

# CONTENTS

Abstract .....	1
Introduction .....	2
Purpose and Scope .....	2
Previous Investigations .....	3
Acknowledgments .....	4
Description of the Basin .....	4
Water Withdrawals .....	10
Precipitation-Runoff Model .....	14
Functional Description of the HSPF Model .....	14
Data Base .....	15
Streamflow Data .....	16
Meteorologic Data .....	17
Water-Withdrawal Data .....	21
Representation of the Basin .....	29
Hydrologic Response Units .....	29
Impervious Areas (IMPLNDs) .....	30
Pervious Areas (PERLNDs) .....	30
Development of PERLND Types .....	31
Residential Areas on Public Water and Onsite Septic Systems .....	32
Stream Reaches .....	33
Hydraulic Characteristics (FTABLEs) .....	34
Wetlands .....	37
Water Withdrawals .....	38
Streamflow Depletion by Ground-Water Withdrawals .....	39
Water Withdrawals in Excess of Streamflow .....	39
Model Calibration .....	42
Mean Annual Discharge .....	44
Monthly Mean Discharge and Seasonal Water Budgets .....	45
Daily Flow .....	46
Flow Duration .....	48
Low Flows .....	49
Miscellaneous Discharge Measurements .....	52
Summary of the Differences Between Simulations with Reading and Centroid Precipitation Data .....	53
Sensitivity Analysis .....	54
Response of Pervious (PERLNDs) and Impervious (IMPLNDs) Land Segments .....	54
Parameter Values .....	58
Model Limitations .....	63
Application of the Model: Effects of Water Withdrawals on Streamflow .....	63
Calibration-Period Simulations .....	64
Long-term Simulations .....	65
Summary .....	70
References .....	73
Appendix A: Documentation of Computer Program STRMDEPL—A Program to Calculate Streamflow Depletion by Wells Using Analytical Solutions .....	75
Appendix B: Ipswich River Watershed Model (HSPF) User Control Input File for PERLND and IMPLND Blocks .....	91

FIGURES

1–5. Maps showing:

1. Location of the Ipswich River Basin and meteorologic sites in northeastern Massachusetts and southern New Hampshire and Maine ..... 5
2. Towns, drainage network, and stream gaging-stations in the Ipswich River Basin ..... 6
3. Generalized surficial geology of the Ipswich River Basin ..... 8
4. Wetlands in the Ipswich River Basin ..... 9
5. Generalized 1991 land use in the Ipswich River Basin ..... 11

6. Graph showing monthly mean streamflows and cumulative monthly mean withdrawals at (A) South Middleton station, (B) Ipswich station, and (C) cumulative monthly mean withdrawals at Sylvania Dam, 1989–93..... 13

7. Schematic of inflows to and outflows from a stream reach (RCHRES) in the Hydrological Simulation Program-FORTRAN (HSPF) ..... 16

8. Map showing model reaches, subbasin boundaries, and water withdrawal locations in the Ipswich River Basin ..... 18

9–27. Graphs showing:

9. Combined actual and 15-day moving average daily ground-water withdrawals from two Wenham water supply wells, and the calculated streamflow depletion in Idlewild Brook, Mass., 1989..... 28
10. Areas of hydrologic response units in the Hydrological Simulation Program-FORTRAN (HSPF) model of the Ipswich River Basin as a percentage of the drainage area above the South Middleton and Ipswich stations and above Sylvania Dam ..... 32
11. Ground-water flow paths illustrating captured recharge and induced infiltration in a hypothetical aquifer: (A) undeveloped aquifer, (B) pumped well with a high water table, (C) pumped well with a low-water table surface, and (D) changing storage when withdrawals exceed captured recharge and induced infiltration..... 40
12. Actual water withdrawals and the withdrawals satisfied by streamflow in the Hydrological Simulation Program-FORTRAN (HSPF) in reach 1 of the Ipswich River Basin for the period June 1, 1991 through August 31, 1991..... 42
13. Relation of simulated mean annual discharge to observed for simulations made with centroid and Reading precipitation data for the Ipswich River at (A) South Middleton station, and (B) Ipswich station, 1989–93 ..... 45
14. Relation of simulated monthly discharge to observed for simulations made with centroid and Reading precipitation data for the Ipswich River at (A) South Middleton station, and (B) Ipswich station, 1989–93 ..... 46
15. Percent error between simulated flow made with the centroid precipitation data and observed flows for the Ipswich River at the (A) South Middleton, and (B) Ipswich stations by month, before and after adjusting evapotranspiration rates for seasonal bias, 1989–93 ..... 47
16. Simulated daily mean discharge to observed for simulations made with centroid and Reading precipitation data for the (A) South Middleton, and (B) Ipswich stations, Ipswich River, 1989–93 ..... 49
17. Simulated and observed daily-mean-discharge hydrographs for simulations made with centroid precipitation data at the (A) South Middleton, and (B) Ipswich stations, Ipswich River, 1989–93 ..... 50
18. Difference between simulated and observed daily mean discharges as a function of time at the (A) South Middleton, and (B) Ipswich stations, Ipswich River, 1989–93..... 51
19. Difference between simulated and observed daily mean discharges as a function of observed discharge at the (A) South Middleton, and (B) Ipswich stations, Ipswich River, 1989–93..... 52
20. Observed and simulated daily mean discharge at the Ipswich station for simulations made with the centroid precipitation, air temperature, and simulated snowpack water for the Ipswich River Basin, February through April 1993..... 53
21. Flow-duration curves for observed and simulated daily mean discharges for simulations made with the centroid and Reading precipitation data for the (A) South Middleton, and (B) Ipswich stations, Ipswich River, 1989–93 ..... 54
22. Discharge simulated with centroid and Reading precipitation data and instantaneous discharge measurements made at Fish Brook near Boxford, July 1993..... 55

23. Runoff as surface-flow, interflow, and base-flow and evapotranspiration losses from surface storage, upper-zone storage, lower-zone storage, and ground-water storage from each hydrologic response unit for: (A) mean annual water budget, (B) wet month water budget—April 1993, and (C) dry month water budget—August 1993, Ipswich River Basin .....	56
24. Flow-duration curves developed from simulated daily flows for current conditions (base simulation), no withdrawals, only surface-water withdrawals, and only ground-water withdrawals for the Ipswich River at the (A) South Middleton and (B) Ipswich stations, 1989–93 .....	65
25. Hydrographs for current conditions (base simulation), no withdrawals, only surface-water withdrawals, and only ground-water withdrawals for the Ipswich River at the (A) South Middleton and (B) Ipswich stations, 1989–93 .....	66
26. Flow-duration curves for average water withdrawals with 1991 land-use conditions, no withdrawals with 1991 land-use conditions, and no withdrawals with undeveloped land-use conditions for the Ipswich River at the (A) South Middleton, and (B) Ipswich stations for long-term simulations (1961–95) .....	67
27. Log-Pearson Type III low-flow exceedence probabilities and recurrence intervals for (A) 1-day, (B) 7-day, and (C) 30-day annual minimum mean streamflows based on long-term (1961–95) simulations of average water withdrawals, no withdrawals with 1991 land-use conditions, and no withdrawals with undeveloped land-use conditions, for the Ipswich River at the South Middleton and Ipswich stations .....	68

## TABLES

1. Monthly mean streamflow at the South Middleton and Ipswich stations, and cumulative monthly mean water withdrawals to the stations and Sylvania Dam, Ipswich River Basin, Mass., 1989–93.....	12
2. Organization and description of Data Set Numbers (DSNs) in the Watershed Data Management (WDM) system for the Ipswich River Basin .....	17
3. Meteorologic stations and data used to develop grid-cell data for the Ipswich River Basin, Mass.....	19
4. Summary of municipal water-use information in the Ipswich River Basin.....	22
5. Massachusetts Department of Environmental Protection registered or permitted public and commercial water withdrawals in the Ipswich River Basin.....	23
6. Estimated effective impervious area by land use, Ipswich River Basin .....	30
7. Hydrologic response units (HRUs) used to represent the Ipswich River Basin, and their contributing areas to the South Middleton and Ipswich stations, and to Sylvania Dam .....	31
8. Stream reaches (RCHRES) in the Hydrological Simulation Program-FORTRAN model of the Ipswich River Basin.....	35
9. Deficit between actual water withdrawals and the withdrawal satisfied by streamflow in the Hydrological Simulation Program-FORTRAN (HSPF) for Ipswich River reaches above the South Middleton station, 1989–93 .....	41
10. Summary of annual, monthly, and daily model-fit statistics at South Middleton and Ipswich stations for Hydrological Simulation Program-FORTRAN (HSPF) simulations made with centroid and Reading precipitation data, Ipswich River Basin, 1989–93 .....	43
11. Observed and simulated annual discharge at South Middleton and Ipswich stations for Hydrological Simulation Program-FORTRAN (HSPF) simulations made with centroid and Reading precipitation data, Ipswich River Basin, 1989–93 .....	44
12. Summary of seasonal model-fit statistics at South Middleton and Ipswich stations for Hydrological Simulation Program-FORTRAN (HSPF) simulations made with centroid and Reading precipitation data, Ipswich River Basin, 1989–93 .....	48
13. Summary of low-flow model-fit statistics at the South Middleton and Ipswich stations for Hydrological Simulation Program-FORTRAN (HSPF) simulations made with centroid and Reading precipitation data, Ipswich River Basin, 1989–93 .....	55
14. Relative sensitivity of simulated flow characteristics to HSPF model parameter or storage change, Ipswich River Basin, 1989–93 .....	59
15. Sensitivity of runoff characteristics, as the percent error from the observed value, to selected model PERLND parameters and wetland storage values, in the HSPF Ipswich River Basin model, 1989–93 .....	61
16. Alternative water withdrawals and land-use scenarios simulated for the Ipswich River Basin.....	64

## CONVERSION FACTORS AND VERTICAL DATUM

### CONVERSION FACTORS

	<b>Multiply</b>	<b>By</b>	<b>To obtain</b>
<b>Length</b>			
	inch (in.)	2.54	centimeter
	inch (in.)	25.4	millimeter
	foot (ft)	0.3048	meter
	mile (mi)	1.609	kilometer
<b>Hydraulic gradient</b>			
	foot per mile (ft/mi)	0.1894	meter per kilometer
<b>Area</b>			
	acre	4,047	square meter
	acre	0.4047	hectare
	acre	0.004047	square kilometer
	square mile (mi <sup>2</sup> )	259.0	hectare
	square mile (mi <sup>2</sup> )	2.590	square kilometer
<b>Volume</b>			
	million gallons (Mgal)	3,785	cubic meter
	gallon per day (gal/d)	0.003785	cubic meter per day
	inch per hour per acre (in/h/acre)	10.28	meter per hour per hectare
<b>Flow rate</b>			
	cubic foot per second (ft <sup>3</sup> /s)	0.02832	cubic meter per second
	million gallons per day (Mgal/d)	0.04381	cubic meter per second
	inch per hour (in/h)	0.0254	meter per hour
	million gallons per day per square mile [(Mgal/d)/mi <sup>2</sup> ]	1,461	cubic meter per square kilometer
	inch per year (in/yr)	25.4	millimeter per year
<b>Hydraulic conductivity</b>			
	foot per day (ft/d)	0.3048	meter per day
<b>Diffusivity</b>			
	foot squared per second (ft <sup>2</sup> /s)	0.09290	meter squared per second

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$^{\circ}\text{F} = (1.8 \times ^{\circ}\text{C}) + 32$$

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$^{\circ}\text{C} = (^{\circ}\text{F} - 32) / 1.8$$

### VERTICAL DATUM

**Sea level:** In this report, “sea level” refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

**Altitude,** as used in this report, refers to distance above or below sea level.