1972-1985 shows that the model's simulations become increasingly different from observed values with time and the errors are not systematically high or low.
2) The proposed 0.5-mgd diversion would produce approximately 2 feet of additional drawdown from 1986 to 1995 at the nearest observation well (the Esso 6-inch well) and roughly 0.5 ft at the farthest well (Neutral Zone well), assuming a 15-percent growth rate in other municipal users, according to the model.
3) The model does not account for hydraulic continuity with the underlying bedrock aquifer. This may account for some of the error observed. Recalibrating the model to take into account field investigations since Meisler's work may increase the model's accuracy.

4) The model should not be used as the sole basis for decisions on the ground-water resources of the area. However, in conjunction with other sources of information it is an adequate tool for decision-making by planners and other officials if the limitations of the data and modeling results are recognized and understood.

5) Further updating of the model is not advisable. A more precise model that better accounts for the distribution of pumpage in both aquifers, as well as the relationship between the aquifers and their recharge and discharge areas, should be developed.

## BIBLIOGRAPHY

Bauersfeld, W.R., Moshinsky, E.W., Pustay, E.A., and Jones, W.D., 1987, Water resources data, New Jersey, Water Year 1987, v.1., Atlantic Slope Basins, Hudson River to Cape May: U.S. Geological Survey Water-Data Report NJ-87-1, 347p.

Geonics, 1986, Proposed diversion of 0.3 million gallons of water per day from the valley-fill aquifer in Florham Park Boro, Morris County, New Jersey: Consultants report prepared for Linpro Florham Park Land Ltd., Clinton, NJ, 27p.

Lyttle, P.T. and Epstein, J.B., 1987, Geologic map of the Newark 1° x 2° quadrangle, New Jersey, Pennsylvania, and New York, U.S. Geological Survey Misc. Investigation Series Map I- 1715, scale 1:250,000.

Meisler, Harold, 1976, Computer simulation model of the Pleistocene valley-fill aquifer in Southwestern Essex and Southeastern Morris Counties, New Jersey: U.S. Geological Survey Water-Resources Investigations 76-25, 70p.

Nichols, W. D., 1968, Bedrock topography of Eastern Morris and Western Essex Counties: New Jersey, U.S. Geological Survey Misc. Geol. Investigations Map I-549.

Office of Demographic and Economic Analysis, 1985 (reprinted 1988): Population projections for New Jersey and Counties: 1990 to 2020, N.J. Department of Labor, Division of Planning and Research, Trenton, New Jersey, 48p.

Pinder, G.F., 1970, A digital model for aquifer evaluation: Techniques of Water-Resources Investigations of the U.S. Geological Survey, Book 7, Chapter c1, 18p.

Trescott, P.C., 1973, Iterative digital model for aquifer evaluation: U.S. Geological Survey open-file report., 18p.

Trescott, P.C., Pinder, G.F., and Larson, S.P., 1976, Finite- difference model for aquifer simulation in two dimensions with results of numerical experiments: U.S. Geological Survey, Techniques of Water-Resources Investigations, Book 7, Chapter C1, 116p.

**SIMULATED DRAWDOWNS, 1972-1995, IN THE PLEISTOCENE BURIED VALLEY AQUIFERS IN SOUTHWESTERN ESSEX AND SOUTHEASTERN MORRIS COUNTIES, NEW JERSEY (New Jersey Geological Survey Open-File Report OF-89-1)**