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Geohydrology and Water Quality of Stratified-Drift Aquifers in the Lower Merrimack and Coastal River Basins, Southeastern New Hampshire

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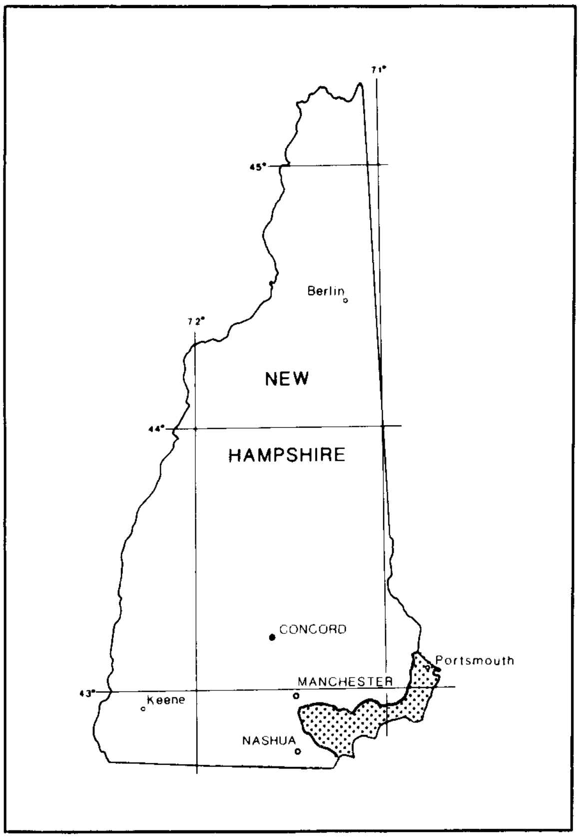
U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 91-4025



Prepared in cooperation with the

NEW HAMPSHIRE DEPARTMENT OF ENVIRONMENTAL SERVICES
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ponds. Figure 13 shows a typical seismic-reflection profile for a traverse across the western shore of Cobbetts Pond in a region of hydrologic connection between pond and aquifer. Hydraulic conductivity of the pond bottom was assumed to be 2 ft/d), and the thickness of the material was assumed to be 2 ft. These estimates were based on values calculated for riverbed deposits (Haeni, 1978; de Lima, 1989), and were assumed to be representative of the pond-bottom hydrology.

The final parameter, specific yield, was estimated to be 0.2 for this unconfined aquifer and was assigned to the entire model area.

Application of numerical model

Five wells were simulated in the model and pumped at various rates until the limits for drawdown were attained at the end of 180 days. Five wells were needed because the model cells that contained the pumped wells went dry if the total discharge simulated was distributed among fewer wells. The locations of the wells and resultant drawdowns are shown in figure 17. The combined pumping rate of the five wells, 0.64 Mgal/d, represents the estimated potential yield of the basin. The potential yield as used in this report describes the rate at which water can be withdrawn from a basin under conditions of pumping for 180 days without recharge and without having adverse impacts on the water resource (see glossary).

Sensitivity analysis

A sensitivity analysis of some of the model parameters was done to show the effect these parameters have on estimates of potential yield. The analysis determined the relative importance of input data values on calculations of potential yield and provided a basis for assessing uncertainty in the simulations given the likely range in each value.

The principal input parameters of aquifer hydraulic conductivity, pond-bottom conductance, specific yield, and duration of pumping were independently increased and decreased by a constant factor throughout the modeled area while other parameters were left unchanged. A reference simulation was selected to represent the best estimate of the hydrologic properties of the aquifer. This reference serves as a standard from which subsequent simulations with different input values can be compared. The amount of adjustment of each parameter differed according to the likely range of each parameter.

The results of the analysis of each change in parameter value are shown in figures 18 and 19 for an east-west profile along column 44 (fig. 15). The profile includes the hypothetical production well of largest simulated discharge (0.135 Mgal/d) and represents an area of the model (column 44, row 11) where the greatest difference in drawdowns occurred between simulations. The computed percentage changes in storage and leakage and the drawdowns for each simulation are listed for comparison in table 5. It should be emphasized that these data represent changes in two of three components of recharge, aquifer storage, and pond and river leakage. Not represented is the change in recharge from till and bedrock uplands, which is commonly simulated in numerical ground-water flow models. The superposition technique, however, simplifies the flow regime by simulating the till-aquifer boundary as "no flow", where additional flow is not induced across this boundary. The tabulated results, therefore, are intended only to show relative differences in the simulations.

Aquifer hydraulic-conductivity (K_a) values were multiplied by factors of 1 (model standard), 2, and 0.5 in three separate simulations. Doubling the hydraulic conductivity of the aquifer resulted in a 32-percent overall reduction in drawdown at production wells and a decrease in the natural ground-water flow to the ponds. The reduction in drawdown extended generally to a distance of 1,500 ft from well locations, beyond which drawdowns were slightly greater than at corresponding cells in the model standard.

Reducing the hydraulic conductivity by 0.5 had the greatest effect on drawdown at well locations for these simulations. Overall, drawdown increased by 57 percent at production wells, and a greater percentage of water came from aquifer storage. Drawdowns decreased slightly relative to the model standard near the till-aquifer boundaries.

Pond-bottom conductance (K_b) values were multiplied by factors of 1 (model standard), 10, and 0.1 in three separate simulations. These changes resulted in computed heads that were identical to those of the model standard. No change in the proportions of water derived from the two sources (table 5) was observed. The insensitivity of the model shows that pond leakage is not the primary control on the availability of water to the simulated production wells, even though one simulated production well was within 600 ft of Cobbetts Pond. The results are probably a reflection of (1) limited

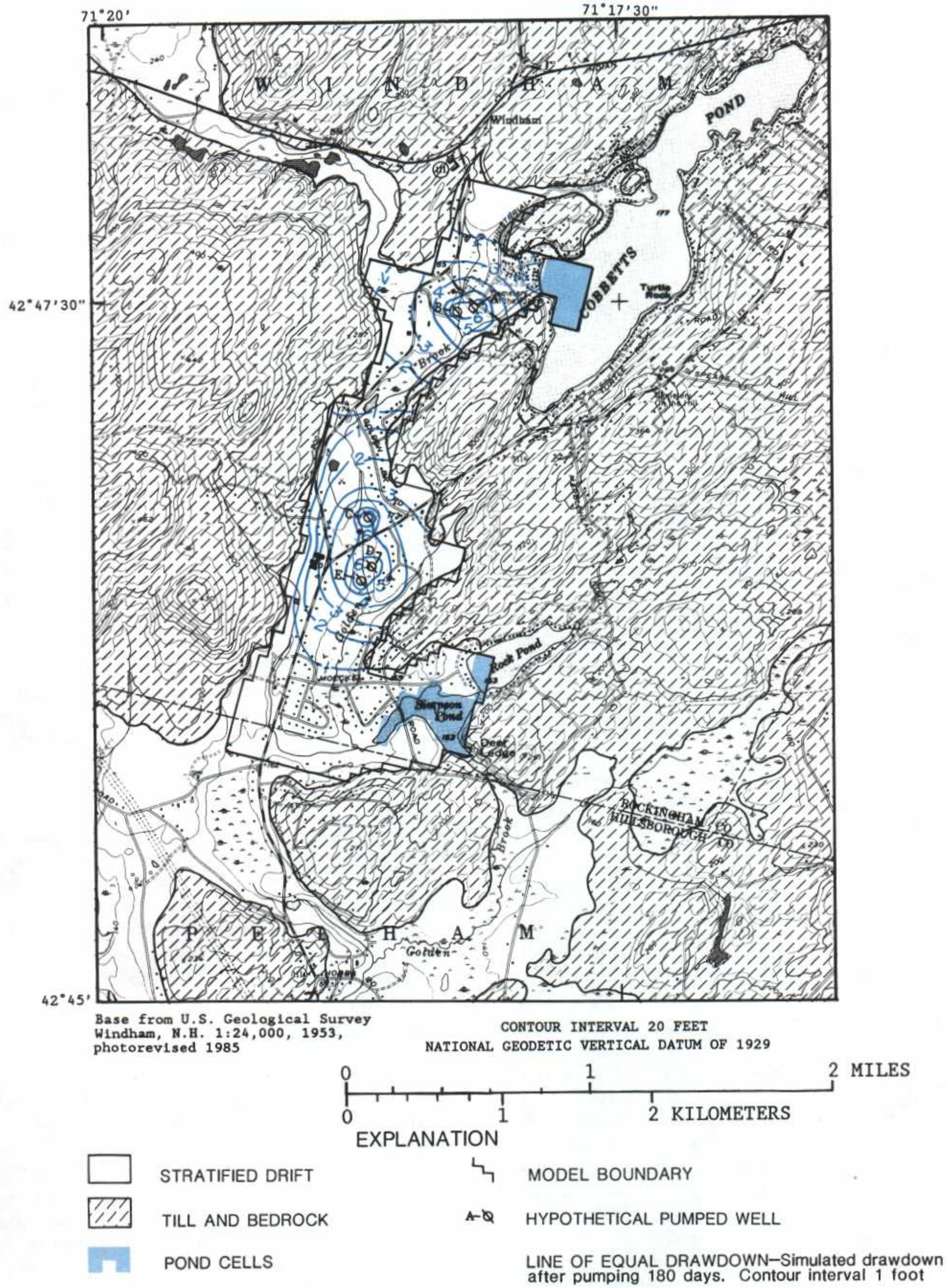


Figure 17.--Drawdown resulting from pumping five hypothetical wells completed in the Windham-Cobbetts Pond aquifer after pumping at a combined rate of 0.64 million gallons per day for 180 days.

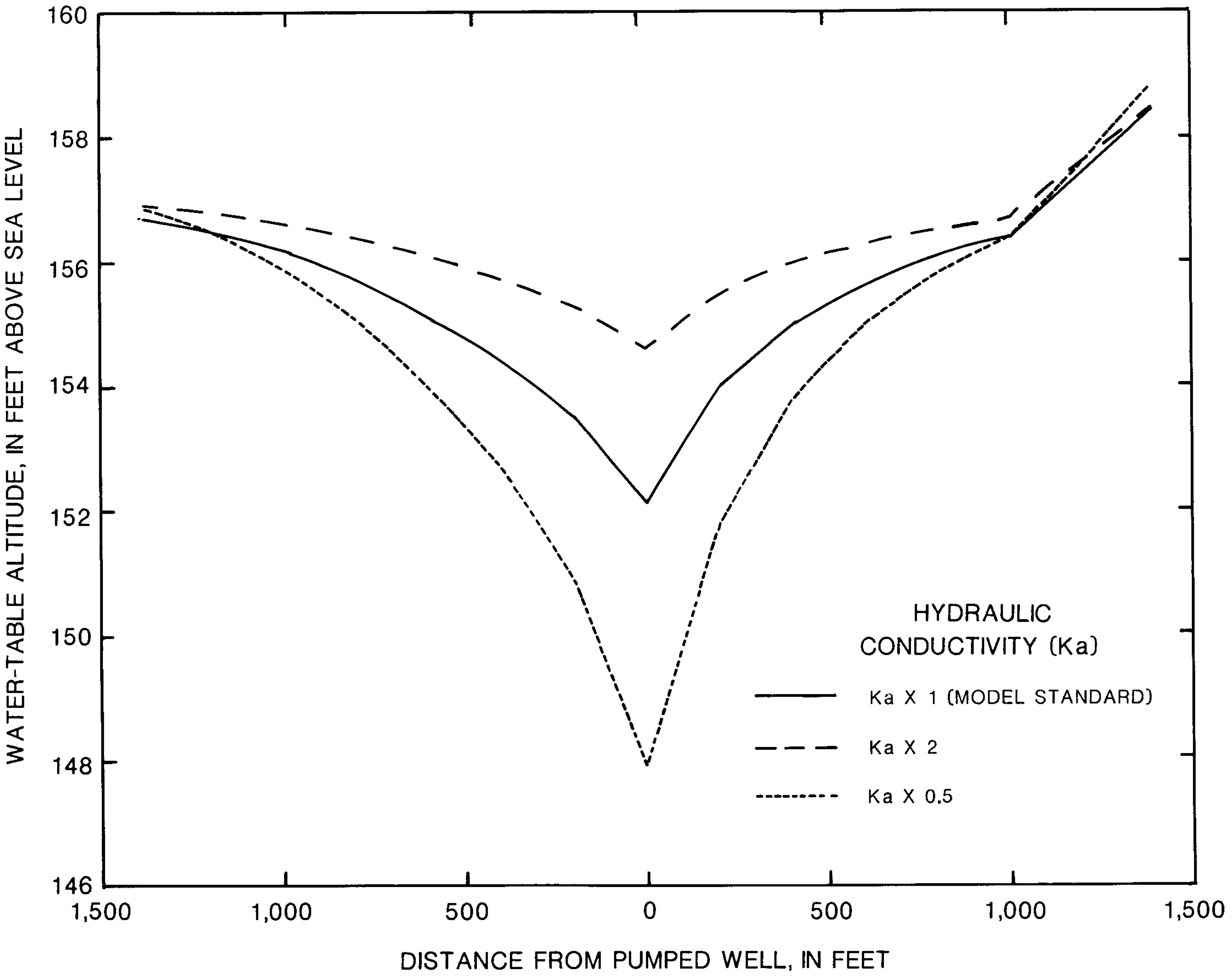


Figure 18.--Effects of varying hydraulic conductivity on results at hypothetical well D from the Windham-Cobbetts Pond model.

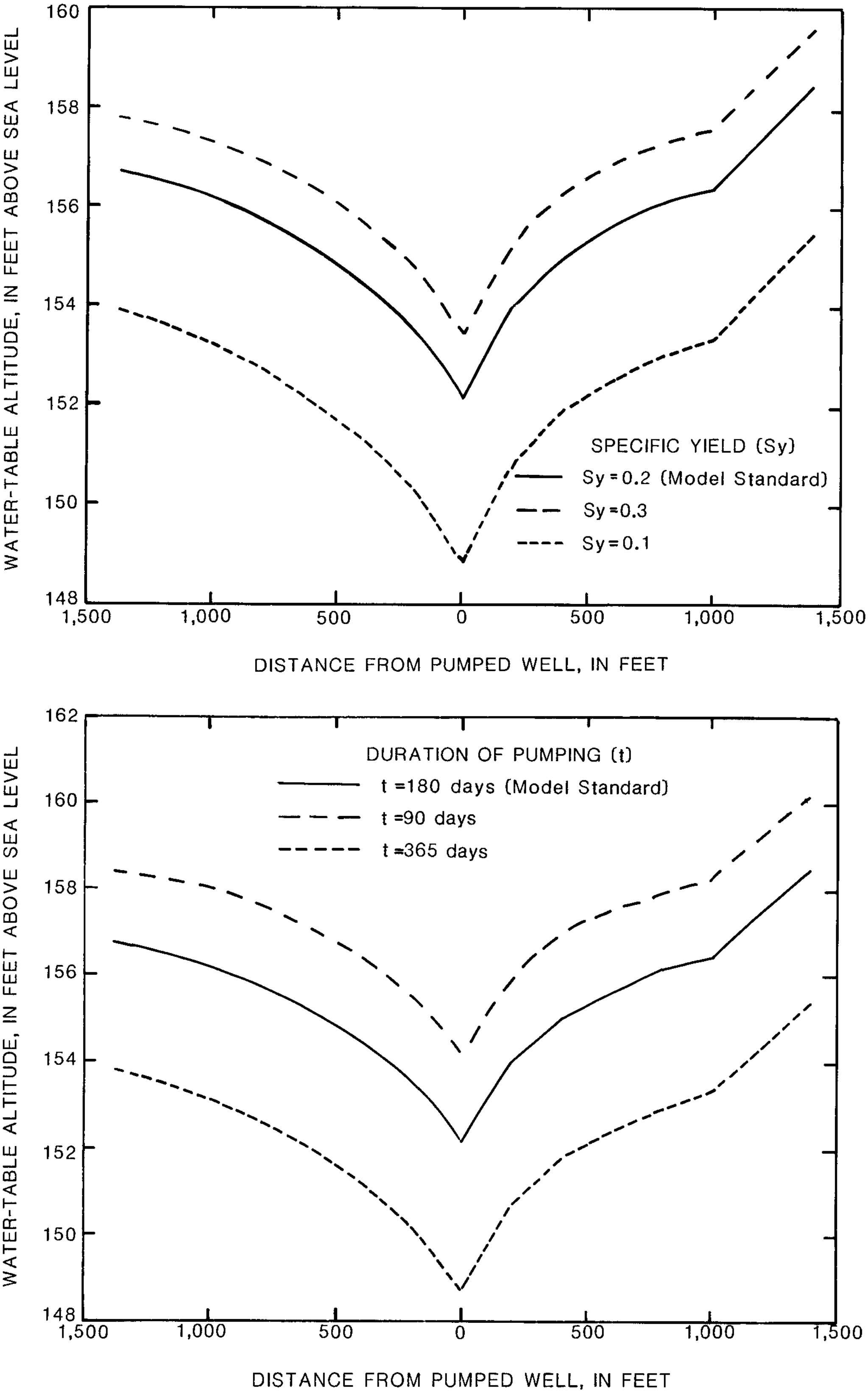


Figure 19.--Effects of varying specific yield and duration of pumping on results at hypothetical well D from the Windham-Cobbetts Pond model.

Table 5.--*Summary of aquifer-evaluation results showing sensitivity of model parameters*

[Mgal/d, million gallons per day; ft, feet; K_a, horizontal hydraulic conductivity; K_b, pond- and river-bottom conductance; S_y, specific yield; t, duration of pumping, in days; --, simulation failure, no values computed]

Model parameters	Change in storage (Mgal/d)	Change in flux to surface water[1] (Mgal/d)	Percentage of change in storage	Percentage of change in ground-water flux to surface water	Average drawdown at production wells[2] (ft)	Percentage difference from model standard in drawdown at production wells
Windham-Cobbetts Pond aquifer						
Model standard[3]	0.60	0.04	94	6	7.6	--
$K_a \times 2$	.57	.07	90	10	5.2	32
$K_a \times 0.5$	.62	.02	97	3	12	-57
$K_b \times 10$	.60	.04	94	6	7.6	0
$K_b \times 0.1$	.60	.04	94	6	7.6	0
$S_y \times 0.3$	.61	.03	96	4	6.4	16
$S_y \times 0.1$	.57	.07	90	10	10.7	-41
t = 90	.62	.02	97	3	5.7	25
t = 365	.57	.07	89	11	10.3	-36
Kingston-Powwow River aquifer						
Model standard[4]	.48	3.52	12	88	8	--
$K_a \times 2$	.36	3.64	9	91	4.2	48
$K_a \times 0.5$	--	--	--	--	--	--
$K_b \times 10$	.36	3.64	9	91	7.1	11
$K_b \times 0.1$	1.27	2.73	32	68	11.1	-39
$S_y = 0.3$	.63	3.37	16	84	7.8	3
$S_y = 0.1$	.29	3.71	7	93	8.2	-3
t = 90	.75	3.25	19	81	7.6	5
t = 365	.29	3.71	7	93	8.2	-3

[1] Includes induced infiltration and ground water captured before it reaches surface-water bodies.

[2] Computed (by use of equation 3) as the average drawdown for all production wells in the simulation.

[3] Simulation with five wells pumping at a combined discharge of 0.64 Mgal/d.

[4] Simulation with eight wells pumping at a combined discharge of 4.0 Mgal/d. Model parameters represent best estimates of the natural system, $K_a \times 1$, $K_b \times 1$, $S_y = 0.2$, and t = 180 days.

ground-water flow in the narrow section of stratified drift that connects Cobbetts Pond to the aquifer and (2) the distance separating the wells from Simpsons pond.

Specific yield (S_y) was set equal to 0.2 (model standard), 0.3, and 0.1 in three separate simulations. Simulated drawdowns were sensitive to small changes in the specific yield. An increase in specific yield to 0.3 had a large effect, reducing drawdowns not only at well locations but also throughout the modeled area (fig. 19). By decreasing the specific yield to a value of 0.1, drawdowns increased considerably throughout the aquifer as less water was held in storage, and pumping stress affected a large part of the aquifer.

Duration of pumping (t) values of 180 days (model standard), 90 days, and 365 days were used in three separate simulations. The effect of changing the transient simulation from 180 days to shorter and longer periods was also evaluated. As expected, the simulations indicated that overall drawdown in the aquifer was less after 90 days than after 180 days. The simulation for 365 days showed a significant decrease in head relative to the model standard as aquifer storage became depleted. Numerical oscillation and convergence were problems in the 365-day simulation as some model cells near till-aquifer borders went dry.

Application of analytical method

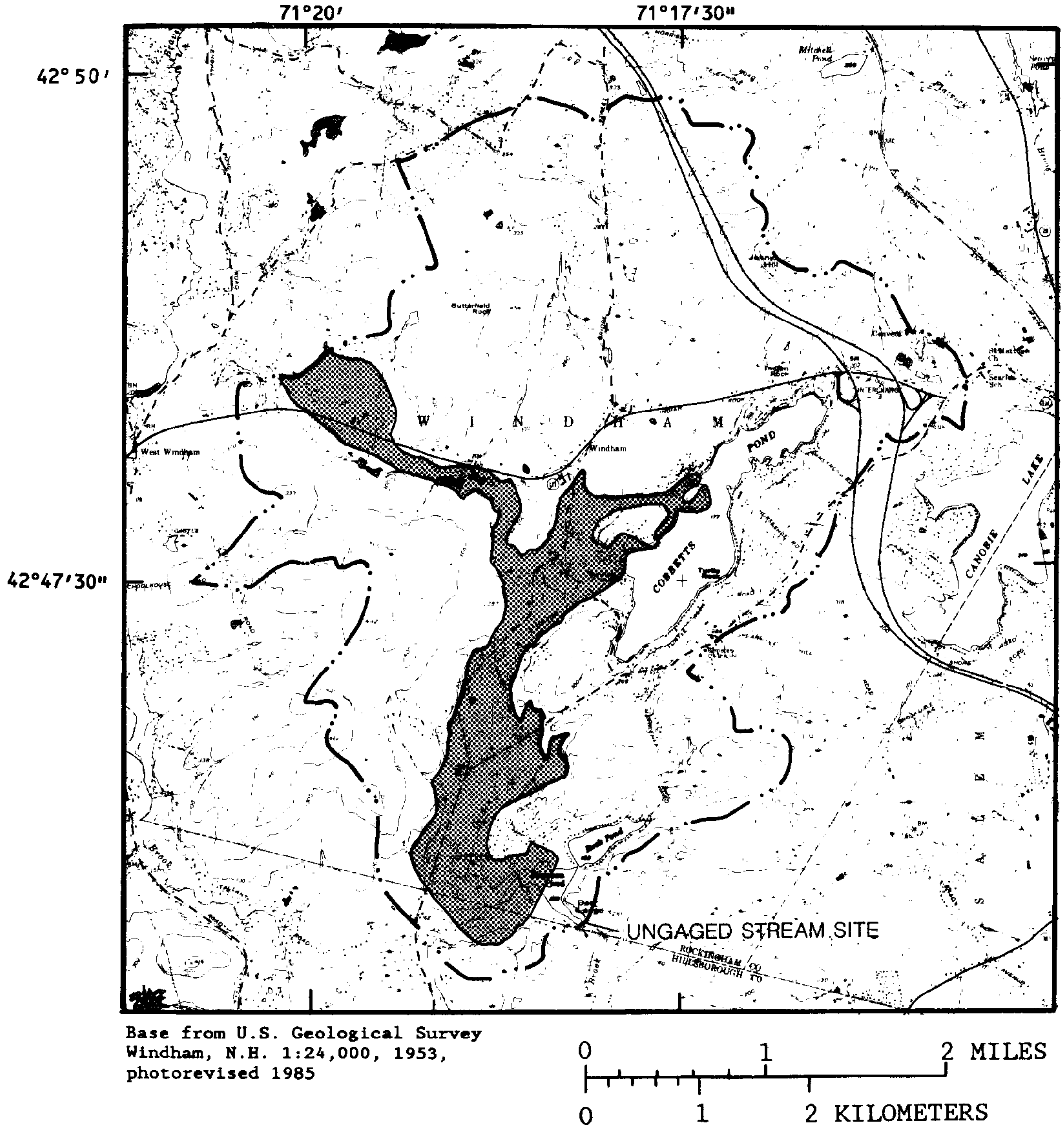
Application and results of the analytical method to estimate potential yield for this valley aquifer are shown in figure 20. The segment of the map used in figure 20 was taken from plate 1, which shows stratified-drift aquifer boundaries for the western part of the study area. Because this map has contours indicating altitude of land surface and shows areas underlain by stratified drift, it is the only map required for estimating aquifer yield. An estimate of 1.3 ft^3/s or 0.84 Mgal/d for the $Q_{7,10}$ is obtained by use of this method. This is slightly larger than the potential-yield estimate of 0.64 Mgal/d determined from the numerical model. Together, the analytical and numerical results indicate that this small basin of thin stratified drift is capable of yielding less than 1 Mgal/d but probably more than 0.5 Mgal/d under long-term pumping. These estimates are based on a conservative withdrawal scheme that makes use of available storage and does not influence pond stages.

Well-capture area

Well-capture areas were constructed by use of the method of superposition and information shown in figures 16 and 17. Figure 16 shows the configuration of the initial water table and figure 17 shows the drawdown contours constructed from drawdowns computed from the two-dimensional numerical model. The result of superimposing drawdowns on the initial water-table altitudes is shown in figure 21. Because topographic maps with a (10-20 ft) contour interval were used for vertical control to construct the water-table maps and natural water-level fluctuations up to 5 ft may occur in the coarse-grained stratified-drift aquifers (fig. 12) the uncertainty of water levels shown in figures 17 and 21 is approximately 10 ft. The shaded area in figure 21 is the area contributing ground water to the wells after 180 days of pumping. The contributing area is assumed to extend into the till uplands where the shaded areas reach the till-aquifer boundary. This assumption is considered reasonable because the drawdowns calculated by the model were minor (4 ft or less) at the "no-flow" boundaries such that the condition of no additional flow across the model boundary is reasonably met. The effect of allowing these minor (4 ft) or less drawdowns at model boundaries is to estimate a contributing area that is slightly larger than what would be estimated if no drawdowns occurred at model boundaries. The size of the contributing area is about 0.9 mi^2 within the model-area boundaries. An additional 1.6 mi^2 of till uplands outside of the model boundaries is estimated to contribute water to the wells. Most evident from this analysis is that the size of the estimated contributing area (2.5 mi^2) is much larger than the area encompassed by the 400-foot protective radius currently required by New Hampshire State law.

Kingston-Powwow River Aquifer

The Kingston-Powwow River aquifer, in Kingston is the largest continuous aquifer in the study area and is an example of an outwash plain composed of well-sorted glaciofluvial sand and gravel materials. Presently, this ground-water resource is undeveloped as a public supply; most town residents are served by individual home wells. A major hydrologic feature of the Kingston-Powwow River aquifer is the extensive area of surface water in contact with permeable stratified-drift deposits.



Base from U.S. Geological Survey
Windham, N.H. 1:24,000, 1953,
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CONTOUR INTERVAL 20 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

EXPLANATION

▨ COARSE-GRAINED STRATIFIED DRIFT

··——·· DRAINAGE-BASIN DIVIDE

EXAMPLE

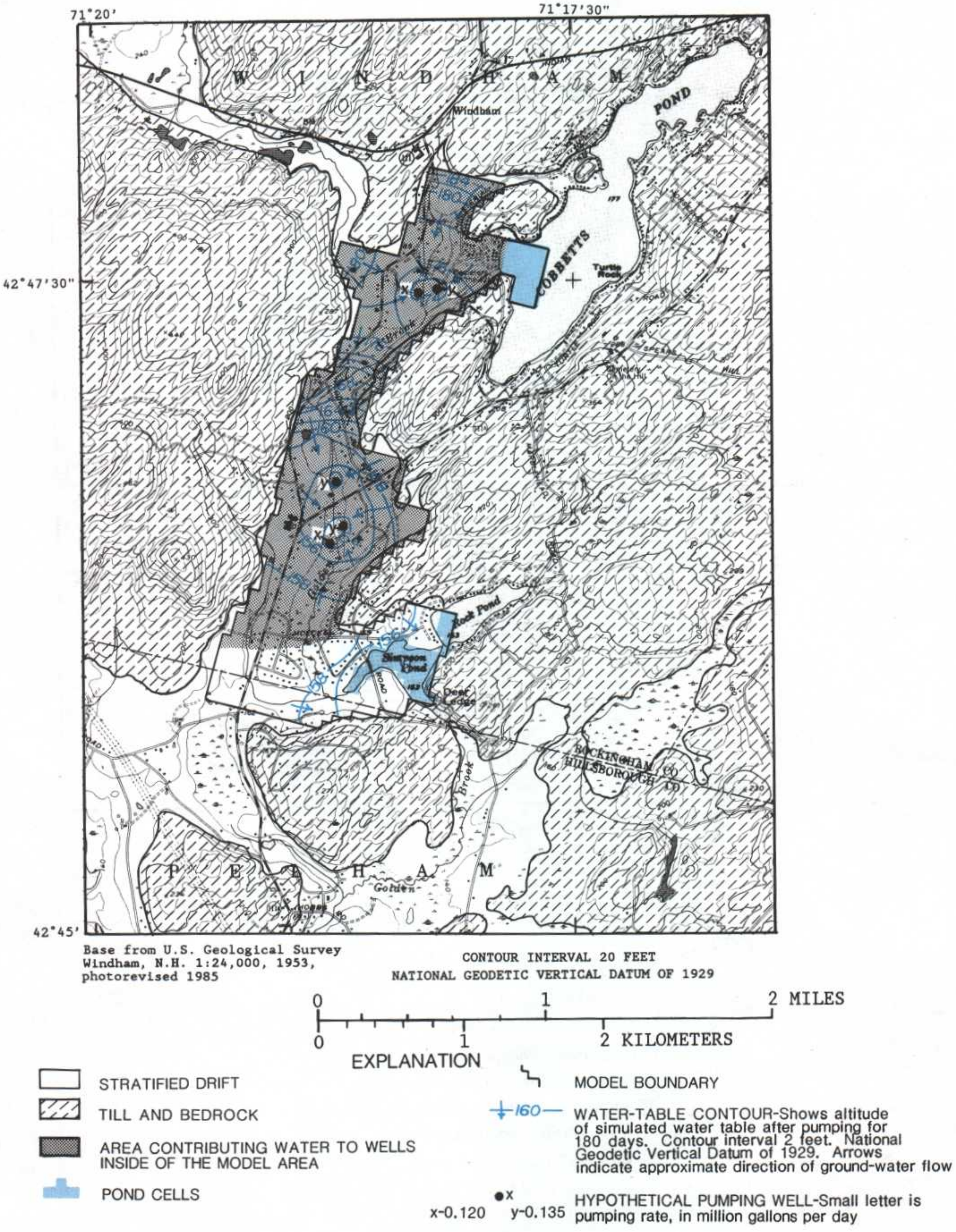
1. Drainage-basin divide is drawn on map
2. Area enclosed by divide is measured as 11.5 square miles
3. Area of coarse-grained statified drift is measured as 1.8 square miles
4. Using the following equation:

$Q_{7,10}$ is 0.67 A_{sd} + 0.01 A_{till},

$Q_{7,10}$ is 0.67(1.8) + 0.01(9.7)

$Q_{7,10}$ is 1.3 cubic feet per second or 0.84 millions gallons per day

Figure 20.--Method of determining potential yield of aquifer from the 7-day, 10-year low-flow estimate at an ungaged stream site.



Base from U.S. Geological Survey
Windham, N.H. 1:24,000, 1953,
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CONTOUR INTERVAL 20 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

EXPLANATION

☐	STRATIFIED DRIFT
▨	TILL AND BEDROCK
▩	AREA CONTRIBUTING WATER TO WELLS INSIDE OF THE MODEL AREA
🟦	POND CELLS
┐	MODEL BOUNDARY
—160—	WATER-TABLE CONTOUR-Shows altitude of simulated water table after pumping for 180 days. Contour interval 2 feet. National Geodetic Vertical Datum of 1929. Arrows indicate approximate direction of ground-water flow
●x x-0.120 y-0.135	HYPOTHETICAL PUMPING WELL-Small letter is pumping rate, in million gallons per day

Figure 21.--Calculated water-table configuration based on simulated drawdown after 180 days of pumping from the Windham-Cobbetts Pond aquifer.

Three ponds--Great, Powwow, and Country Ponds--overlie glaciofluvial stratified drift and cover 1.6 mi^2 or 17 percent of the total aquifer surface. The Powwow River connects the ponds and is regulated by the Trickling Falls dam at the eastern shore of Powwow Pond. The ponds and river are a major control of the regional ground-water-flow system and locally receive both surface-water and ground-water discharge (pl. 7A). Surface-water outflow from this system is regulated to maintain a constant water level in the ponds throughout the recreation season (from March through October). The river and the ponds could probably supply abundant induced recharge to properly located wells.

The Kingston-Powwow River aquifer was modeled and evaluated by use of the same numerical and analytical methods described for the Windham-Cobbetts Pond aquifer. The finite-difference grid used to discretize the aquifer is shown in plate 7B. The grid consisted of 122 rows and 118 columns with uniform cell dimensions of 200 ft on a side. The active model area was 9.4 mi^2.

Boundary conditions

The external boundaries of the model (pls. 7A and 7B) coincided with surface-water divides or with the geologic contact between the aquifer and either till or silts and clays (pl. 5). These areas were simulated as no-flow boundaries; no change in flow across the boundary was assumed to occur during pumping.

The bottom boundary of the aquifer is the contact between highly permeable stratified drift and the less permeable till, bedrock, or fine-grained marine deposits. This boundary also was treated as a no-flow boundary in the model. Some leakage probably occurs across this boundary in the aquifer, but it is assumed to be small relative to the flow in the aquifer.

The internal boundaries include the Powwow River, till and bedrock outcrops, and Great, Powwow, and Country Ponds. The river and ponds were treated as river cells that simulate a leaky boundary. Till and bedrock outcrops that rise above the outwash plain were simulated as no-flow boundaries. The locations and types of all boundaries simulated are shown in plate 7A.

Aquifer parameters

Parameters assigned to the model were derived from similar sources and procedures as those used for the Windham-Cobbetts Pond aquifer. Maps of transmissivity and saturated thickness (pl. 5) were used to assign values of hydraulic conductivity in the model. The water-table and surface-water elevations were set equal to zero throughout the model area. Depths of the river and ponds were determined from seismic-reflection data. Vertical hydraulic conductivities of river and pond-bottom sediments (river and pond-bottom conductance) were assumed to be 2 ft/d, and the thickness of material was assumed to be 2 ft. Specific yield was estimated to be 0.2 over the entire modeled area.

Application of numerical model

Eight wells were introduced to the model and pumped at various rates until the predetermined limits for drawdown were attained. Wells were located within 600 ft of surface-water bodies because of the increased recharge that would be available from induced infiltration. Plate 7C shows the location of these hypothetical production wells and the drawdown simulated after 180 days of pumping. The combined pumping rate of the eight wells, 4.0 Mgal/d, represents the estimated potential yield of the aquifer. The number of hypothetical wells was the maximum feasible given present knowledge and practical considerations. Production wells simulated elsewhere either yielded small volumes that would be impractical for public or commercial water systems or failed to meet the siting criteria.

Sensitivity analysis

A sensitivity analysis was also done for the Kingston-Powwow River model to test the sensitivity of model results to changes in input parameters. The parameters and ranges in values selected were the same as those used for the Windham-Cobbetts Pond aquifer model.

The results of the analysis of each change in parameter value are shown in figures 22 and 23 for an east-west profile along row 47. The profile includes the production well with the highest simulated discharge (1.0 Mgal/d) and represents an area of the model where the largest difference in drawdowns occurred between simulations. Changes in natural ground-water flow to surface water and storage, as well as drawdowns for each simulation, are listed for comparison in table 5. These data were computed in the same way as for the Windham-Cobbetts Pond aquifer and offer a basis

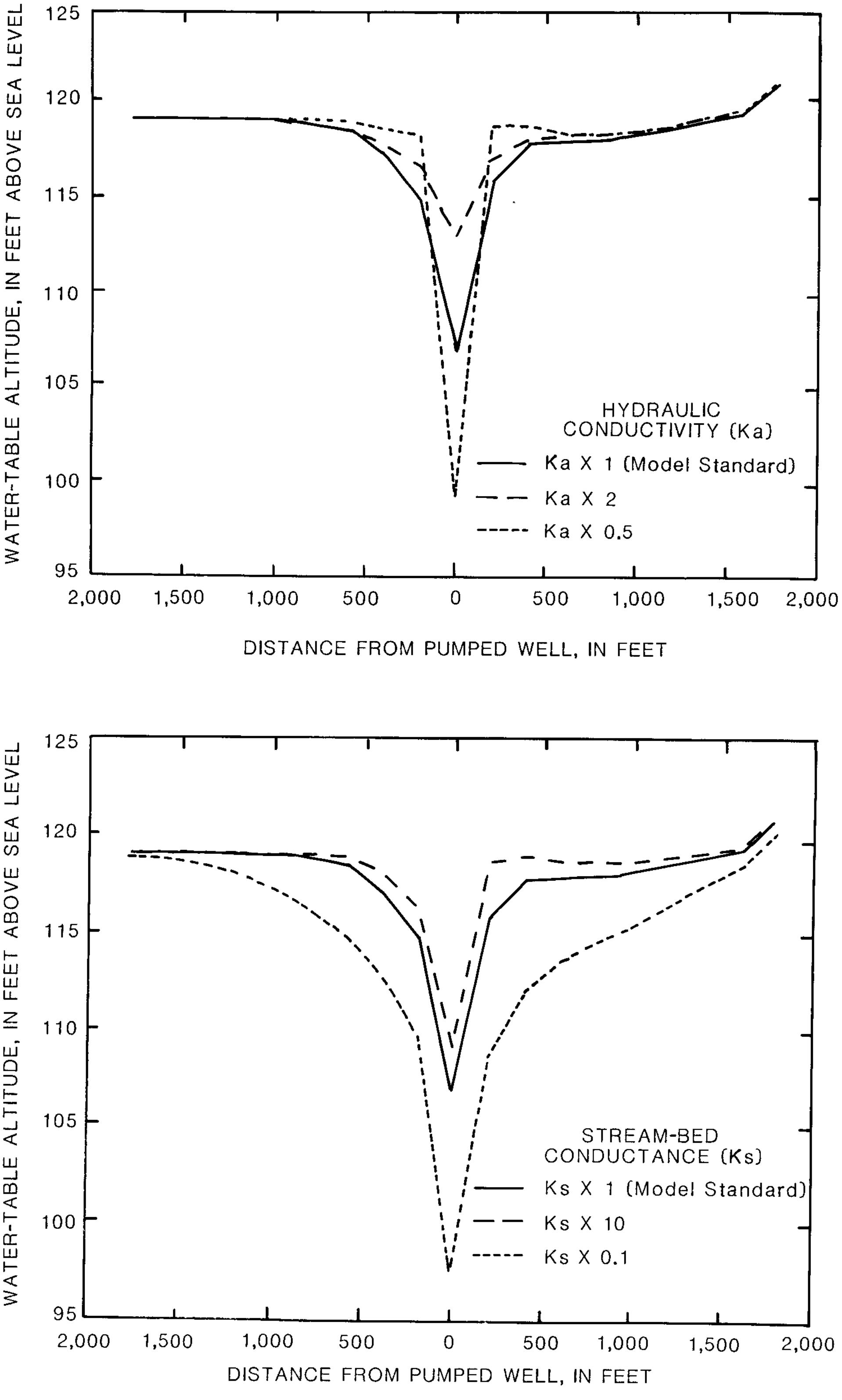

Figure 22.--Effects of varying hydraulic conductivity and streambed conductance on results from the Kingston-Powwow River model.

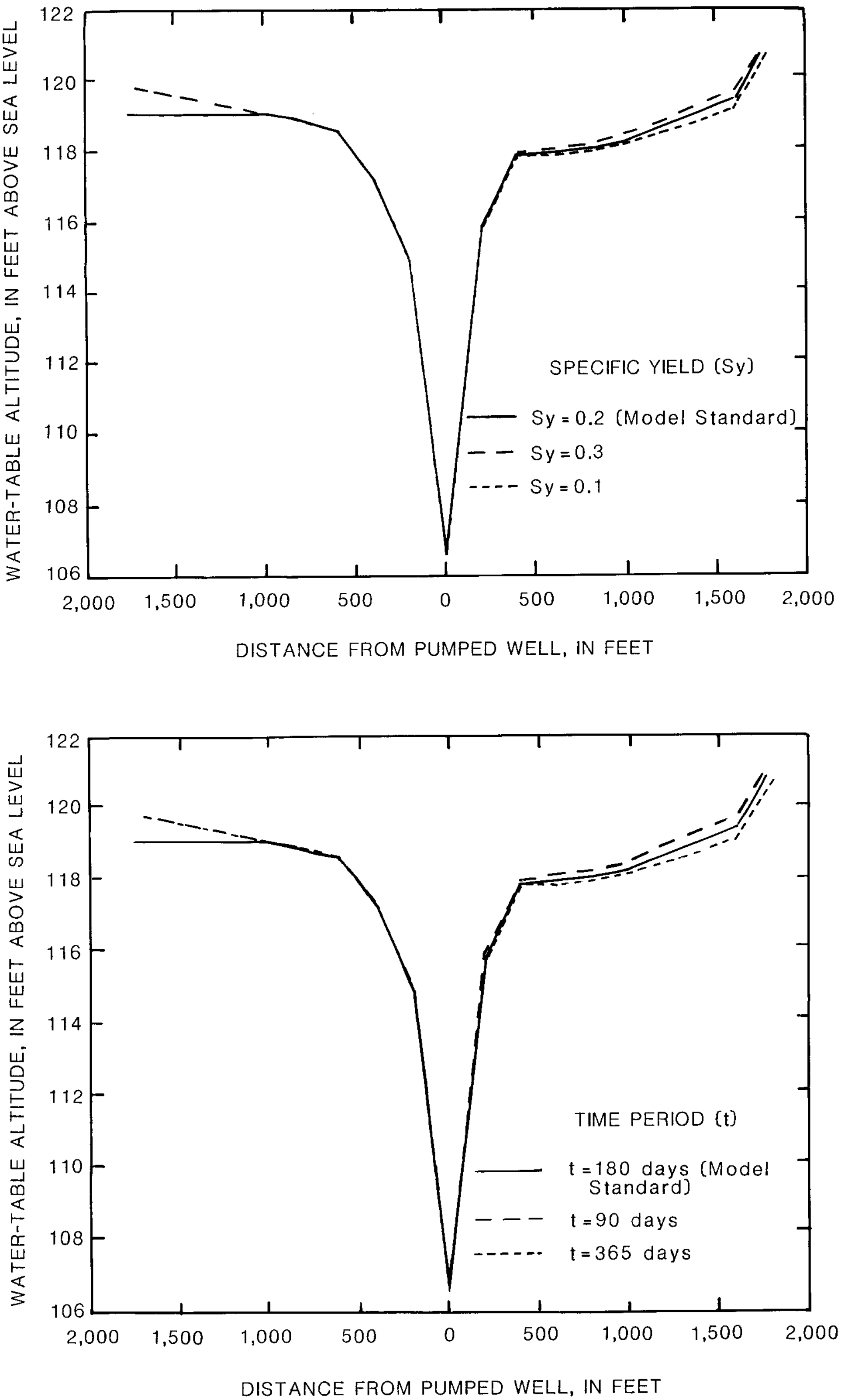

Figure 23.--Effects of varying specific yield and duration of pumping on results from the Kingston-Powwow River model.

for the comparison of results between the two aquifers.

Aquifer hydraulic-conductivity (K_a) values were multiplied by factors of 1 (model standard), 2, and 0.5 in three separate simulations. Results indicated that changes in hydraulic conductivity have a large effect on the ground-water flux to the river and ponds. An increase in hydraulic conductivity by a factor of 2 resulted in a slight reduction in the ground-water flow to the river and ponds and (or) a small increase in the induced recharge from these surface-water sources. This simulation had the greatest effect on reducing the drawdown at the pumping centers, a 48-percent reduction relative to the standard simulation.

Reducing the hydraulic conductivity by 0.5 resulted in drawdowns that exceeded the model constraints and dried up two of the eight wells. This model, therefore, appears to have been sensitive to reductions in hydraulic conductivity, as was the Windham-Cobbetts Pond aquifer model. In the Kingston-Powwow River aquifer, a smaller proportion of the recharge to wells came from aquifer storage than from the capture of ground-water flow before it reached the surface-water sources and (or) from induced infiltration. The siting of hypothetical production wells in thick saturated areas close to ponds and rivers, therefore, was necessary to achieve maximum yields.

River and pond-bottom conductance (K_b) values were multiplied by factors of 1 (model standard), 10, and 0.1 in three separate simulations. Increasing the bottom conductance by a factor of 1 and 10 had only a small effect. Simulated heads rose less than 1 ft, and the ground-water flux across the river and pond bottoms changed only slightly. The insensitivity of the model indicated that use of the standard conductance causes the leaky boundary to be, effectively, a constant-head boundary that poses no limit to the amount of surface water available for induced recharge to the wells.

Much greater changes in model results occurred when the bottom conductance was decreased by a factor of 10. Heads within 2,000 ft of the wells decreased by an average of 2 ft and, a greater proportion of water was derived from aquifer storage. These results contrast sharply with findings from the Windham-Cobbetts Pond model, for which bottom conductance had no affect on computed head values. The results underscore the importance of accurately determining bottom-conductance values for aquifer systems where induced infiltration is the primary source of water.

Specific yield (S_y) was set equal to 0.2 (model standard), 0.3, and 0.1 in three separate simulations. The change in specific yield had only a small effect on computed heads and ground-water discharge in the model. Specific yield equal to 0.3 resulted in a greater proportion of water being derived from aquifer storage and head values that were somewhat greater than for corresponding cells in the standard simulation. By decreasing specific yield to 0.1, heads decreased by less than 0.5 ft at well locations because less water was available from aquifer storage and a greater proportion was derived from capture of ground-water flow and (or) induced recharge from surface water.

Duration of pumping (t) values of 180 days (model standard), 90 days, and 365 days were used in three separate simulations. Duration of pumping had little effect on model results. Drawdowns simulated at well locations were slightly less after 90 days of pumping than after 180 days, and a greater percentage of the total withdrawal was derived from aquifer storage. Increasing the duration of pumping to 365 days had less effect on drawdowns at pumping centers; the average increase in drawdown was only 0.2 ft for the eight wells in the simulation. This minimal drawdown effect contrasts with the results from the Windham-Cobbetts Pond model, which was more sensitive to pumping duration because of the relative lack of hydrologic interconnection between ponds and aquifer.

Application of analytical method

The potential yield was also evaluated by use of the analytical method discussed previously. The percentage of drainage basin underlain by coarse-grained stratified drift is 32 percent and represents an area of 9.4 mi^2. The area of till-covered bedrock in the basin upgradient from the aquifer is 19.8 mi^2. By use of this information and equation 2, the potential yield for the Kingston-Powwow River aquifer is estimated to be 6.5 ft^3/s or 4.2 Mgal/d. This value compares favorably with the potential-yield estimate of 4.0 Mgal/d determined from the numerical model. These estimates indicate that this large aquifer is capable of supplying about 4.0 Mgal/d under long-term pumping.

Well-capture area

Simulated drawdowns after 180 days of pumping were superimposed on the initial water table to estimate the water-table configuration under long-term pumping (pl. 7D). The area of measurable drawdown extends to the external model boundaries and is similar to, but not identical with, the contributing area. The size of the contributing area is estimated to be 4.9 mi^2 and represents 52 percent of the active model area. Clearly, this exceeds the area determined by the 400-ft protective radius (0.144 mi^2 for eight wells) as required by New Hampshire regulations.

LOCATIONS AND DESCRIPTIONS OF SELECTED STRATIFIED-DRIFT AQUIFERS

Stratified-drift aquifers at Derry-Island Pond, Windham-Cobbetts Pond, Kingston-Powwow River, North Hampton-Knowles Pond and central Greenland (pls. 1-3), are considered to be favorable stratified-drift aquifers in the study area for developing new ground-water supplies. These favorable ground-water areas meet the following criteria: (1) the aquifer is generally composed of well-sorted sand and gravel, (2) the aquifer has a saturated thickness of 40 ft or more, and (3) the aquifer is either undeveloped or the full potential yield of the ground-water resource has not been attained by present pumpage. Many other areas underlain by well-sorted stratified drift may also yield large quantities of ground water; however, they either will probably not sustain yields of 0.5 Mgal/d or more or they are currently developed to near their maximum potential yields.

Preliminary estimates of the quantity of water potentially available in ground-water areas is considered to be the sum of (1) the amount of precipitation that falls directly on the aquifer and becomes ground water, (2) water from adjacent areas of till and bedrock that enters the sand and gravel aquifer, and (3) streamflow across the aquifer that might be induced to infiltrate the sand and gravel. Methods for evaluating each of these recharge sources have been discussed previously in the section on "Recharge."

Derry-Island Pond Aquifer

A delta consisting of well-sorted sand and gravel forms a flat-topped triangular plain at the confluence of Taylor Brook and Island Pond in eastern Derry (pl. 1). During deglaciation, meltwater streams flowed in the narrow linear valley of Taylor Brook and carried stratified sediments from the glacier and uplands into a former glacial lake now occupied by Island Pond. These proglacial sediments range from well-sorted sand and gravel deposits near the mouth of Taylor Brook to varved clay deposited some distance from the delta front in Island Pond. The stratified-drift aquifer is approximately 1.1 mi^2 in area and ranges from 10 to 90 ft in thickness. The aquifer is thickest and transmissivity is greatest along the west shore of the pond (pl. 4). In addition, permeable glacial materials and recent beach deposits along the west shore provide a strong hydrologic connection between pond and aquifer, making this section of the aquifer the most favorable for ground-water development.

The aquifer area includes many year-round residences and seasonal homes. Centralized water or sewer systems have not been built within the area. Each home maintains a private, on-site water well and a septic system. The collective effect of these homes and their septic systems on ground-water quality has not been evaluated and is a central issue in determining whether this aquifer can be developed for public water supply.

The aquifer configuration and sediments along the aquifer-pond boundary were investigated by use of seismic-reflection methods. One seismic-reflection profile (fig. 14 and pl. 2) shows an irregular bedrock surface for a north-to-south traverse across the outlet of Taylor Brook near the toe of the delta. Bedrock depths range from 12 to 125 ft below the pond surface. The transition between glacial lakebed materials and coarse-grained stratified-drift materials is also apparent from the profile. Fine-grained lakebed materials are laminar bedded and have a layer-cake appearance in contrast with the stratified-drift materials deposited along the flanks of bedrock knobs that have a chaotic pattern with less laminar definition.

A USGS well, DFW-424, was drilled in the stratified drift at the outlet of Taylor Brook after an inspection of the profile showed thick deposits of relatively coarse-grained material and a bedrock depth of about 80 ft below pond surface. The well log for DFW-424 confirms the seismic-reflection results in regard to the texture of materials and bedrock depth. An upper zone of coarse sand of glaciofluvial origin changes to a lower zone of fine and very fine sand of glacial-lake origin generally below 40 ft at the Taylor Brook outlet.

The quantity of ground water potentially available from this aquifer is a function of the recharge from precipitation and the amount of surface water from Island Pond that could be induced to infiltrate the aquifer. The average recharge from precipitation on the 1.1-mi^2 stratified-drift aquifer is estimated to be 1.2 Mgal/d. Indirect recharge from

2.9 mi^2 of adjacent till and bedrock is estimated to be 2.6 Mgal/d.

The amount of water available as induced recharge from Island Pond would largely be a function of the distance between a production well and the pond-aquifer boundary. By placing a hypothetical production well in the area between the 40- to 80-ft saturated-thickness contours near the pond, most of the water captured would be expected to come from induced infiltration and not from depletion of aquifer storage. Because well location plays such an important role in the amount of water captured by induced recharge, a more detailed analysis than that presented in this section would be needed to make estimates of potential yield for specific well-field arrangements.

Another potential source of induced recharge is Taylor Brook, which flows across the delta and discharges into Island Pond. The amount of water potentially available from this source during dry conditions can be estimated by solving equation 4 for the $Q_{7,10}$. The $Q_{7,10}$ for the Taylor Brook basin is estimated to be $0.41 \text{ ft}^3/\text{s}$ on the basis of a drainage area of 5.3 mi^2, 10 percent of which is covered by stratified drift and 90 percent of which is covered by till. By comparison, low-flow discharge was $0.48 \text{ ft}^3/\text{s}$ on August 26, 1987, near the outlet of Taylor Brook (table 3). The average flow duration on this date for three New England coastal rivers (Oyster River of southeastern New Hampshire, Parker River of northeastern Massachusetts, and Royal River of south-eastern Maine) was 97.5 percent. Flow at this duration is only slightly more than the $Q_{7,10}$ for streams in New England. If similar relations apply to Taylor Brook and the low flow ($0.48 \text{ ft}^3/\text{s}$) is nearly equal to the $Q_{7,10}$ for this brook, an additional 0.3 Mgal/d of water from induced infiltration would be available for withdrawal from wells.

The amount of water available from precipitation (1.1 Mgal/d), induced infiltration (0.3 Mgal/d), and ground-water discharge from upland till and bedrock (2.6 Mgal/d) equals 4 Mgal/d. This estimate is based on the assumption that all of the recharge from precipitation could be captured by wells and that recharge from the pond is not considered.

Windham-Cobbetts Pond Aquifer

A valley train of well-sorted stratified drift material extends from the western shore of Cobbetts Pond in Windham southerly through a narrow, linear valley into the town of Pelham and then to Massachusetts. Sand and gravel that fills the valley was deposited by meltwater streams discharging from a glacier upvalley near Cobbetts Pond. This valley train originates from a head of outwash that was formed by deposition in contact with ice and appears as a distinct ridge of pebble-cobble gravel along the western rim of Cobbetts Pond.

Results from a seismic-reflection traverse along the western shore of the pond show a relatively thin zone of coarse boulder gravel that fills a narrow bedrock channel (fig. 13). The southern wall of the channel rises steeply and extends to just below the pond surface. The other buried channel wall, not shown, truncates at the boundary between till and stratified drift 500 ft to the north. The area of aquifer between these no-flow boundaries is the primary conduit for the water flow between the pond and aquifer.

Golden Brook is a small regulated stream that is the major drain for the valley. Sluice gates at the outlet of Cobbetts Pond are used to maintain the pond level for recreation, consequently, the brook often runs dry during periods of little or no precipitation, and the flow in the brook cannot be relied on as a source for induced infiltration.

Aquifer thickness is greatest near the channel of Golden Brook, where the thickness of the saturated zone averages 30 to 50 ft and is as much as 60 ft. The aquifer thins to the south and southeast of Moeckel Road, where 10 to 20 ft of saturated thickness is common.

The aquifer area primarily includes suburban residential and commercial land use and is thickly settled in most places. Most homes have an on-site well and a septic system; however, the Southern New Hampshire Water Company supplies water at an average of 75,000 gal/d to communities within the aquifer area by pumping from bedrock wells.

The potential yield of this pond-aquifer system was evaluated by applying the superposition method to a finite-difference model as described in a previous section of this report. Results from the model indicate that a potential yield of 0.6 Mgal/d is available from the pond-aquifer system on the basis of a simulation of five production wells pumped for 180 days during a period of no recharge.

Kingston-Powwow River Aquifer

A large outwash plain consisting of glaciofluvial stratified drift extends across the towns of Kingston, East Kingston, and Newton (fig. 2). This, the largest stratified-drift aquifer in the study area (10.5 mi^2), was built from a network of braided melt-water streams carrying sand and gravel downvalley from a melting glacier. The melting of remnant blocks of ice in the outwash plain left behind numerous kettles; the largest are now occupied by Great, Powwow, and Country Ponds. Connecting the ponds is the Powwow River, which follows the glacial drainage and outflows to Powwow Pond.

During deglaciation, sea level rose and the ocean inundated about one-third of the aquifer area, leaving behind marine silts and clays in a southeast-trending, broad, shallow basin. The boundary line, marked by open circles on plate 2, is the inferred western limit of the marine inundation for this aquifer and is based on well data and surficial geology of the basin. East of this marker, the aquifer consists of a thin layer of outwash and beach deposits (less than 20 ft thick) over relatively impermeable marine silts and clays. West of the boundary, the aquifer consists primarily of glaciofluvial stratified drift overlying a thin discontinuous mantle of till on bedrock.

One of two known productive zones of the aquifer is in a buried valley of thick glaciofluvial material along the axis of the Powwow River immediately south of Great Pond (pl. 2). Saturated thickness exceeds 100 ft in places and averages about 60 ft throughout the 1.5-mi length of the valley. Great Pond, the Powwow River, and Country Pond all connect to the buried valley and could provide large amounts of recharge to this lightly populated aquifer section.

Another productive zone of the aquifer is between Greenwood and Great Ponds. The topography of the area is that of a knob-and-kettle landscape characteristic of collapsed outwash formed from the melting of remnant ice blocks. Much of the coarse stratified drift was deposited against glacial ice and averages from 40 to 60 ft in saturated thickness. State ownership of land along the northeastern shore of Great Pond has kept this aquifer section relatively undeveloped.

Water use for the entire aquifer is from on-site wells that supply individual homes, businesses, and schools. Potential yield was estimated for this aquifer by use of the numerical model mentioned in the previous section. Results from eight wells pumping continuously for a 180-day period of no recharge indicate that this aquifer is capable of yielding about 4 Mgal/d.

North Hampton-Knowles Pond Aquifer

The aquifer in North Hampton is an elongate low-relief kame delta consisting of coarse ice-contact stratified drift (pl. 3). The site is about 0.7 mi^2 in area and is primarily bordered by impermeable fine-grained marine deposits that separate the aquifer from nearby sources of recharge, specifically the Winnicut River and the extensive Cornelius swamp. The headwaters of Cornelius Brook and several small ponds are within the aquifer, but, because they are underlain by marine sediments, limited surface-water recharge is available to the aquifer.

Water levels in USGS observation well NSW-69 and seismic-refraction results for a 1,500-ft survey near Knowles Pond indicate that saturated thickness is 40 to 60 ft along the Cornelius Brook channel. Saturated materials composed of permeable sand, gravel, and cobbles form a zone of high transmissivity. The area is moderately developed with residences and is presently undeveloped as a public water supply. The yield for the 0.7-mi^2 aquifer is estimated to be 0.6 Mgal/d; however, this value could be less if the North Hampton-Knowles Pond aquifer is hydraulically connected with the aquifer to the north of Route 95, where two gravel-packed wells currently withdraw ground water at a combined rate of 0.8 Mgal/d. Potential yield for the combined aquifers is estimated to be 1.3 Mgal/d on the basis of increased land area of stratified drift. Ground-water withdrawal of 0.8 Mgal/d leaves 0.5 Mgal/d available for additional ground-water development. These preliminary estimates indicate that additional pumping from this aquifer is possible, although more detailed work is needed to determine the effects of current pumpage on water levels and the water balance in the aquifer.

Aquifers that lack contact with streams, such as at Knowles Pond, could be used as seasonal storage reservoirs. The aquifer could be pumped heavily and water levels drawn down in the summer with little effect on streamflow. For the remainder of the year, when water supplies could be obtained from sources sustained by induced infiltration, the aquifer would remain idle and recover from the heavy use. This concept would be of practical significance only in the context of a regional water system that interconnected several surface and (or) ground-water sources (Randall and others, 1988b).

Greenland Aquifer

The aquifer in central Greenland is a large kame delta completely within marine deposits adjacent to Great Bay, a saltwater body (pl. 3). The site is 2.5 mi^2 in area and consists of unconfined and confined aquifers separated by discontinuous layers of marine silt and clay. The largest and most productive part of this aquifer is unconfined.

A municipal well, Greenland number 5 (GTW1), is the only large-production well currently tapping the unconfined aquifer. This well is 1,400 ft west of Interstate 95 in one of two productive zones of the aquifer and has a maximum rated yield of 0.7 Mgal/d. Observations from the drilling of a 2.5-in. test well and results from a 12-day aquifer test on an 8-in. well at this well site indicate that the transmissivity for the aquifer section is 4,100 ft^2/d and that saturated thickness averages 40 ft. Drawdowns were noted to continue at a predictable rate on the 12th and last day of the test as the well was pumped at 524 gal/min. These drawdowns indicate that stabilization had not occurred and that ground water was continually being removed from storage with little or no contribution from surface-water recharge. The aquifer is partially protected from saltwater intrusion by a ridge of bedrock that crops out near the mouth of the Winnicut River and by the surrounding impermeable marine deposits. This configuration limits recharge to the aquifer by induced infiltration.

Another small but productive area of the aquifer is immediately east of Interstate 95 near Breakfast Hill Road. Aquifer thickness averages 40 ft, and the materials consist of coarse ice-contact gravel interfingering with marine silt and clay. A 10-day pump test was done at well GTW-49 by the Portsmouth Water Department to determine the feasibility of the site for a municipal-well installation. Results indicate a transmissivity of 4,500 ft^2/d. The water was principally derived from aquifer storage with no recharge by induced infiltration. Although the aquifer has the potential to supply significant amounts of water, the site has not been developed because of its proximity to the Coakley landfill hazardous-waste site, where the extent of contaminant migration is uncertain.

Potential yield for the 2.5-mi^2 aquifer is estimated to be 2.3 Mgal/d. Subtracting the 0.7 Mgal/d withdrawn from the Greenland number 5 well leaves a total estimated aquifer yield of 1.6 Mgal/d. Because of the uncertainty in the flow and the potential for migration of contaminants from the Coakley landfill to the Breakfast Hill Road area, the aquifer section most promising for further consideration is near the State-owned gravel pit west of Interstate 95.

GROUND-WATER QUALITY

Water in the stratified-drift aquifers of the lower Merrimack River and coastal river basins is generally suitable for drinking and other domestic purposes. Concentrations of dissolved constituents are low, and turbidity and color are generally absent. Ground-water-quality degradation has occurred near at least 16 sites in the 327 mi^2 study area (fig. 24 and pls. 1-3). Six of these sites are included on the National Priority List (NPL) of hazardous-waste sites by the U.S. Environmental Protection Agency (1986) and will be evaluated under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) of 1980. Ten hazardous-waste sites require monitoring of ground-water quality under the Federal Resource Conservation and Recovery Act (RCRA) of 1976. Contaminants in the shallow stratified-drift aquifers at these sites limit the availability of potable water for municipal and domestic uses.

Ground-water samples were collected from 24 USGS observation wells and 6 municipal wells, in April and August 1987, to characterize background water quality of the stratified-drift aquifers. These samples were collected at wells where the water quality is most likely to reflect natural conditions. The only exception is municipal well PXW-2, which serves Pease Air Force Base (AFB) in the towns of Newington and Portsmouth. The water from this well is known to be contaminated with trichloroethylene (TCE) (Bradley, 1982). Because of the well's high yield, Pease AFB decided to treat the water and continue to use it as a drinking-water supply.

Methods described by Fishman and Friedman (1989) were used in the collection and the analysis of ground-water samples. All samples were analyzed by the USGS National Water Quality Laboratory in Arvada, Colo. Statistical results of the chemical analysis of the ground-water samples are summarized in table 7 and presented for comparison with the U.S. Environmental Protection Agency (1989) and New Hampshire Water Supply Engineering Bureau (1990) drinking-water regulations.

Dissolved constituents commonly found in ground water from the stratified-drift aquifers are calcium, magnesium, sodium, bicarbonate, sulfate, chloride, and silica. They are derived from many sources: calcium, bicarbonate, and silica are derived primarily from soil and rock weathering; sulfate is contributed by precipitation; organic material is derived from sediments; and sodium and chloride come from soil and rock weathering and precipitation. Elevated concentrations of sodium and chloride also commonly result from salt used to deice roads.

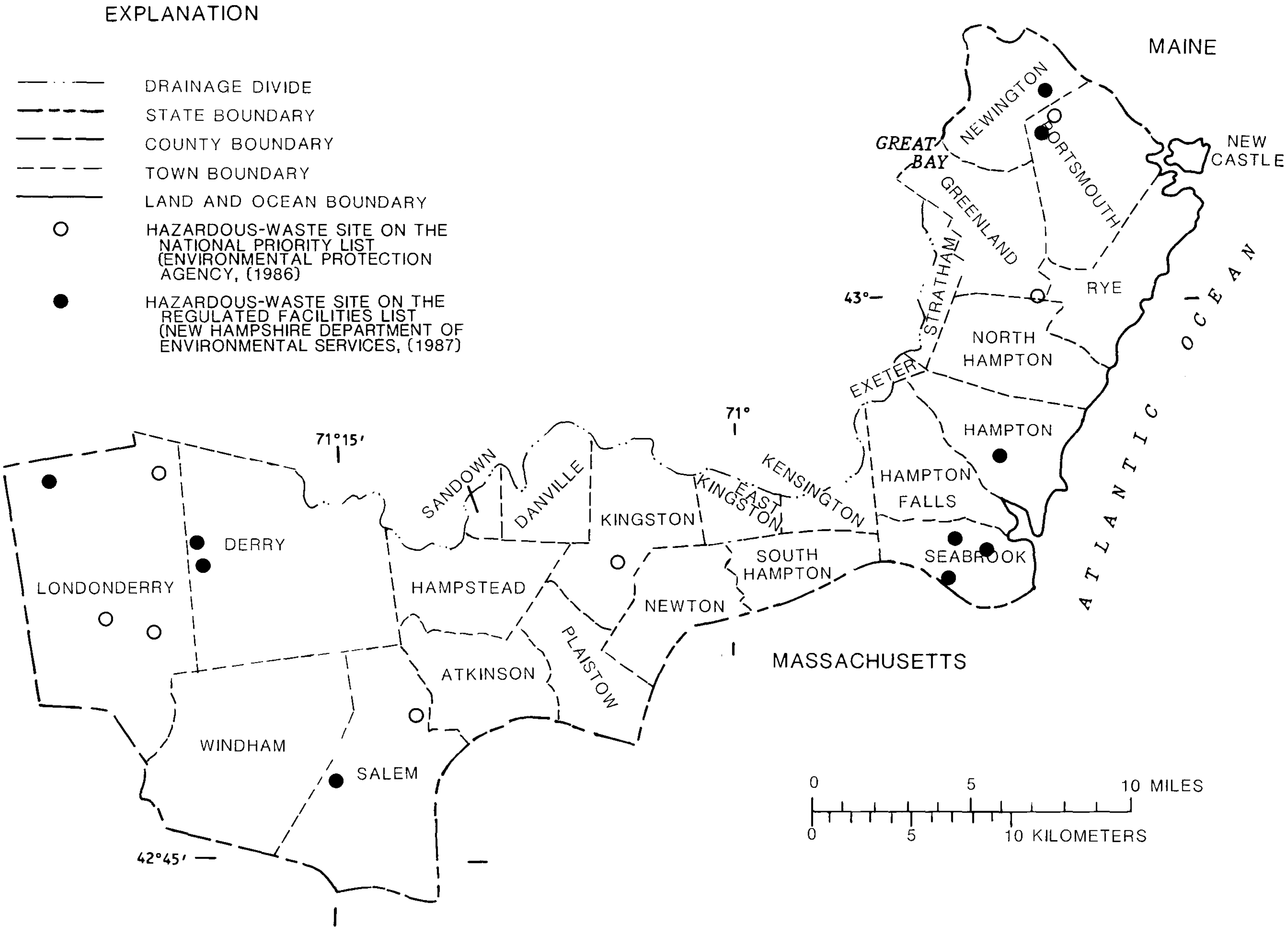

Figure 24.--Locations of hazardous-waste sites.

Physical and Chemical Properties

Graphical representations of the chemical analyses are presented on plates 1-3 and show variations in the chemistry of aquifer water. Concentrations of dissolved constituents (expressed in milliequivalents per liter) are plotted at the appropriate well site, and the points are connected to form irregular polygons called Stiff diagrams (Stiff, 1951). Four cations, sodium (Na), potassium (K), magnesium (Mg), and calcium (Ca), are plotted along the axis to the left of the zero point. Five anions, chloride (Cl), fluoride (F), sulfate (SO_4), bicarbonate (HCO_3), and carbonate (CO_3), are plotted along the axis to the right of the zero point. The shape of the closed figure characterizes the water composition. Dissolved-solids concentration, as indicated by the width of the figures, tends to increase from the west to the east. This variation may be caused by the deposition of salt aerosols from ocean storms, the presence of saline connate residues in the marine silts and clays of the seacoast region, and (or) greater contact time for mineral-water reactions in the more impermeable marine deposits that comprise most of the seacoast aquifers.

Total Dissolved Solids

Total dissolved solids in water includes all ionized and nonionized dissolved solids in solution, but excludes colloids and dissolved gases (Davis and DeWiest, 1966). Concentration of total dissolved solids in the samples ranged from 22 mg/L (milligrams per liter) to 500 mg/L, and the mean was 149.3 mg/L. The concentration in one water sample (from well PXW-5) equalled the recommended limit of 500 mg/L for total dissolved solids established by the New Hampshire Water Supply Engineering Bureau (1990) for public drinking water. Water from this well also had the highest specific conductance. If total dissolved solids are unknown, specific conductance can be used to estimate the value. One equation used is

$$KA = S, \qquad (5)$$

where K is specific conductance in μS/cm (microsiemens per centimeter at 25 degrees Celsius);

A is a constant (for natural waters, A ranges from 0.55 to 0.75) (Hem, 1985); and

S is total dissolved solids, in milligrams per liter.

Specific Conductance

Specific conductance, a measure of the ability of water to conduct electrical current, ranged from 24 to 860 μS/cm, and the mean was 252 μS/cm. For all samples, the median (215 μS/cm) and maximum (860 μS/cm) exceeded the median (132 μS/cm) and maximum (469 μS/cm) specific conductance of waters from large municipal-supply wells tapping stratified-drift aquifers Statewide (Morrissey and Regan, 1987).

Three wells yielding water with elevated total dissolved solids and specific conductance are close to roads or airport runways that have been salted. Well NIW-35 is near a Pease Air Force Base runway, well PXW-5 is next to New Hampshire State Highway 101 in Portsmouth, and well SAW-49 is near Town Farm Road in Salem. The data from this study indicate that past or present road-salting practices continue to influence ground-water chemistry in shallow stratified-drift aquifers.

pH

The pH of water is a measure of the water's hydrogen-ion activity. The pH scale ranges from 0 to 14; each unit increase in the scale represents a tenfold decrease in hydrogen-ion activity. Water having a pH of 7.0 is neutral, less than 7.0 is acidic, and greater than 7.0 is alkaline. At a pH below 6.5, some metals in metallic piping can dissolve and a metallic taste can be imparted to the water (U.S. Environmental Protection Agency, 1989). The pH of 30 samples measured in the field ranged from 5.80 to 8.48 and the median pH was a slightly acidic 6.6. In addition, there is a definite trend of increasing pH from the western section towards the eastern section of the study area. The most acidic ground-water samples (pH from 5.80 to 5.86) were from wells LRW-70, WPW-37, and WPW-38 in the towns of Londonderry and Windham. The most basic ground-water sample (pH 8.48) was from well NSW-69 in the seacoast town of North Hampton.

Alkalinity

Alkalinity is a measure of the capacity of a solution to resist a change in pH due to the addition of acid and is also a measure of the concentrations of carbonate ($CO_3^{=}$), bicarbonate (HCO_3^{-}), and hydroxide (OH^{-}) ions. The relatively low alkalinity of the ground water in the stratified-drift aquifers indicates little buffering capacity or ability to resist acidification. Alkalinity determined in the field ranged from 3 to 158, expressed as mg/L of $CaCO_3$ (calcium carbonate), and the mean was 51 mg/L. The sample with the highest alkalinity (158 mg/L) was obtained from well NSW-70. The highest alkalinities were determined in waters from wells in the eastern part of the study area. In general, the stratified-drift aquifers and bedrock do not contain significant carbonate minerals; consequently, water associated with them has a low alkalinity and low buffering capacity.

Calcium, Magnesium, and Hardness

Calcium and magnesium are common elements of alkaline-earth minerals. Calcium and magnesium are also the principal cations in most natural ground water (Hem, 1985). Concentrations of calcium ranged from 1.4 to 78 mg/L, and the mean was 22 mg/L. Concentrations of magnesium in the samples ranged from 0.4 to 18 mg/L, and the mean was 5.0 mg/L.

Hardness of water, expressed in mg/L as $CaCO_3$, is caused by divalent metallic cations dissolved in water. In fresh water these cations primarily are calcium and magnesium, but iron, strontium, and manganese may also contribute to hardness. Hardness ranged from soft (5 mg/L) to very hard (270 mg/L). (Table 6 describes hardness classification.)

Seventeen samples with a hardness of less than 60 mg/L were classified as soft water (table 6). Ten samples were moderately hard water from 72 to 120 mg/L and three wells contained hard water (from 130 to 180 mg/L). Water from wells NSW-70 and PXW-5 was very hard (concentrations of 220 mg/L and 270 mg/L). Water from these last two wells also had the highest concentrations of calcium and magnesium, the two principal components of hardness.

Sodium

Concentrations of sodium for all samples ranged from 1.7 to 88 mg/L, and the mean was 19 mg/L. The concentration of sodium (88 mg/L) in the water sample from well SAW-49 was the highest determined. All of the sodium concentrations were less than the secondary drinking-water standard (100 mg/L) established by the New Hampshire Water Supply Engineering Bureau (1990) for drinking water. At present, sodium concentrations pose a potential health problem for people who require sodium-restricted diets and who have wells near, or down-gradient from, heavily salted roads or salt-storage areas.

Chloride

Concentrations of chloride for all samples ranged from 2.2 to 200 mg/L, and the mean was 36.8 mg/L. All of the concentrations of chloride were below the secondary drinking-water standard of 250 mg/L (New Hampshire Water Supply Engineering Bureau, 1990).

Table 6.--*Classification of hardness of water*

[Modified from Durfor and Becker, 1964, p. 27]

Descriptive rating	Range of hardness, as $CaCO_3$ (milligrams per liter)
Soft	0 – 60
Moderately hard	61 – 120
Hard	121 – 180
Very hard	181 or greater

Sulfate

The sulfate (SO_4) ion is one of the major anions in natural waters. Sulfate is reduced to hydrogen sulfide (H_2S) gas under anaerobic conditions, and its odor can be detected at only a few tenths of a milligram per liter of H_2S. Presence of H_2S could be a problem in stratified-drift aquifers that are near, under, or overlain by peat bogs or swamps. Concentrations of sulfate for all the samples ranged from 3.5 to 65 mg/L, and the mean was 17 mg/L. None of the samples had concentrations that exceeded the New Hampshire Water Supply Engineering Bureau secondary drinking-water standard of 250 mg/L.

Iron and Manganese

High concentrations of iron and manganese were the most common water-quality problems found during this investigation. Iron concentrations above the New Hampshire Water Supply Engineering Bureau secondary drinking-water standard of 300 μg/L (micrograms per liter) (New Hampshire Water Supply Engineering Bureau, 1990) were measured in samples from seven wells--7,400 μg/L at KTW-42, 5,300 μg/L at KTW-78, 5,300 μg/L at DFW424, 5,000 μg/L at KTW-39, 3,600 μg/L at KTW-41, 2,400 μg/L at KTW-77, and 460 μg/L at SAW-50. Five of these seven samples came from wells in Kingston. Elevated concentrations of iron and manganese are not known to be harmful to humans, but they can stain clothing and plumbing fixtures and give water an objectionable taste and color. Two-thirds of all the samples had concentrations of manganese above the New Hampshire Water Supply Engineering Bureau secondary drinking-water standard of 50 μg/L. Concentrations of manganese ranged from less than 1 μg/L (HEW-7) to 1,100 μg/L, and the mean was 391 μg/L.

Trace Elements

Aluminum is the third most abundant element in the Earth's outer crust, but it rarely occurs in solution in natural water at concentrations greater than about a few tens of micrograms per liter (Hem, 1985, p. 73). The exceptions are waters that are highly acidic. Aluminum concentrations for all the samples ranged from less than 10 μg/L to 210 μg/L, and the mean was 28 μg/L. Aluminum concentrations that exceeded the New Hampshire Water Supply Engineering Bureau secondary drinking-water standard of 50 μg/L were determined in samples from four wells--210 μg/L at KTW-40, 190 μg/L at KTW-42, 160 μg/L at KTW-45, and 60 μg/L at DFW-424.

Arsenic in ground water can originate from geologic or anthropogenic sources. Geologic sources of arsenic include dissolution of minerals such as arsenopyrite. An example of an anthropogenic source is use of pesticides that contain arsenic, which can enter ground water through waste disposal or agricultural drainage. Because arsenic can be toxic to humans in trace amounts, the USEPA (1988) set a Maximum Contaminant Level[2] (MCL) of 50 μg/L. This level was not exceeded by any of the samples collected for this study. The highest arsenic concentration determined was 14 μg/L in a sample from well DFW-424. Although arsenic is not a major concern in these stratified-drift aquifers, about 10 to 15 percent of water from bedrock wells tested in New Hampshire exceeded the U.S. Environmental Protection Agency's MCL for arsenic (Morrissey and Regan, 1987).

Strontium is chemically similar to calcium, and replaces calcium or potassium in igneous-rock minerals in minor amounts. Natural concentration of strontium in water is usually limited by ion exchange with calcium-rich clays (Hem, 1985). Concentrations of strontium ranged from 20 μg/L to 350 μg/L, and the mean was 116 μg/L. At present, no Federal or New Hampshire drinking-water regulations or standards have been set for strontium.

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[2] MCL = Maximum Contaminant Level: Enforceable, health-based regulation that is to be set as close to the level at which no known or anticipated adverse effects on the health of a person occur as is feasible. The definition of feasible means the use of best technology, treatment techniques, and other means that the Administrator of the U.S. Environmental Protection Agency finds, after examination for efficacy under field conditions and not solely under laboratory conditions, are generally available (taking cost into consideration).

Organic Compounds

Water samples from selected USGS observation wells drilled during this investigation were analyzed for 36 priority volatile organic compounds summarized in table 7. The five wells not sampled for organic compounds--HEW-7, NSW-70, PXW-5, RYW-38, and SGW-1--are municipal wells that are routinely sampled by the New Hampshire Water Supply and Pollution Control Division. The only municipal well that was sampled for volatile organic compounds was PXW-2 (also known as the Haven Supply well), which serves Pease Air Force Base.

Volatile organic compounds (VOC) were detected at trace concentrations in water from four wells and at low concentrations in a fifth well. Water from well SAW-50, in Salem, contained 0.2 μg/L of tetrachloroethylene; water from KFW-17, in Kensington, contained 1.3 μg/L of 1,1,1-dichloroethylene; water from KTW-42, in Kingston, contained 0.2 μg/L of trichloroethylene; and water from KTW-46, also in Kingston, contained 0.3 μg/L of toluene. The concentrations are all close to the detection limits of the analytical procedures used, and, because only one volatile organic compound was found in such small amounts at each of these wells, contamination is unlikely. If ground water is contaminated, a number of constituents will commonly be observed in an analysis as, for example, PXW-2 contained three contaminants--0.7 μg/L chloroform, 2.4 μg/L 1,2-transdichloroethene, and 5.7 μg/L trichloroethylene. Trichloroethylene is the only constituent whose concentration in water from PXW-2 exceeds the New Hampshire Water Supply Engineering Bureau drinking-water standards for volatile organic compounds.

Contamination Sources

Contamination of ground water from human activities can come from many sources. Activities that may degrade the water quality of ground water include landfill disposal of household and industrial wastes; storage and spreading of road deicing salt; agricultural practices, which include spreading of commercial fertilizers and spraying of pesticides; spreading or landfill disposal of sludge from municipal sewage systems; or leakage from fuel, septic (especially in densely populated areas), and chemical-storage tanks. Overpumping of wells can induce saltwater intrusion in coastal areas by increasing the hydraulic gradient between the saltwater and freshwater interface. Evidence is increasing that "acid rain" can lower the pH in ground water, especially in New England, where soils and rocks have little buffering effect. With a decrease in pH, concentrations of dissolved trace metals such as aluminum could increase in ground water.

Extensive ground-water contamination has occurred at seven uncontrolled hazardous-waste sites. Six sites--the Auburn Road Landfill site in Londonderry, the Tinkham Garage/Woodland Village Condominiums site in Londonderry, the Ottati and Goss/Great Lakes Container Corporation site in Kingston, the Coakley Landfill site in North Hampton, the Holton Circle site in Londonderry, and the Pease Air Force Base of Newington-Portsmouth (pls. 1-3)--are on the U.S. Environmental Protection Agency's National Priority List of hazardous-waste sites (U.S. Environmental Protection Agency, 1986) (fig. 24). In addition, the Duston Road site of Salem is classified by the State of New Hampshire as a high priority hazardous-waste site warranting remedial cleanup activities (New Hampshire Water Supply and Pollution Control, W.A. Healy, written commun., April 1985).

The Auburn Road Landfill site is in the northeastern corner of Londonderry near the towns of Auburn (to the north) and Derry (to the east). A study of this site by a private consultant identified about 1,000 buried drums containing VOCs (NUS Corporation, 1986). Another private consultant, under contract to the USEPA, is conducting a final Remedial Investigation/Feasibility Study (RI/FS) that will identify the nature and extent of site contamination and the remedial action needed to clean up the site. Currently, the only remedial action taken has been the removal of the buried drums, which was scheduled to be completed by 1989.

The Tinkham Garage/Woodland Village Condominiums site is in the town of Londonderry near the intersection of Interstate 93 and State Route 102. The Tinkham Garage was first used as an area for storage, maintenance, and cleaning of tanker trucks. In 1982, contaminants were detected in the soil behind the garage and the condominium complex. Further tests detected contaminants in septic tanks and ground water from nearby bedrock wells. A draft RI/FS was prepared that characterized ground-water flow in the bedrock aquifer and identified the extent of the plume of contamination (NUS Corporation, 1985). The major volatile organic compounds detected in the ground water were 1,2-dichloroethane and trichloroethylene (NUS Corporation, 1985). The New Hampshire Water Supply and Pollution Control Division authorized the installation of a municipal drinking-water supply for the residences

Table 7.--*Summary of results of water-quality analyses*

[A "less than" symbol (<) precedes a value if a concentration is less than detection limit (reporting limit) indicated for that analysis. °C, degrees Celsius; μS/cm, microsiemens per centimeter; mg/L, milligrams per liter, μg/L, micrograms per liter; --, no data]

Property or constituent	MCL[1]	SMCL[2]	NHMCL[4]	NHSMCL[5]	Number of samples	Mean[6]	Median	Standard deviation[6]	Minimum	Maximum
Specific conductance, field (μS/cm at 25 °C)	--	--	--	--	30	252.1	215	199.4	24	860
Temperature (°C)	--	--	--	--	29	10.4	10	2.0	8	16.5
Oxygen dissolved, (mg/L as O_2)	--	--	--	--	17	4.6	4.3	3.5	0	11.3
pH, field (standard units)	--	6.5 - 8.5	--	6.5 - 8.5	30	--	6.66	--	5.80	8.48
Color (platinum-cobalt units)	--	15	--	15	30	10.9	2	26.1	1	110
Alkalinity, field (mg/L as $CaCO_3$)	--	--	--	--	30	51.0	36.0	44.8	3	158
Hardness, total (mg/L as $CaCO_3$)	--	--	--	--	30	74.5	54.5	64.6	5	270
Solids, sum of constituents, dissolved (mg/L)	--	500	--	500	30	149.3	122	107.8	22	500
Calcium, dissolved (mg/L as Ca)	--	--	--	--	30	21.48	17.0	18.36	1.4	78
Magnesium, dissolved (mg/L as Mg)	--	--	--	--	30	5.02	3.55	4.59	.4	18
Chloride, dissolved (mg/L as Cl)	--	250	--	250	30	36.8	19.5	46.67	2.2	200
Sodium, dissolved (mg/L as Na)	--	20	250	100 - 250	30	19.38	10	22.73	1.7	88
Nitrogen, ammonia, dissolved (mg/L as N)	--	--	--	--	30	.019	.004	.054	<.01	.26
Potassium, dissolved (mg/L as K)	--	--	--	--	30	3.05	2.65	1.57	.3	7.5
Sulfate, dissolved (mg/L as SO_4)	--	250	--	250	30	16.52	14	12.75	3.5	65
Fluoride, dissolved (mg/L as F)	4	2	4	2	30	.10	.1	.092	<.1	.5
Carbon, organic, dissolved (mg/L as C)	--	--	--	--	30	1.71	1.1	1.55	.7	8.3
Silica, dissolved (mg/L as SiO_2)	--	--	--	--	30	14.76	13.5	5.08	7.3	28
Arsenic, dissolved (μg/L as As)	50	--	50	--	29	1.73	.75	2.77	<1	14
Barium, dissolved (μg/L as Ba)	1,000	--	5,000	--	23	21.48	23	12.09	4	53

Table 7.--*Summary of results of water-quality analyses*--Continued

Property or constituent	MCL[1]	SMCL[2]	NHMCL[4]	NHSMCL[5]	Number of samples	Mean[6]	Median	Standard deviation[6]	Minimum	Maximum
Beryllium, dissolved (μg/L as Be)	--	--	--	--	30	--	--	--	<10	--
Boron, dissolved (μg/L as B)	--	--	--	--	30	13.65	10	10.43	<10	50
Cadmium, dissolved (μg/L as Cd)	10	5	5	--	30	--	--	--	<1	4
Chromium, dissolved (μg/L as Cr)	[3]50	--	100	--	30	--	--	--	<10	20
Cobalt, dissolved (μg/L as Co)	--	--	--	--	30	1.77	1	2.1	<1	9
Copper, dissolved (μg/L as Cu)	--	1,000	--	1,000	30	2.07	1	2.11	<1	10
Iron, dissolved (μg/L as Fe)	--	300	--	300	26	1,183.0	84.5	2,179.0	<3	7,400
Lead, dissolved (μg/L as Pb)	50	--	50	20	30	--	--	--	<5	--
Manganese, dissolved (μg/L as Mn)	--	50	--	50	28	391.1	235	409.4	<1	1,100
Molybdenum, dissolved (μg/L as Mo)	--	--	--	--	30	.63	.3	1.68	<1	8
Mercury, dissolved (μg/L as Hg)	2	--	2	--	30	--	--	--	<.1	--
Nickel, dissolved (μg/L as Ni)	--	--	--	--	30	3.16	2	3.19	<1	13
Silver, dissolved (μg/L as Ag)	50	--	50	90	30	--	--	--	<1	1
Strontium, dissolved (μg/L as Sr)	--	--	--	--	30	115.6	90.5	86.27	20	350
Zinc, dissolved (μg/L as Zn)	--	5,000	--	5,000	23	4.61	4	3.38	<3	13
Antimony, dissolved (μg/L as Sb)	--	--	--	--	30	--	--	--	<1	2
Aluminum, dissolved (μg/L as Al)	--	50	--	50	30	27.8	5.92	56.49	<10	210
Lithium, dissolved (μg/L as Li)	--	--	--	--	23	4.92	3.59	3.96	<4	16
Selenium, dissolved (μg/L as Se)	10	--	50	--	30	.66	.59	.855	<1	4
Dichlorobromomethane, total (μg/L)	--	--	--	--	25	--	--	--	<.2	--
Carbon tetrachloride, total (μg/L)	5	--	5	5	25	--	--	--	<.2	--
1,2-Dichloroethane, total (μg/L)	--	--	--	--	25	--	--	--	<.2	--

Table 7.--*Summary of results of water-quality analyses*--Continued

Property or constituent	MCL[1]	SMCL[2]	NHMCL[4]	NHSMCL[5]	Number of samples	Mean[6]	Median	Standard deviation[6]	Minimum	Maximum
Bromoform, total (μg/L)	--	--	--	--	25	--	--	--	<.2	--
Chlorodibromomethane, total (μg/L)	--	--	--	--	25	--	--	--	<.2	--
Chloroform, total (μg/L)	--	--	--	--	25	--	--	--	<.2	.7
Toluene (μg/L)	--	--	2,000	40	25	--	--	--	<.2	.3
Benzene, total (μg/L)	5	--	5	--	25	--	--	--	<.2	--
Chlorobenzene, total (μg/L)	--	--	--	--	25	--	--	--	<.2	--
Chloroethane, total (μg/L)	--	--	--	--	25	--	--	--	<.2	--
Ethylbenzene, total (μg/L)	--	--	700	30	25	--	--	--	<.2	--
Methylbromide, total (μg/L)	--	--	--	--	25	--	--	--	<.2	--
Methylchloride, total (μg/L)	--	--	--	--	25	--	--	--	<.2	--
Methylene chloride, total (μg/L)	--	--	--	--	25	--	--	--	<.2	--
Tetrachloroethylene, total (μg/L)	--	--	5	--	25	--	--	--	<.2	.2
Trichlorofluoromethane, total (μg/L)	--	--	--	--	25	--	--	--	<.2	--
1,1-Dichloroethane, total (μg/L)	--	--	--	--	25	--	--	--	<.2	--
1,1-Dichloroethylene, total (μg/L)	--	--	70	--	25	--	--	--	<.2	--
1,1,1-Trichloroethane, total (μg/L)	--	--	200	--	25	--	--	--	<.2	1.3
1,1,2-Trichloroethane, total (μg/L)	--	--	--	--	25	--	--	--	<.2	--
1,1,2,2 Tetrachloroethane, total (μg/L)	--	--	--	--	25	--	--	--	<.2	--
1,2-Dichlorobenzene, total (μg/L)	--	--	--	--	25	--	--	--	<.2	--
1,2-Dichloropropane, total (μg/L)	--	--	5	--	25	--	--	--	<.2	--
1,2-Transdichloroethene, total (μg/L)	--	--	--	--	25	--	--	--	<.2	2.4
1,3-Dichloropropene, total (μg/L)	--	--	--	--	25	--	--	--	<.2	--

Table 7.--*Summary of results of water-quality analyses*--Continued

Property or constituent	MCL[1]	SMCL[2]	NHMCL[4]	NHSMCL[5]	Number of samples	Mean[6]	Median	Standard deviation[6]	Minimum	Maximum
1,3-Dichlorobenzene, total (μg/L)	--	--	600	10	25	--	--	--	<.2	--
1,4-Dichlorobenzene, total (μg/L)	--	--	--	5	25	--	--	--	<.2	--
2-Chloroethylvinylether, total (μg/L)	--	--	--	--	25	--	--	--	<.2	--
Dichlorodifluoromethane, total (μg/L)	--	--	--	--	25	--	--	--	<.2	--
Trans-1,3-dichloropropene, total (μg/L)	--	--	--	--	25	--	--	--	<.2	--
Cis-1,3-dichloropropene, total (μg/L)	--	--	--	--	25	--	--	--	<.2	--
1,2-Dibromoethylene, total (μg/L)	--	--	--	--	25	--	--	--	<.2	--
Vinylchloride, total (μg/L)	--	--	2	--	25	--	--	--	<.2	--
Trichloroethylene, total (μg/L)	--	--	5	--	25	--	--	--	<.2	5.7
Styrene, total (μg/L)	5	--	5	10	25	--	--	--	<.2	--
Xylene, total (μg/L)	--	--	10,000	20	25	--	--	--	<.2	--

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[1] MCL (Maximum contaminant level) is an enforceable, health-based maximum level (concentration) for contaminants in public drinking-water supplies as defined in the national primary and secondary drinking-water regulations established by the U.S. Environmental Protection Agency [U.S. Environmental Protection Agency, 1989].

[2] SMCL (Secondary maximum contaminant level) is a nonenforceable, aesthetically-based maximum level (concentration) for contaminants in public drinking-water supplies as defined in the national primary and secondary drinking-water regulations established by the U.S. Environmental Protection Agency [U.S. Environmental Protection Agency, 1989].

[3] MCL for chromium is 50 μg/L Cr^{+6} or 50 μg/L Cr^{+3}.

[4] New Hampshire Maximum Contaminant Levels (NHMCL) set by the New Hampshire Water Supply Engineering Bureau [New Hampshire Water Supply Engineering Bureau, 1990].

[5] New Hampshire Secondary Maximum Contaminant Levels (NHSMCL) set by the New Hampshire Water Supply Engineering Bureau [New Hampshire Water Supply Engineering Bureau, 1990].

[6] Statistics involving values less than detection limit were assigned values calculated by means of a technique described by Gilliom and Helsel (1986).

whose wells were contaminated or threatened by contamination from this site.

The Ottati and Goss/Great Lakes Container Corporation hazardous-waste site is on land west of State Route 125 in Kingston. The site was used for the storage and reconditioning of drums from 1955 through 1980. By 1980, the site contained an estimated 4,300 drums of unknown chemical waste (Goldberg-Zoino and Associates, 1986). Most of these drums were stored outdoors with no protection from the weather. Clean-up activities began in 1981, and drum-removal operations were completed by the summer of 1982. A preliminary hydrogeologic investigation, by a private consulting firm (Ecology and Environment, Inc., 1982) has indicated an extensive ground-water-contaminant plume that extends from the site towards Country Pond to the southeast. Another private consulting firm is completing a final RI/FS that will define the nature and extent of site contamination and identify the remedial action needed to complete clean-up activities at the site.

The Coakley landfill covers 20 acres in a residential area in North Hampton. The landfill borders the towns of Greenland to the northwest and Rye to the northeast. Originally a sand and gravel quarry, the site was converted to a landfill in 1971. Thirteen residential wells, to the north, east, and south of the site, have been closed because of contamination by VOCs from the landfill (New Hampshire Water Supply and Pollution Control Division, 1985a). A private consultant completed a draft RI/FS in 1988 that defined the nature and extent of site contamination and remedial action needed to clean up the site (Roy F. Weston, Inc., 1988-1989). As of 1990, no remedial action has been taken at the site except to cap the landfill and install catchment drains around its perimeter.

The Holton Circle site is in a residential cul-de-sac off Pillsbury Road in the town of Londonderry. Small concentrations of VOCs were detected in water samples from the unconsolidated and bedrock aquifers in 1988.

Pease Air Force Base is on a peninsula between Great Bay and the Piscataqua River in the towns of Portsmouth and Newington. A private consultant, under contract to the U.S. Air Force, did an Installation Restoration Program, Phase II Stage 1 Confirmation/Quantification Study at Pease Air Force Base during 1986. In this study, 20 sites were investigated for possible contamination. Past activities at Pease Air Force Base in support of aircraft maintenance has resulted in the generation of small quantities of hazardous wastes, including spent degreasers, solvents, paint strippers, and contaminated jet fuels (Roy F. Weston, Inc., 1986).

The Duston Road site is near the intersections of Duston Road, Eyssi Drive, and Atkinson Road in Salem. Ground water near the Duston Road site was determined to be contaminated with VOCs in October 1983 (New Hampshire Water Supply and Pollution Control Division, 1985b). The source of contamination proved to be drums buried in the overburden layer. In August 1984, more than 63 barrels, as well as debris and contaminated soil, were removed. Contamination at the site extends into the thin, sandy aquifer and the crystalline bedrock aquifer (New Hampshire Water Supply and Pollution Control Division, 1985b). In addition, some contaminants were found in Dietal Pond and Providence Hill Brook. Because ground water was contaminated in many nearby domestic wells, including wells finished in unconsolidated deposits and bedrock, a town water line was extended to the affected area in October 1984 to provide potable water.

Ten facilities (fig. 24 and pls. 1-3) are on the New Hampshire Water Supply and Pollution Control Division and New Hampshire Waste Management Divisions's RCRA Regulated Facilities List (New Hampshire Department of Environmental Services, 1987). Three of these sites are in Seabrook, two are in Derry, two are in Newington, one is in Salem, one is in Hampton, and one is in Londonderry.

SUMMARY AND CONCLUSIONS

The lower Merrimack and coastal river basins in southeastern New Hampshire encompass 327 mi^2, of which 24 percent is covered by stratified-drift deposits. About 79 percent of the water pumped by high-capacity wells is derived from wells screened in coarse-grained stratified drift. Population for the 25 communities of the study area was 228,495 in 1987, and is projected to increase at an average annual rate of 3.32 percent to the end of the century. The quantity and quality of ground-water resources are generally sufficient for immediate water needs, however, stresses from a rapid population increase have caused local deterioration in quality and shortages that have forced some communities to seek water from increasingly distant sources.

At present, the maximum yield of all community water-supply systems that withdraw water from the stratified drift is estimated to be 6 Mgal/d. Towns served by high-yielding gravel-packed wells include