CASE STUDY OF A REHABILITATION PROGRAM FOR A 10 MILLION GALLON PER DAY WELL FIELD[a]

by Doreen Sousa and Vincent W. Uhl, Jr.

ABSTRACT

Geraghty & Miller, Inc. has, over the past three decades, been involved with ground-water development and management programs for the City of East Orange Water Department, New Jersey, USA. During the early part of this century the City purchased approximately 2300 acres of land for a Water Reserve; four well fields developed in this reserve provide approximately 10 million gallons per day for the City's water-supply needs. In the late 1950's to early 1960's a major well replacement program was initiated and approximately 10 production wells were replaced in three well fields.

This paper provides an assessment of well yield declines for wells completed in bedrock and unconsolidated aquifers over the past three decades and the results of major well rehabilitation programs. For the most part, well rehabilitation has involved mechanical surging with double-surge blocks in combination with air-lift pumping. In addition, sodium hexametaphosphate, a dispersing agent, has been used in several of the wells during the rehabilitation process.

During the most recent rehabilitation program (1988 through 1990), the degree of improvement in specific capacity and well yield was quantified for each well and an economic analysis was developed that compares the costs for well redevelopment to the costs for the installation of new 800 gpm replacement wells.

INTRODUCTION

The City of East Orange, located in northern New Jersey (Figure 1) has, since the early part of this century, derived its water supply from a Water Reserve located approximately 7.5 miles west of the city proper (Figure 2). Four major well fields currently produce approximately 10 million gallons per day (MGD) or 37,900 cubic meters per day (m^3/d) from this Water Reserve, which is comprised of approximately 2,300 acres. These four well fields: the Braidburn, Dickinson, Canoe Brook, and Slough Brook Well Fields have a total of 18 production wells in service. Twelve wells derive ground water from a sequence of unconsolidated glacial deposits referred to as the Buried Valley Aquifer System and six wells are completed in fractured bedrock comprised of sandstone, shale, and basalt.

The Water Reserve consists of woodlands, wetlands, and flood plains which are essentially undeveloped although a golf course, roads, and rights-of-way for utility lines lie within the confines of the Reserve. Since the beginning of the 20th century, the Water Reserve has served to:

- Protect the quality of the underlying aquifer systems by providing a buffer between the well fields and land uses that could impact ground-water quality including industrial, commercial, and residential land uses.
- Maintain natural recharge capabilities to the underlying aquifer systems, and provide areas that can be used for artificial recharge.

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- Provide access to existing wells for operation and maintenance and to new sites for replacement production wells.

In summary, the Water Reserve protects ground-water quality at and upgradient of production wells, and enhances natural recharge to the underlying aquifer system as the land use in the Reserve is essentially in a natural state. The Water Reserve represents the only source of water supply for the City of East Orange, which has a population of approximately 75,000.

AQUIFER SYSTEMS

The principal bedrock aquifer underlying the Water Reserve and the surrounding area is an interbedded reddish brown shale, sandy shale, sandstone, and conglomerate of the Brunswick Formation; the Slough Brook wells are completed in this aquifer system. A minor bedrock aquifer comprised of basalt rocks interbedded with the sandstone and shale rocks occurs in the northern portion of the Canoe Brook Well Field; production wells CB-5 and CB-6 are completed in both sandstone/shale rocks of the Brunswick Formation and basalt rocks. Individual wells completed in these bedrock aquifer units can yield from less than 100 to as much as 400 gallons per minute (gpm) or 380 to 1,500 liters per minute (lpm). The depth to bedrock, under the Water Reserve ranges from 70 to 150 feet (21 to 41 meters) below ground surface.

The Water Reserve is located in the Passaic River Basin, once the site of Glacial Lake Passaic during the Wisconsin (most recent) glacial period. Glacial meltwater streams incised channels into the bedrock, producing narrow gorges that were subsequently filled by a complex sequence of sand, gravel, silt, and clay deposits. The lower portion of these sediments is dominated by glacial outwash, which is comprised of a prolific aquifer referred to as the Buried Valley Aquifer. The locations of the East Orange Well Fields and proximate Buried Valley Systems are shown on Figure 3.

The Buried Valley Aquifer is predominately comprised of coarse sand and gravel deposits capable of storing and transmitting large quantities of ground water. Individual wells completed in areas where the permeable Buried Valley deposits attain thicknesses on the order of 50 feet (15 meters) or greater can yield from 750 to more than 1,500 gpm (2,835 to 5,670 lpm). Overlying the Buried Valley Aquifer deposits, and in some areas resting directly on bedrock, is a heterogeneous, less permeable sequence of sand, silt, clay, swamp muck, and till. These less permeable unconsolidated deposits of glacial and recent origin act as a semi-confining layer.

All of the confining layers and aquifers (bedrock and Buried Valley) comprise one hydrogeologic system in which the individual units are hydraulically interconnected. Figure 4 illustrates the ground-water system functioning in Canoe Brook Valley, which is characteristic of other valleys in the general region surrounding the Water Reserve. Under pumping conditions, the Buried Valley Aquifer behaves as a leaky artesian system, wherein leakage from the overlying confining units and underlying bedrock provides the major source of recharge to the extensive network of production wells in the area. Before pumping from wells began, ground water discharged to streams, ponds, and wetlands. Now, however, pumpage is great enough to have changed the natural direction of ground-water flow and lowered water levels significantly in the Buried Valley Aquifer.

HISTORY OF GROUND-WATER DEVELOPMENT IN THE WATER RESERVE

Original Well Field Installation

The City of East Orange purchased the Orange Water Company in 1902 and acquisition of property for the Water Reserve started during this period. Initial production well installations began during the period from 1903 to 1905 when six wells were installed in the Canoe Brook and Slough Brook Well Fields. In 1905 these six wells were placed into operation at a pumping rate of approximately 2.5 MGD (9,500 m^3/d).

The water reserve was expanded in 1911 to include the Dickinson Well field and later to include the Braidburn Well Field. Production wells were installed in these two well fields during the 1920's and 1930's.

Major Well Replacement and Expansion Program in 1959-60

Many of the current Braidburn, Dickinson and Canoe Brook wells were installed in a major expansion program in 1959-60. This program involved the installation of six new production wells in the Braidburn and Dickinson well fields, and four wells in the Canoe Brook well field. All of these wells are currently in operation and many are the focus of the current well redevelopment and rehabilitation program.

Additional wells were installed from the mid-1970's to the mid-1980's in the Braidburn (B-4), Dickinson (D-4), and Canoe Brook Well Fields (CB-5 and CB-6). Several of these wells were installed as back-up wells, however, due to current water demand some are being used on a full-time basis.

1976-1978 Rehabilitation Program

In 1976 Geraghty & Miller conducted a program to assess well yield and specific capacity conditions in the Braidburn, Dickinson and Canoe Brook well fields. The program involved establishing baseline conditions and comparing current specific capacities to original well installation specific capacities, and the redevelopment of selected wells. The rehabilitation program resulted in increasing well yields at selected wells, however, several wells appeared to be improperly designed in that excessive amounts of the gravel pack were drawn into the wells through the well screen during the well redevelopment process.

CURRENT WELL REHABILITATION AND REPLACEMENT PROGRAM

As a result of declining well yields and specific capacities in several production wells, the City of East Orange Water Department initiated a program to evaluate current well yield and specific capacity conditions. Based on an evaluation of these data, a program was formulated for well redevelopment and replacement. The principal elements of this program have included:

- The conductance of pumping tests to establish current well efficiencies and specific capacities for all of the City's production wells.
- The redevelopment of ten production wells.
- The drilling of test borings and installation of test wells in proximity to four proposed replacement wells.
- The installation of replacement wells.

This program is on-going and as such certain parts of the program are completed while others are in progress.

Pre-Redevelopment Pumping Tests

The first step in this program involved conducting pumping tests on all of the City's production wells to establish current conditions prior to developing recommendations for future well redevelopment and/or well replacement activities. Table 1 provides a comparison of original specific capacities (when the wells were first installed) with 1988/89 pre-redevelopment specific capacities. The range in specific capacity decline was from less than 1% to greater than 50%. Based on an analysis of the pumping test data, three basic recommendations were made:

- <u>No action</u>; this alternative was selected for wells that had specific capacity declines less than 20% (Wells D-4, CB-4, SB-2, and SB-3).

- Well Replacement; This alternative was selected for wells that had excessive amounts of gravel pack entering through the well screen during the 1976-78 well rehabilitation program (Wells B-3, D-1, D-2, and D-3).

- Well Rehabilitation: This alternative was used for wells that had shown a decline in specific capacity greater than 20%.

Well Rehabilitation Program

Well redevelopment activities commenced in 1989 and to date six wells have been redeveloped; four wells remain to be redeveloped. As indicated in Table 2, three of these wells (B-4, CB-2 and CB-3) are completed in glacial outwash deposits and three in a consolidated bedrock aquifer (CB-5, SB-1, and SB-4)

The wells were redeveloped using a double-surge block and air-lift pumping system which served to remove both water and sediments from the well during the redevelopment process. In addition, sodium hexametaphosphate (Calgon), a dispersing agent, was used in the redevelopment process to remove clays that occur naturally in the unconsolidated glacial aquifer materials.

At the inception of the program, during the redevelopment of Canoe Brook 2 (CB-2), Calgon was used after a week of mechanical redevelopment on this well. The degree of specific capacity improvement due to the use of Calgon was quantified and found to represent approximately 35% of the total specific capacity improvement in this well. Given these results, a decision was made to use Calgon during the redevelopment of all wells completed in the glacial outwash deposits.

During the well redevelopment process, short-term pumping tests were run to gauge the effectiveness of redevelopment on an individual well. As long as the specific capacities calculated from these tests showed an increase, redevelopment continued. When the specific capacities from successive tests showed little or no increase, well redevelopment was stopped.

Another field technique involved observation of the nature and quantity of sediment pulled in through the well screen during the redevelopment process. Some of these sediments were pumped out during redevelopment, while the coarse grained deposits settled to the bottom of the well. When the quantity of sediment decreased significantly both in the pumped discharge and in the bottom of the well, well redevelopment was nearing completion.

The time required to rehabilitate the production wells ranged from 2 to 3 weeks. In general, rehabilitation was accomplished within a shorter period for the bedrock wells as compared to the glacial wells.

Table 2 provides a comparison of pre- and post-redevelopment specific capacities for the six wells. This table quantifies the degree of improvement in specific capacity as a result of well redevelopment which ranged from 1.2 to 35.4 gpm/ft (14.9 to 439.0 lpm/m). Table 3 provides a comparison of the original well installation and post-redevelopment specific capacities; as indicated the well redevelopment process did not result in any well being restored to its original specific capacity. The degree of restoration ranged from 69% to 92%.

The conductance of pre- and post- redevelopment pumping tests allowed for a quantification of the degree of improvement in well yield for individual wells. Table 4 provides such a summary wherein the increase in specific capacity is multiplied by the operating drawdown to provide the degree of improvement in well yield (note: operating drawdown is the difference between static water levels and pumping water levels prior to the initiation of well rehabilitation activities).

The degree of well yield improvement ranged from 32 to 350 gpm (122 to 1323 lpm). Table 4 also provides a summary of the costs associated with redevelopment activities for each well. These include the drillers costs for pumping tests, removing and installing pumping equipment, and well redevelopment, as well as the consultant costs. Overall per well redevelopment costs ranged from $10,000 to $27,300.

In that the overall program involved the installation of replacement wells, it was possible to develop a comparison between the costs of developing additional water for the water utility by redevelopment as compared to replacement wells.

Production Well Replacement Program

Based on the review of prior (1976-78) well redevelopment efforts and the 1988-89 pre-redevelopment specific capacity tests, a decision was made to replace four existing production wells. All four of these wells could not be redeveloped to any degree in the previous well redevelopment program as large amounts of the gravel pack were pulled through the well screens during redevelopment attempts. The principal factor responsible for this was improper well screen and gravel pack design for the wells.

In addition, since Production Wells Braidburn-3 and Dickinson-2 had relatively low well yields, an aspect of the well replacement program involved a test boring program in proximity to these two wells to locate areas where the Buried Valley deposits were deeper and thicker.

A summary of the elements and costs associated with the well replacement program is provided below and outlined in Table 5. Initially a test boring and test well program was conducted to both identify locations for replacement wells and provide design criterion for all four replacement wells. This was followed by the application for permits for well drilling and wetland encroachment.

Next, specifications and bidding documents were prepared and the project was put out to public bid. Final activities involve the installation of the replacement production wells and the installation of appropriate pumping equipment and piping.

The costs associated with the replacement wells are presented in Table 5 and include both consultant and contractor costs. The total costs for one 800 gpm (3025 lpm) production well are approximately $351,000, as compared to $105,800 for well redevelopment resulting in an additional 907 gpm (3430 lpm).

SUMMARY

- The pre-redevelopment pumping tests allowed for a quantification of reduction in specific capacity and for a prioritization of a well rehabilitation program. For this program, a decrease in specific capacity on the order of 20% or more was used as a guideline for wells that needed to be redeveloped.

- Redevelopment was accomplished using a double-surge block with an air-lift pumping system; most of the wells were rehabilitated within two to three weeks.

- Post-redevelopment specific capacity tests allowed for a quantification of the degree of improvement in specific capacity and improvements ranged from 8 to 35.4 gpm-/ft (99.2 to 439.0 lpm/m) for the glacial wells and from 1.2 to 1.5 gpm/ft (14.9 to 18.6 lpm/m) for the bedrock wells.

- The use of operational drawdowns in combination with specific capacity increases allowed for a quantification of increases in well yields which ranged from 160 to 350 gpm (605 to 1323 lpm) for the glacial wells and 32 to 45 gpm (122 to 170 lpm) for the bed rock wells.

- The costs associated with well redevelopment for the six wells have been $105,800; the total increase in yield to date for the well fields as a result of the well redevelopment program has been 907 gpm (3430 lpm).

- The costs associated with installing a new 800 gpm (3025 lpm) production well were approximately $351,000 for a contractor and consultant.

In that the installation of new replacement wells in New Jersey and in other parts of the world can be significantly more costly than well redevelopment, proper well maintenance and rehabilitation may, for many utilities and industries represent a more cost-effective solution to meeting their water supply needs.

ACKNOWLEDGEMENTS

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TABLE 1. COMPARISON OF SPECIFIC CAPACITIES FROM ORIGINAL WELL INSTALLATION TO THE 1988-89 PRE-REDEVELOPMENT PUMPING TESTS

	ORIGINAL WELL INSTALLATION				PRE-REDEVELOPMENT				SPECIFIC CAPACITY
	YEAR	Q/s (gpm/ft)	Q (gpm)	t (min)	YEAR	Q/s (gpm/ft)	Q (gpm)	t (min)	DECLINE (percent)
BRAIDBURN WELL FIELD									
B-1	1959	59.0	1004	240	1988	42.9	908	240	27 %
B-2	1960	61.0	998	60	1988	40.5	837	60	34 %
B-3	1960	44.0	999	60	1988	19.5	870	60	56 %
B-4	1974	64.0	1001	60	1988	51.0	1138	60	20 %
DICKINSON WELL FIELD									
D-1	1960	65.5	1002	60	1988	46.7	750	60	29 %
D-2	1959	31.3	1011	240	<-----NOT TESTED----->				---
D-3	1959	133.0	1013	240	1988	96.0	700	240	28 %
D-4	1984	38.4	1005	240	1989	36.9	896	240	4 %
CANOE BROOK WELL FIELD									
CB-1	1960	57.3	750	240	1989	30.5	550	240	47 %
CB-2	1960	105.0	756	60	1989	53.8	563	60	49 %
CB-3	1960	109.4	744	60	1989	60.0	240	60	45 %
CB-4	1960	202.7	750	240	1989	177.6	255	240	12 %
CB-5	1972	11.3	500	40	1989	7.1	421	40	37 %
CB-6	1972	5.4	250	240	1989	3.2	172	240	41 %
SLOUGH BROOK WELL FIELD									
SB-1	1978	10.2	250	60	1989	6.4	250	60	37 %
SB-2	1979	10.1	205	60	1989	11.1	215	60	0 %
SB-3	1978	11.9	250	100	1989	14.1	250	100	0 %
SB-4	1977	11.0	361	60	1989	8.7	399	60	21 %

Q/s - Specific Capacity in gallons per minute per foot of drawdown.

Q - Flow in gallons per minute.

TABLE 2. COMPARISON OF PRE- AND POST-REDEVELOPMENT SPECIFIC CAPACITIES; 1988–1990 PROGRAM

	PRE-REDEVELOPMENT YEAR	Q/s (gpm/ft)	Q (gpm)	t (min)	POST REDEVELOPMENT YEAR	Q/s (gpm/ft)	Q (gpm)	t (min)	INCREASE IN Q/s (gpm/ft)	AQUIFER
BRAIDBURN WELL FIELD										
B–4	1988	51.0	1138	60	1990	59.0	1125	60	8.0	GLACIAL
CANOE BROOK WELL FIELD										
CB–2	1989	53.8	563	60	1989	72.1	590	60	18.3	GLACIAL
CB–3	1989	60.0	240	40	1990	95.4	450	40	35.4	GLACIAL
CB–5	1989	7.1	421	40	1990	8.6	445	40	1.5	BEDROCK
SLOUGH BROOK WELL FIELD										
SB–1	1989	6.4	250	60	1990	7.9	250	60	1.5	BEDROCK
SB–4	1989	8.7	399	60	1990	9.9	363	60	1.2	BEDROCK

Q/s – Specific Capacity in gallons per minute per foot of drawdown.
Q – Flow in gallons per minute.

TABLE 3. COMPARISON OF ORIGINAL WELL INSTALLATION AND 1989–1990 POST-REDEVELOPMENT SPECIFIC CAPACITIES

	ORIGINAL WELL INSTALLATION YEAR	Q/s (gpm/ft)	Q (gpm)	t (min)	POST-REDEVELOPMENT YEAR	Q/s (gpm/ft)	Q (gpm)	t (min)	% OF ORIGINAL (1)
BRAIDBURN WELL FIELD									
B–4	1974	64.0	1001	60	1990	59.0	1125	60	92 %
CANOE BROOK WELL FIELD									
CB–2	1960	105.0	756	60	1989	72.1	590	60	69 %
CB–3	1960	109.4	744	60	1990	95.4	450	60	87 %
CB–5	1972	11.3	500	40	1990	8.6	445	40	76 %
SLOUGH BROOK WELL FIELD									
SB–1	1978	10.2	250	60	1990	7.9	250	60	77 %
SB–4	1977	11.0	361	60	1990	9.9	363	60	90 %

Q/s – Specific Capacity in gallons per minute per foot of drawdown.
Q – Flow in gallons per minute.
(1) – Post development specific capacity as a percentage of the original specific capacity.

TABLE 4. SUMMARY OF WELL YIELD IMPROVEMENT AND RELATIVE COSTS OF REDEVELOPMENT

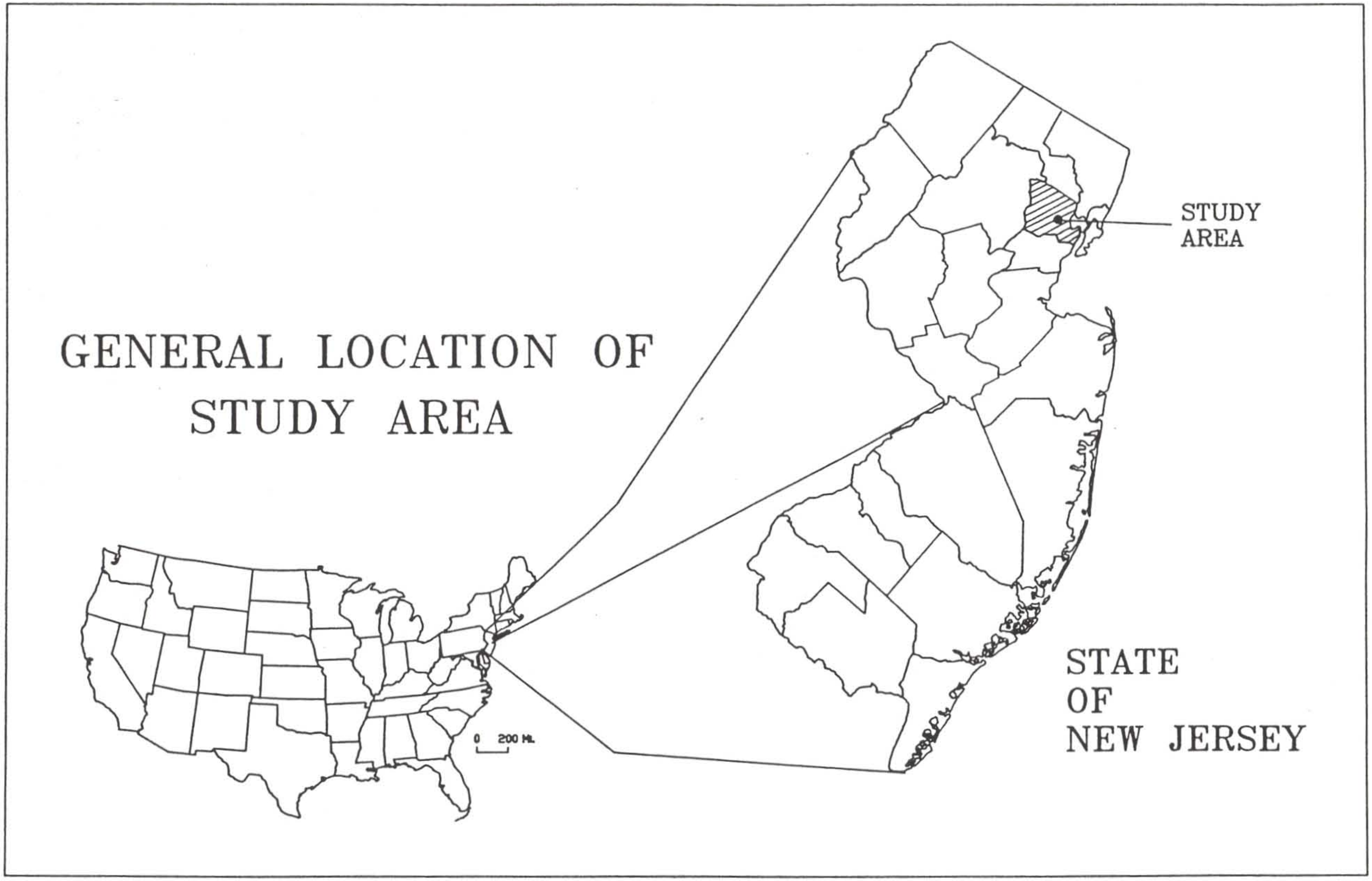
	INCREASE IN Q/s (gpm/ft)	OPERATING DRAWDOWN (feet)	FLOW GAINED (gpm)	COSTS (U.S.)
BRAIDBURN WELL FIELD				
B-4	8.0	20	160	$27,300
CANOE BROOK WELL FIELD				
CB-2	18.3	15	275	$27,000
CB-3	35.4	10	350	$18,000
CB-5	1.5	30	45	$12,000
SLOUGH BROOK WELL FIELD				
SB-1	1.5	30	45	$11,500
SB-4	1.2	27	32	$10,000
		TOTAL:	907 gpm	$105,800

Q/s - Specific Capacity in gallons per minute per foot of drawdown.
gpm - gallons per minute
Costs presented in U.S. dollars.

TABLE 5. AVERAGE COSTS FOR A NEW 800 GPM PRODUCTION WELL

	DRILLER	CONSULTANT
BORING & TEST WELL PROGRAM	$25,000	$15,000
PERMITING, SPECIFICATION & BID DOCUMENT PREPARATION, MEETINGS	0	$25,000
PRODUCTION WELL INSTALLATION AND TESTING	$128,000	$30,000
PIPING, PUMP, ELECTRICAL & MECHANICAL MODIFICATIONS	$118,000	$10,000
TOTAL COST PER WELL	$271,000	$80,000

Costs presented in U.S. dollars.


GENERAL LOCATION OF
STUDY AREA
STUDY
AREA
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OF
NEW JERSEY

FIGURE 1

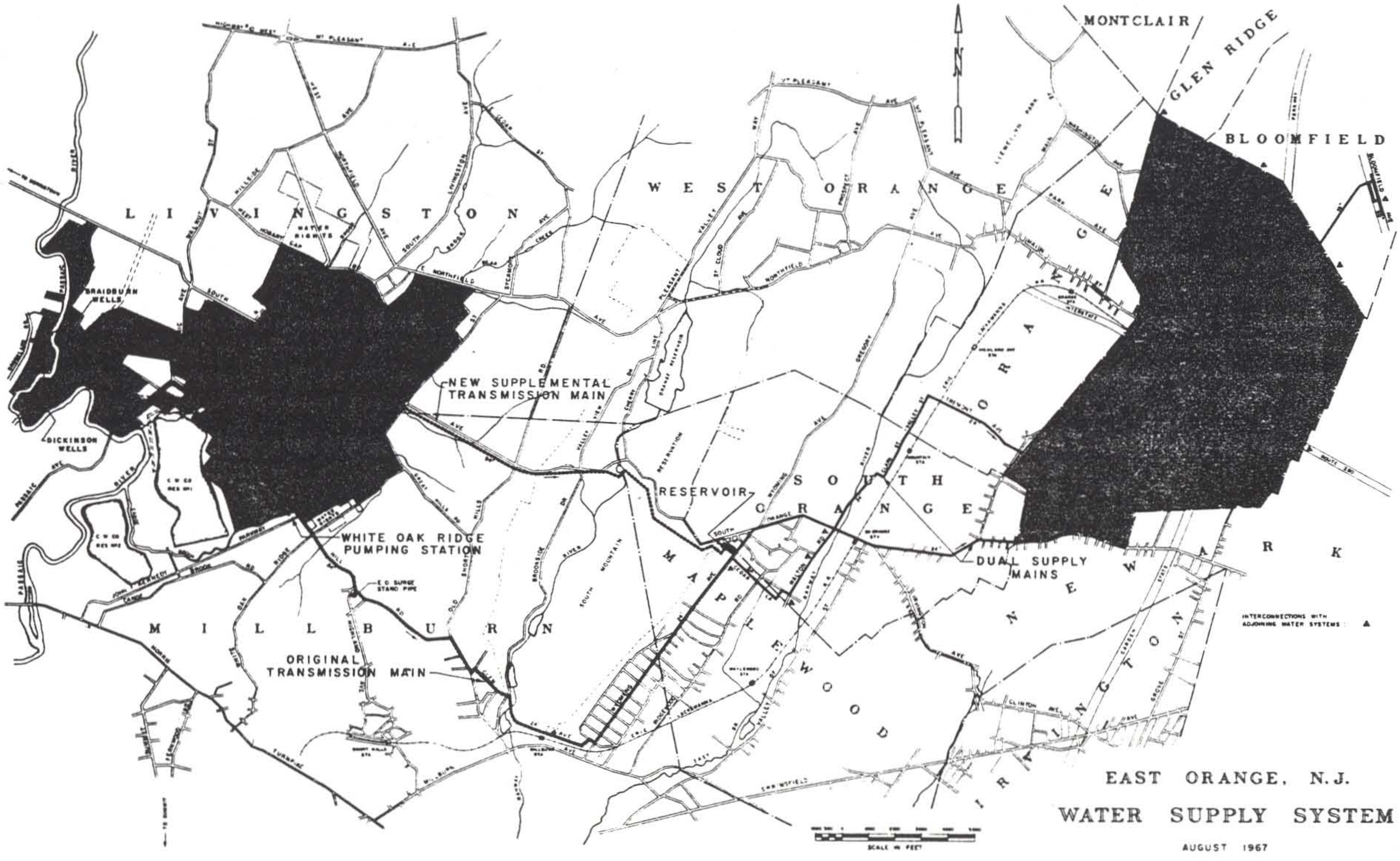
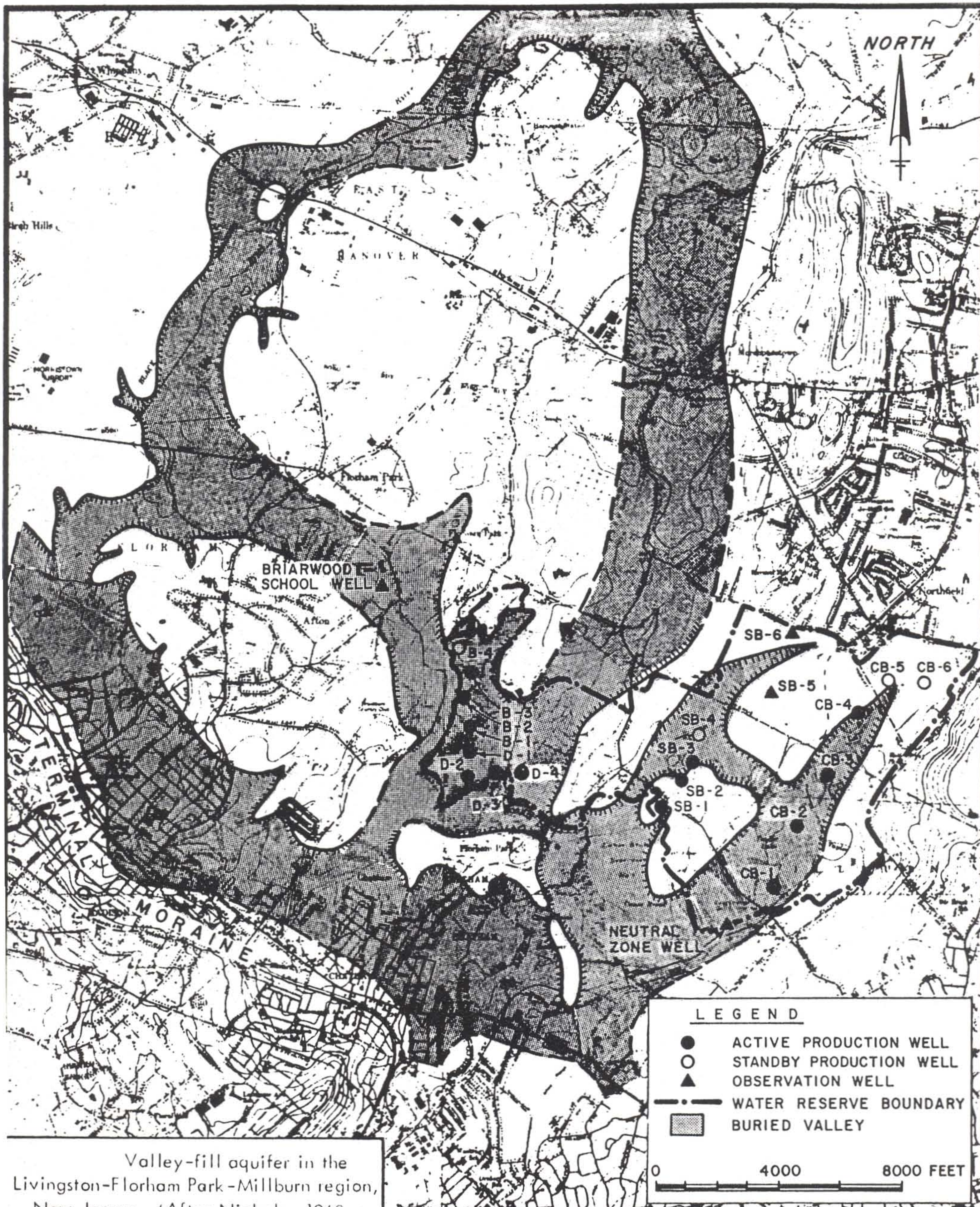
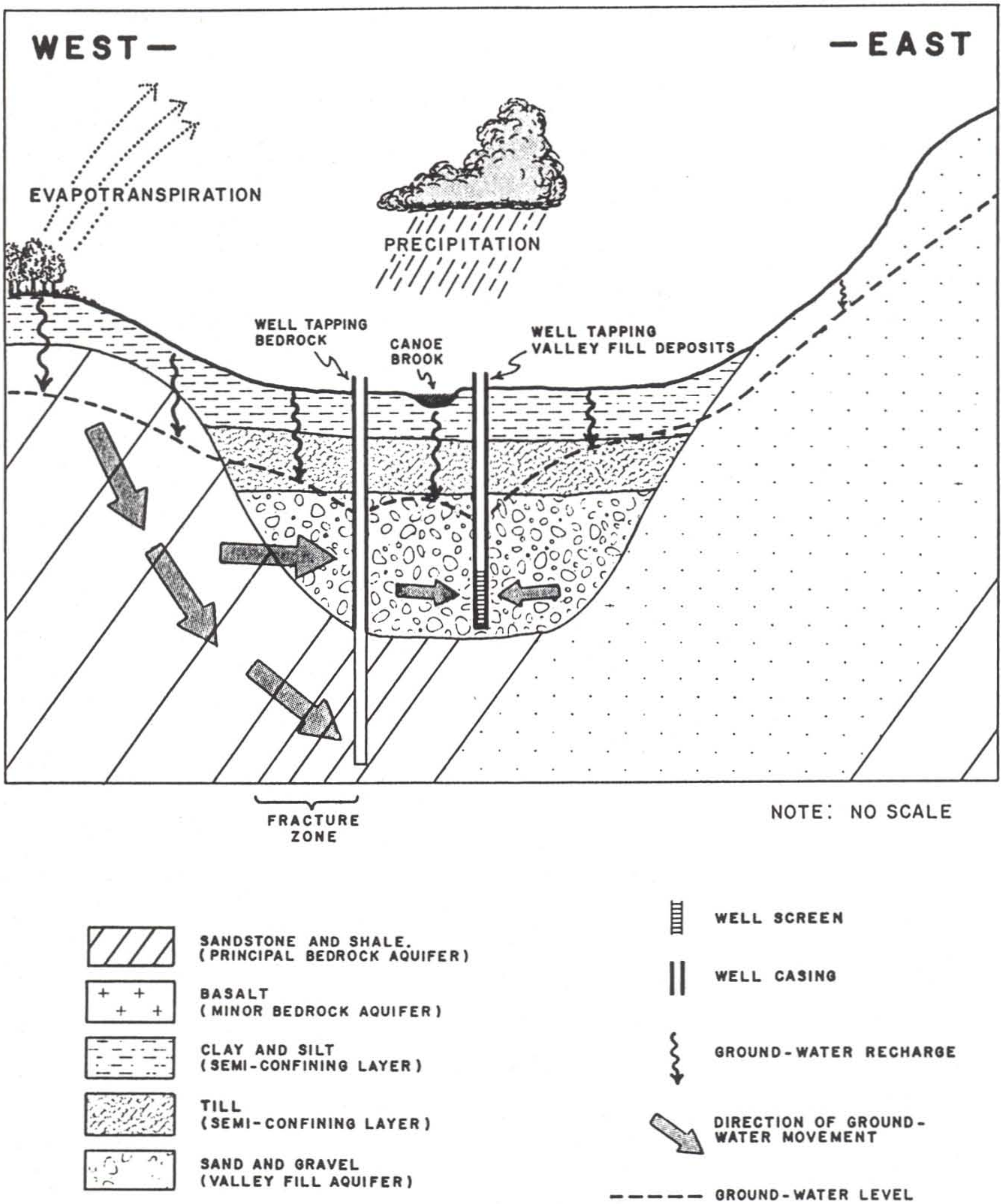

MONTCLAIR
GLEN RIDGE
BLOOMFIELD
W E S T O R A N G E
L I V I N G S T O N
BRAIDBURN WELLS
DICKINSON WELLS
NEW SUPPLEMENTAL TRANSMISSION MAIN
RESERVOIR
S O U T H O R A N G E
O R A N G E
WHITE OAK RIDGE PUMPING STATION
DUAL SUPPLY MAINS
N E W A R K
M I L L B U R N
ORIGINAL TRANSMISSION MAIN
M A P L E W O O D
I R V I N G T O N
INTERCONNECTIONS WITH ADJOINING WATER SYSTEMS
SCALE IN FEET
EAST ORANGE, N.J.
WATER SUPPLY SYSTEM
AUGUST 1967

FIGURE 2



Valley-fill aquifer in the Livingston-Florham Park-Millburn region, New Jersey. (After Nichols, 1968.)

FIGURE 3



Schematic diagram of the Canoe Brook valley ground-water system, City of East Orange Water Reserve.

FIGURE 4