Prepared in cooperation with the
U.S. Department of Agriculture, Natural Resources Conservation Service, and the
Rhode Island Water Resources Board

Simulated Effects of Water Withdrawals and Land-Use Changes on Streamflows and Groundwater Levels in the Pawcatuck River Basin, Southwestern Rhode Island and Southeastern Connecticut

Scientific Investigations Report 2009–5127

U.S. Department of the Interior
U.S. Geological Survey

Cover. Photograph shows Wood River at Hope Valley, Rhode Island. (Photograph by Peter Flinker, Dodson Associates, Ltd.)

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Part 5. HSPF and MODFLOW—Capabilities, Limitations, and Integration

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KEN SALAZAR, Secretary

U.S. Geological Survey
Marcia K. McNutt, Director

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Conversion Factors, Datum, and Abbreviations

Inch/Pound to SI

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
million gallons (Mgal)	3,785	cubic meter (m^3)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
	Flow rate	
miles per hour (mi/hr)	1,609	meter per hour (m/hr)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
cubic foot per second per square mile [(ft^3/s)/mi^2]	0.01093	cubic meter per second per square kilometer [(m^3/s)/km^2]
gallon per year (gal/yr)	0.003785	cubic meter per year (m^3/yr)
gallons per year per yard		cubic meter per year per meter
gallons per year per acre		cubic meter per year per hectare
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
million gallons per day per acre [(Mgal/d)/ac]		cubic meter per day per hectare [(m^3/d)/hectare]
inch per acre (in/ac)		millimeter per hectare
inch per year (in/yr)	25.4	millimeter per year (mm/yr)
	Hydraulic conductivity	
foot per day (ft/d)	0.3048	meter per day (m/d)
	Transmissivity*	
foot squared per day (ft^2/d)	0.09290	meter squared per day (m^2/d)

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

$$°C=(°F–32)/1.8$$

Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29) or to the North American Vertical Datum of 1988 (NAVD 88), as specified.

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Altitude, as used in this report, refers to distance above the vertical datum.

Transmissivity: The standard unit for transmissivity is cubic foot per day per square foot times foot of aquifer thickness [(ft^3/d)/ft^2]ft. In this report, the mathematically reduced form, foot squared per day (ft^2/d), is used for convenience.

ACRONYMS AND ABBREVIATIONS

ABF	Aquatic Baseflow
AIC	Akaike Information Criterion
ANNIE	Interactive hydrologic analyses and data management software program
CGAP	Channel Geometry Analysis software program
DSN	Data Set Number associated with the Watershed Data Management database
EPRCMM	Eastern Pawcatuck River conjunctive-management model
ET	Evapotranspiration
FBWR	Fisherville Brook Wildlife Refuge
FTABLE	Function table that defines the relation between depth, storage, and discharge of water in a reach
GENFTBL	GENerate FTaBLe software program
GENSCN	GENerate SCeNarios software program
GIS	Geographic information system
HAP	Hunt-Annaquatucket-Pettaquamscutt
HRU	Hydrologic response unit
HSPEXP	Expert system for the HSPF model
HSPF	Hydrologic Simulation Program–FORTRAN
IDCONS	Constituent identification attribute associated with the Watershed Data Management database
IDLOCN	Stream reach identification attribute associated with the Watershed Data Management database (for example, BEAV3 identifies the lower Beaver River)
IDSCEN	Scenario identification attribute associated with the Watershed Data Management database
IHM	Integrated Hydrologic Model
IMPLND	HSPF impervious-area land element
LID	Low-impact development
LULC	Land Use Land Cover
LWCMM	Lower Wood conjunctive-management model
MAGIC	University of Connecticut–Map and Geographic Information Center
METCMP	METerologic CoMPutation software
MFE	Model-fit efficiency
MODFLOW	Modular groundwater-flow model
MULT	Multiplier field in uci file of HSPF model
NIC	Narragansett Improvement Company
NOAA	National Oceanic and Atmospheric Administration

NPDES	National Pollutant Discharge Elimination System
NRCS	Natural Resources Conservation Service
NWIS	National Water Information System
NWS	National Weather Service
PERLND	HSPF pervious-area land element
PET	Potential evapotranspiration
PEST	Parameter estimation program
PROVID	Providence–T.F. Green Airport, Warwick, Rhode Island
RCHRES	HSPF river or reservoir reach; the accompanying number identifies the reach in the model input file.
RIDEM	Rhode Island Department of Environmental Management
RIGIS	Rhode Island Geographic Information Systems
RIWRB	Rhode Island Water Resources Board
SA	Special action in the HSPF program
SSURGO	Soil Survey Geographic Database produced by the NRCS
STR	Stream-routing package in MODFLOW
STRMDEPL	Analytical program to compute streamflow depletion from a pumped well
SWSTAT	Surface-water statistics program
uci	HSPF user control input file
URI	University of Rhode Island
USGS	U.S. Geological Survey
WDM	Watershed Data Management database
WUSG	Pawcatuck Watershed Water Use Stakeholders Group

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Abstract

The Pawcatuck River Basin, in southwestern Rhode Island and southeastern Connecticut, is an important high-quality water resource that provides water for domestic and public supplies, irrigation, recreation, and a rich aquatic ecosystem. Streamflow records for several rivers in the basin indicate that during the summer, withdrawals could be affecting aquatic habitat and diversity, water quality, and the value of the rivers as scenic and recreational resources. Concerns over the effects of water withdrawals on streamflow, pond levels, groundwater levels, and aquatic habitat in the basin prompted the development of surface-water, groundwater, and conjunctive-management models. Separate models were developed because linking surface-water and groundwater models was not feasible in this geologic setting. Each individual model provided an accurate representation of the part of the hydrologic system under consideration. A precipitation-runoff model was developed for the entire basin on the basis of the Hydrologic Simulation Program-FORTRAN (HSPF) model. Groundwater-flow models were developed for the lower Wood River and the eastern Pawcatuck River areas in the basin on the basis of groundwater-flow models (MODFLOW). In addition, conjunctive-management models were developed for subareas of the two groundwater model areas. These models were used to evaluate current conditions, long-term conditions, water-management alternatives, and land-use changes in the basin. Additionally, the results from MODFLOW were compared to the results of a streamflow-depletion algorithm in the HSPF model.

Part 1. Water Resources in the Pawcatuck River Basin

Climate, streamflow, groundwater-level, pond-level, and water-use data were collected throughout the 303-square-mile Pawcatuck River Basin during 2000–04 to support development of the models. Additionally, hydrogeologic data were compiled for the modeling efforts from previous studies throughout the basin. Climate data were collected at two sites in the basin and compiled for four National Weather Service sites. Streamflow data were collected at 18 continuous streamflow-gaging stations for at least 2 years of the study period. Monthly streamflow measurements were collected at 36 partial-record stations for at least 1.5 years. Daily streamflows for these partial-record stations were calculated by using the mathematical procedure Maintenance of Variance Extension (MOVE.1). Groundwater-level data were collected monthly or more frequently at 11 wells and continuously at 8 wells for a least part of the study period in the basin. Pond-level data were collected at 23 ponds for about 1.5 years during the study period. Water-withdrawal data were compiled from 5 large municipal suppliers for 16 wells in the basin. Data on withdrawals for irrigation were collected for 11 turf-farm sites and 3 golf courses. These data were used to develop logistic-regression equations to estimate the probability of irrigation on a specific day during the irrigation season for unmetered turf farms, surface-water withdrawal golf courses, and groundwater withdrawal golf courses using climatic data on total precipitation and potential evapotranspiration during the preceding days. Average hourly withdrawal rates were also estimated by using data collected on hourly irrigation patterns at the 11 turf-farm sites and 3 golf courses. Using the logistic regression equations predicted days of irrigation during the study period and the average hourly irrigation patterns; the irrigation rates for unmetered turf farms, surface-water withdrawal golf courses, and groundwater withdrawal golf courses could be estimated.

Part 2. Simulation of Water-Use and Land-Use Changes on Streamflow with a Precipitation-Runoff Model (HSPF)

The precipitation-runoff model HSPF was developed and calibrated for the Pawcatuck River Basin to evaluate the effect of withdrawals and land-use change on streamflow. The model was calibrated to the period of January 1, 2000, to September 30, 2004, with measured and estimated flows at 17 continuous-record streamflow-gaging stations and 34 partial-record stations. Graphical comparison and statistical analysis with observed flows indicate that the model is generally well calibrated.

Simulated streamflows for the 1960–2004 period were used to evaluate the effects of (1) no withdrawals, (2) current (2000–04) withdrawal, (3) conversion of selected surface-water-irrigation withdrawals to groundwater withdrawals, (4) future water-supply demands, and (5) land-use change. In general, the largest differences between simulations of current water demands and no demands were calculated for the eastern Pawcatuck River subbasins–Chipuxet River (two locations), Chickasheen Brook, and the headwaters of the Pawcatuck River. The effects of switching from direct surface-water withdrawals to groundwater withdrawals at selected sites were most pronounced in the daily mean flow-duration curves for the Beaver and Chipuxet Rivers, which drain subbasins where irrigation withdrawals can affect a large percentage of low flows. Hourly flow fluctuations in the August 2002 hydrograph caused by irrigation withdrawals from surface water were greatly reduced or eliminated entirely by switching to groundwater withdrawals in subbasins where irrigation demands are prevalent. Potential new withdrawals in the eastern Pawcatuck River subbasins resulted in zero flow in the lower Chipuxet River and decreased the lowest flows under current withdrawals by as much as 90 percent compared to simulations with no withdrawals.

Simulations of land-use change evaluated the effects of (1) land-use change only, (2) change in water demands only, and (3) combined effects of land-use change and change in water demands. Overall, about 10 percent of the basin was classified as developed in 1995, but about 50 percent of the basin could be developed within the constraints used in the analysis. Future water-use demands in the basin were estimated to be about 4 times greater for domestic use and about 6 times greater for commercial and industrial use at buildout compared to current (1995–99) use. In general, simulations under buildout conditions indicated that high flows increase slightly and low flows decrease slightly as a result of land-use change relative simulations under current (1995) conditions, but changes in flows generally were not noteworthy. The extent to which streamflow changes in response to development depends on how the land is developed; the pattern and extent of development can differ widely and produce effects different from those simulated, particularly in localized areas.

Part 3. Simulated Effects of Withdrawals on Groundwater Flow (MODFLOW Models)

Groundwater-flow models (MODFLOW) were developed for the lower Wood River and eastern Pawcatuck River areas in the Pawcatuck River Basin for the purposes of assessing the potential effects of groundwater pumping on streamflows and water levels at proposed irrigation and water-supply sites in the study area. The results of the MODFLOW models and a streamflow-depletion algorithm in the HSPF model were compared, and alternatives were evaluated for the conjunctive management of the ground- and surface-water resources of the basin.

The model simulations included analyses of the effects of constant and varying pumping and constant and varying recharge rates, the effects of constant pumping and varying recharge rates, and the effects of different well distances from streams under constant and varying pumping rates. Simulations were made to compare and contrast the effects of these simulations on rivers with both low and high streamflows to determine if the responses of these rivers and the surrounding aquifer to the changes in simulated stresses differed with river size (large versus small).

Simulation results indicate that streamflow depletion is similar between large and small rivers for constant pumping and recharge scenarios as well as during periods when simulated streamflow was at or above average. In both cases, streamflow-depletion rates were about the same as the simulated pumping rates in nearby wells. During dry periods, such as summer (June through August) and early fall (September and October), when simulated streamflows in small rivers is at or near zero, the small rivers are no longer a source of water to pumped wells. In this case, aquifer storage becomes the primary source of water to the pumped wells; this withdrawal from storage results in much greater drawdowns in the nearby aquifer than would have occurred near large rivers or small rivers with moderate streamflow.

Analysis done to determine the effects of relocating irrigation-withdrawal wells away from a river shows that the effects of seasonally variable pumping on streamflow, such as for turf-farm and golf course irrigation, can be reduced by increasing the distance from the wells to the river. This is due to the lag time in the response of the rivers to the pumping stress. As a result, summer irrigation pumping from wells located further away from a river did not affect streamflow until later in the fall (October and November) when streamflows are typically higher than in the summer because of the lower pumping and higher recharge in the fall.

Part 4. Conjunctive-Management Models as Tools for Water-Resources Planning

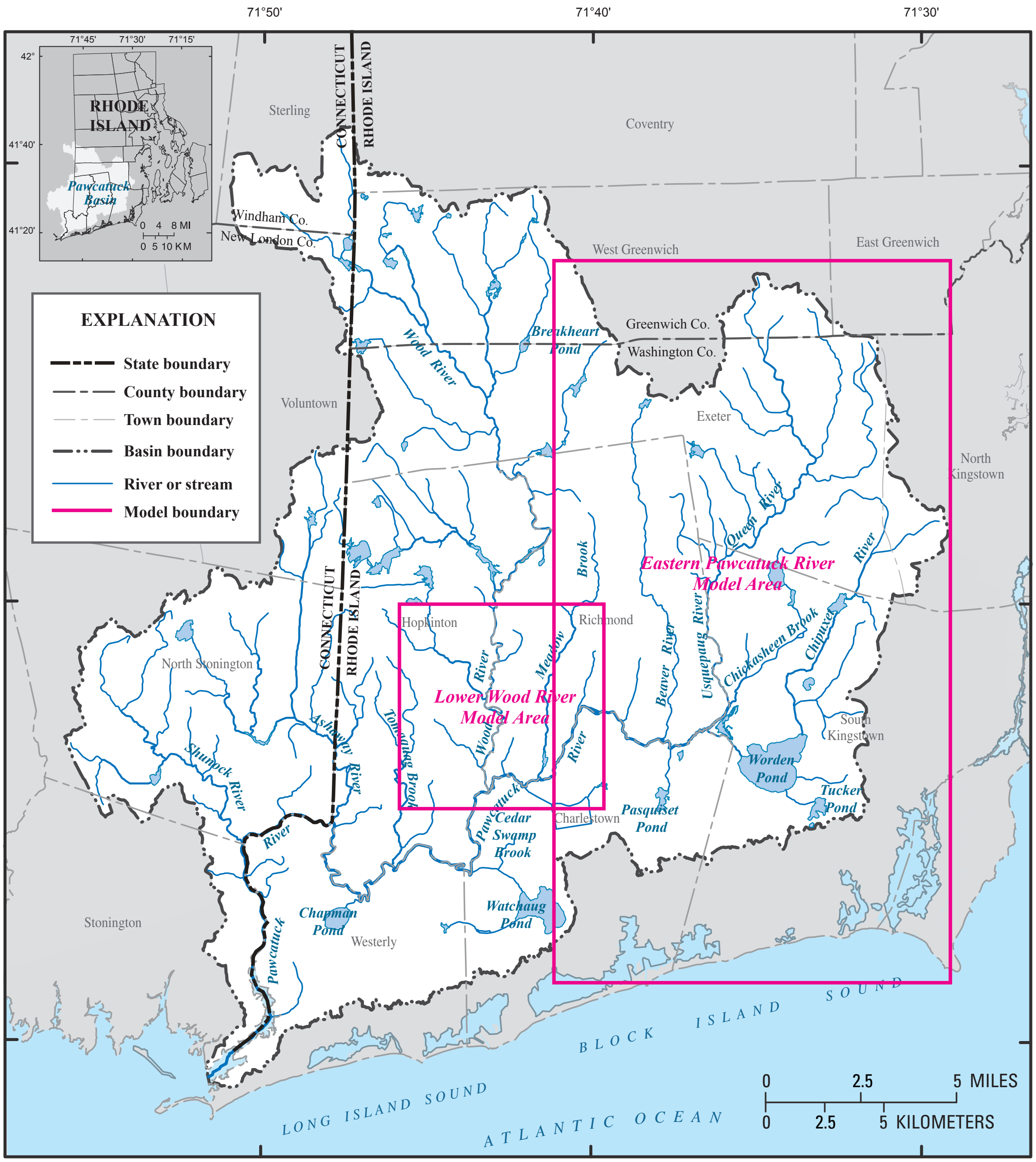
Results from conjunctive-management-model simulations may be used to balance groundwater and surface-water withdrawals needed for water supply and aquatic-habitat protection. Conjunctive-management models were developed for two selected areas in the Pawcatuck River Basin to evaluate the potential for improvements in water-withdrawal strategies in the basin. Two conjunctive-management models, described herein as the eastern Pawcatuck River conjunctive-management model (EPRCMM) and the lower Wood River conjunctive-management model (LWRCMM) were developed. A total of 250 applications of the models were developed and tested for the eastern Pawcatuck River (105 applications) and lower Wood (145 applications) areas. The conjunctive-management model combines results of statistical analysis of water-use data, simulations by the transient numerical groundwater models developed for two selected areas in the basin, and results of streamflow simulations by the basinwide Hydrologic Simulation Program-FORTRAN model. This information is used to formulate linear optimization models for water-resource management. These management models were developed and tested to illustrate the potential effects of the conversion of surface-water withdrawals to groundwater withdrawals, withdrawal-well network design, withdrawal capacity, and streamflow-depletion criteria on the maximum obtainable water yield in each of the two model areas. In both areas, conjunctive-management models using maximum withdrawal capacities of 1.0, 1.4, and 2.0 million gallons per day (Mgal/d) were tested to illustrate the dynamic relations among depletion criteria, network design (the number, type, and location of withdrawal sites), and the production capacity of the water-withdrawal network. The results indicate that the conversion of surface-water withdrawals to groundwater withdrawals for irrigation has the potential benefit of increases in total water yields for a given level of depletion. The simulated addition of potential future production wells to these scenarios indicates that groundwater withdrawals are preferred in management models designed to maximize withdrawals for a fixed set of depletion criteria because these wells would withdraw water throughout the year instead of only during the low-flow irrigation season (summer and early fall). In the EPRCMM area, total annual withdrawals range from about 400 million gallons per year (Mgal/yr) at allowable depletions that are 25 percent of the minimum monthly one-day streamflow to 1,200 to 2,400 Mgal/yr depending on the number of active withdrawal sites, maximum sustainable withdrawal capacities, and allowable streamflow depletions. Similarly, in the LWRCMM area, total annual withdrawals range from about 500 Mgal/yr at allowable depletions that are 25 percent of the minimum monthly one-day streamflow to 1,200 to 3,500 Mgal/yr depending on the number of active withdrawal sites, maximum sustainable withdrawal capacities, and allowable streamflow depletions.

Water-resource managers rely on tools such as HSPF and MODFLOW to address water-resources issues by simulating alternative management strategies. The choice of model, or even the need for a model, however, largely depends on the questions posed. Each model has strengths and weaknesses related to the differing hydrologic processes the models are intended to simulate and the spatial and temporal scales of the models. Comparison of selected results simulated by these two models demonstrates these limitations and the judgment required to determine the suitability of a particular model for making management decisions.

Introduction

The 303-mi^2 Pawcatuck River Basin is located in southwestern Rhode Island and southeastern Connecticut (fig. I–1). The high-quality water in the basin is important for domestic and public supplies, irrigation, recreation, and the aquatic ecosystem. The U.S. Environmental Protection Agency (2005) reports that this area of Rhode Island has a high biodiversity, with 85 percent of the State’s globally rare species and 65 percent of the State’s rare and unique natural communities. The basin has a large area of irrigated agricultural land (4.82 mi^2) (primarily turf farms) and 11 golf courses (0.76 mi^2) that typically need irrigation during the dry periods of the summer when streams and groundwater levels are typically at their lowest levels (Natural Resources Conservation Service, 2003). The U.S. Environmental Protection Agency (2005) reports that the Pawcatuck River Basin has the highest concentration of turf farms in the Nation. Water withdrawals in the basin may be affecting aquatic habitat and diversity, water quality, and the value of the rivers as a scenic and recreational resource. Additionally, there are concerns over the effects of water withdrawals on ponds, groundwater levels, and aquatic habitat. The basin was designated as a sole-source aquifer by the U.S. Environmental Protection Agency, 1988, 2005. Thus, management of water resources in the basin to ensure sustainable supplies and adequate water for aquatic habitat is of concern to governmental agencies, environmental organizations, and private citizens. These concerns are intensified by rapid development and population growth in the region and the likelihood of greater demands for clean water in the future.

The U.S. Department of Agriculture, Natural Resources Conservation Service (NRCS) is a Federal agency that works with communities to improve and protect their soil, water, and other natural resources. The NRCS in Rhode Island works closely with the agricultural community to meet water needs and use water effectively for the production of agricultural products while maintaining the aquatic habitat, water quality, and water used for recreation. The Rhode Island Water Resources Board (RIWRB) is the principal State agency concerned with sustainable water supplies. The RIWRB works closely with the Rhode Island Department of Administration’s Statewide Planning Program to develop and refine policies affecting water supply, including emergency planning (Rhode Island Water Resources Board, 2002). In 1999, the Rhode Island General Assembly designated the RIWRB as the sole authority to devise fair and equitable allocation of state water resources and to ensure that long-term considerations of water supply prevail over short-term considerations.



Base from U.S. Geological Survey digital data,
North American Datum of 1983,
Rhode Island State Plane projection, 1:24,000

Figure I–1. Location of the Pawcatuck River Basin study area and groundwater model extents, southwestern Rhode Island and southeastern Connecticut.

The NRCS and RIWRB began a cooperative study with the U.S. Geological Survey (USGS) in 2002 to develop a physically based precipitation-runoff model, groundwater models, and conjunctive-management models for selected areas of the Pawcatuck River Basin. The results of these models will assist the NRCS, RIWRB, State, and local communities in understanding how streamflow, groundwater levels, and pond levels in the basin may be affected by human activities such as withdrawals for water supply and irrigation. The models also will allow simulation of possible future water-management alternatives to evaluate their effects on streamflows, groundwater levels, and pond levels. In addition, data collected during this study will provide information necessary for stream-habitat assessments and for use in water-management decisions at all levels.

Purpose and Scope

This report describes the development and application of a precipitation-runoff model based on the Hydrologic Simulation Program-FORTRAN (HSPF) (Bicknell and others, 2000), groundwater models based on MODFLOW (Harbaugh and others, 2000), and conjunctive-management models for the Pawcatuck River Basin. It also presents climatological, hydrological, and water-use data collected between 2000 and 2004 to support development and calibration of the models. Information on differences related to streamflow depletion between results obtained from HSPF and MODFLOW are also discussed in the report. The report also includes information about the study area, climate, streamflow, hydrogeology, groundwater and pond levels, water use, methods used to obtain the data, and logistic-regression equations developed to predict the likelihood of turf-farm and golf-course irrigation.

The report is organized as follows: Part 1—Water resources of the basin; Part 2—HSPF modeling results; Part 3—MODFLOW modeling results; Part 4—Conjunctive-management modeling results; and Part 5—Comparison of results from HSPF and MODFLOW modeling. Appendixes at the back of the report provide supporting information concerning data used in the models, calibration of the models, modeling runs, and other technical aspects of the study. The characteristics and scenarios run for the HSPF, MODFLOW, and conjunctive-management models (Parts 2, 3 and 4 of the report, respectively) are summarized in table I–1.

Table I–1. Overview of characteristics and scenarios used in the HSPF, MODFLOW, and conjunctive-management models for the Pawcatuck River Basin, southwestern Rhode Island and southeastern Connecticut, that are described in Parts 2, 3, and 4 of this report.

	Part 2: HSPF model	Part 3: MODFLOW models	Part 4: Conjunctive-management models
		Characteristics	
Spatial domain	Entire basin	1. Lower Wood River area. 2. Eastern Pawcatuck area.	1. Lower Wood River area. 2. Lower Usquepaug-Queen River and Beaver River subbasins (part of eastern Pawcatuck area).
Calibration period	2000–04	2000–04	Not applicable.
Run period	1960–2004	2000–04	1960–2004.
Time step	Hourly	Monthly and weekly	Daily and monthly.
Constraints	Not applicable	Not applicable	1. Maximum rates of streamflow depletion at selected sites. 2. Minimum and maximum withdrawal rates at selected sites. 3. Seasonal withdrawal patterns.
		Scenarios run	
No water withdrawals	Yes	No	Not applicable.
Current water withdrawals	Yes	Yes	Not applicable.
Conversion of surface-water irrigation withdrawals to ground-water withdrawals	Yes	Yes, for selected locations	Yes, for selected locations.
Proposed future water-supply withdrawals	Yes	Yes, for selected locations	Yes, for selected locations.
Buildout: (1) land-use changes only, (2) water-demand changes only, and (3) combined effects of both land-use water-demand changes	Yes	No	No.

Description of the Study Area

The Pawcatuck River Basin is in southwestern Rhode Island in Washington and Kent Counties and in southeastern Connecticut in New London and Windham Counties (fig. I–1). Land area in the basin totals 303 mi^2, of which 246 mi^2 is in Rhode Island and 57 mi^2 is in Connecticut. Ten towns in Rhode Island and four towns in Connecticut are partially or wholly within the basin. In 1990, the basin population was approximately 61,500, and the estimated population during the late 1990s was approximately 67,000 (Wild and Nimiroski, 2004). The Pawcatuck River Basin is part of the Seaboard Lowland section of the New England physiographic province (Denny, 1982). The topography north of the Pawcatuck River is characterized by gently rolling hills with northeast-southwest trending valleys in the eastern part of the basin and northwest-southeast trending valleys in the western part of the basin. South of the Pawcatuck River, the topography is mainly flat. Altitudes are as high as 629 ft on Bald Hill in West Greenwich, R.I., in the northern part of the basin. The Pawcatuck River generally flows from east to southwest before discharging into the Atlantic Ocean (fig. I–1). Climate in the basin is classified as moist continental. Mean annual precipitation is about 51.8 inches per year (in/yr), and the mean annual temperature is about 50°F in the basin (National Oceanic and Atmospheric Administration, 2002). The Pawcatuck River's major tributaries, from east to west, are the Chipuxet, Usquepaug-Queen, Beaver, Wood, Ashaway, and Shunock Rivers. Surficial geology in the basin is mainly glacial stratified deposits along the major river valleys and glacial till or exposed bedrock in the upland area (fig. I–2). Along the southern border of the basin is the Charlestown glacial moraine, which acts as a physical barrier to surface-water flow and directs the Pawcatuck River to its discharge point in the southwestern part of the basin.

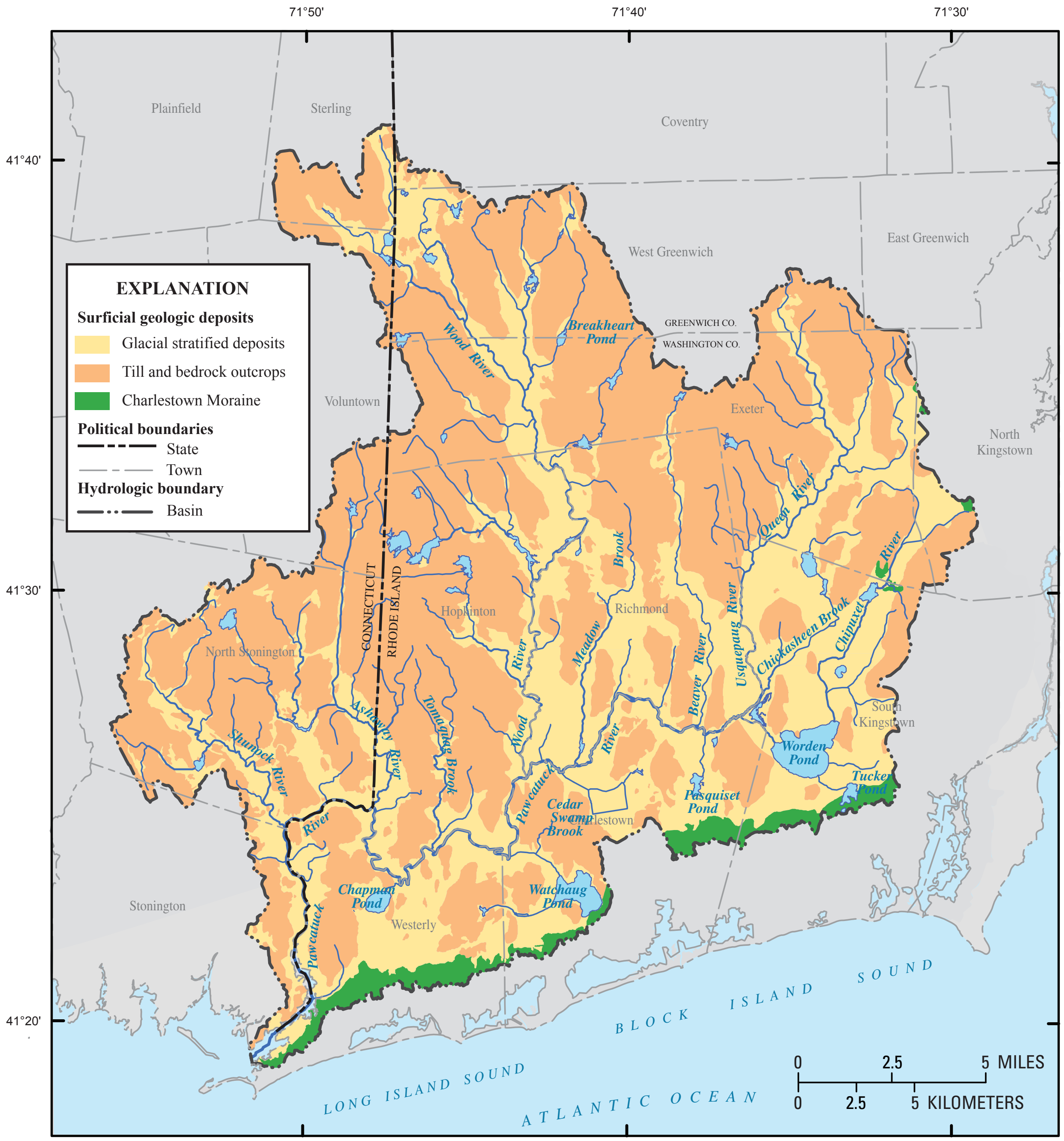
Land use in the basin is about 61 percent forested, 14.8 percent wetlands (2.3 percent nonforested wetlands and 12.5 percent forested wetlands), 10 percent developed (residential, commercial, industrial, and transportation), 9.6 percent open space in undeveloped areas, 2.7 percent water bodies (lakes and ponds), and 1.9 percent irrigated land (golf courses and agriculture). The irrigated agricultural lands, primarily turf farms, are mainly in the eastern part of the basin. The developed area is mainly the southwest part of the basin, including the towns of Westerly, R.I., and Stonington, Conn. (fig. I–3).

Previous Investigations

Many studies done by the USGS have investigated the groundwater and surface-water resources and the water quality of the Pawcatuck River Basin and its subbasins. Groundwater resources in the basin were investigated from the late 1940s to the mid-1990s by Allen and Jeffords (1948), Allen and others (1966), Gonthier and others (1974), Dickerman (1984), Dickerman and Ozbilgin (1985), Johnston and Dickerman (1985), Dickerman and others (1990), Dickerman and Bell (1993), and Dickerman and others (1997). These studies compiled and collected information on the hydrogeology of the basin, particularly aquifer properties that were then used to develop groundwater-flow models. The groundwater-flow models were used to evaluate the effects of pumping alternatives on water levels, baseflow, and wetlands in the sand and gravel valley-fill deposits. The hydrogeologic, streamflow, and water-quality data collected in these studies were presented in data reports by Allen and others (1963), Dickerman (1976), Dickerman and Johnston (1977), Dickerman and Silva (1980), Dickerman and others (1989), and Kliever (1995). The hydrogeology and recharge for the contributing area to a water-supply well in the southwestern and central part of the basin were recently described by Friesz (2004) and Friesz and Stone (2007), respectively.

The Pawcatuck River Basin encompasses all or parts of 12 USGS quadrangles: the Ashaway, Carolina, Coventry Center, Hope Valley, Kingston, Oneco, Old Mystic, Quonochontaug, Slocum, Voluntown, Watch Hill, and Wickford USGS quadrangles. The USGS has published geologic maps describing the surficial and bedrock geology of these quadrangles (Power, 1957, 1959; Moore, 1958, 1959, 1964, 1967; Kaye, 1961; Schafer, 1961, 1965, 1968; Feininger, 1962, 1965a,b,c; Harwood and Goldsmith, 1971a,b; Goldsmith, 1985). The USGS has also published groundwater maps describing the bedrock contours, water-table altitudes, well locations, and till and stratified sand and gravel deposits of these quadrangles (Bierschenk, 1956; Bierschenk and Hahn, 1959; Hahn, 1959; Johnson and Marks, 1959; Mason and Hahn, 1959, 1960; Johnson and others, 1960; LaSala and Hahn, 1960; LaSala and Johnson, 1960; Mason and others, 1960; Randall and others, 1960; Johnson, 1961a,b).

Recently, studies related to streamflow and aquatic habitat in the Pawcatuck River Basin have focused on the Usquepaug-Queen River subbasin. Armstrong and Parker (2003) characterized the aquatic habitat, stream temperature, and fish communities in the subbasin. In that study, minimum streamflow requirements for fish habitat were identified by standard flow-setting techniques for selected riffle sites. Zarriello and Bent (2004) developed a precipitation-runoff model based on HSPF to evaluate the effects of water withdrawals and land-use changes on streamflows in the Usquepaug-Queen River subbasin. The study by Zarriello and Bent (2004) was the pilot study for the present study of the Pawcatuck River Basin. In the early 1990s, a regionalized regression equation for southern Rhode Island streams was developed by Cervione and others (1993) for estimating the 7-day low flow that is expected to occur once every 10 years (commonly referred to as the 7Q10). Additionally, they also provided estimates of low-flow durations (for the 80th, 90th, 95th, 98th, and 99th percentiles) and the 7Q10 for 22 partial-record stations in the Pawcatuck River Basin. All 22 partial-record stations were also monitored for streamflow during the present study.



Base from U.S. Geological Survey digital data,
North American Datum of 1983,
Rhode Island stateplane projection, 1:24,000,
Surficial geology from Rhode Island Geographic Information System (RGIS), 1995

Figure I–2. Location of surficial geology in the Pawcatuck River Basin, southwestern Rhode Island and southeastern Connecticut.

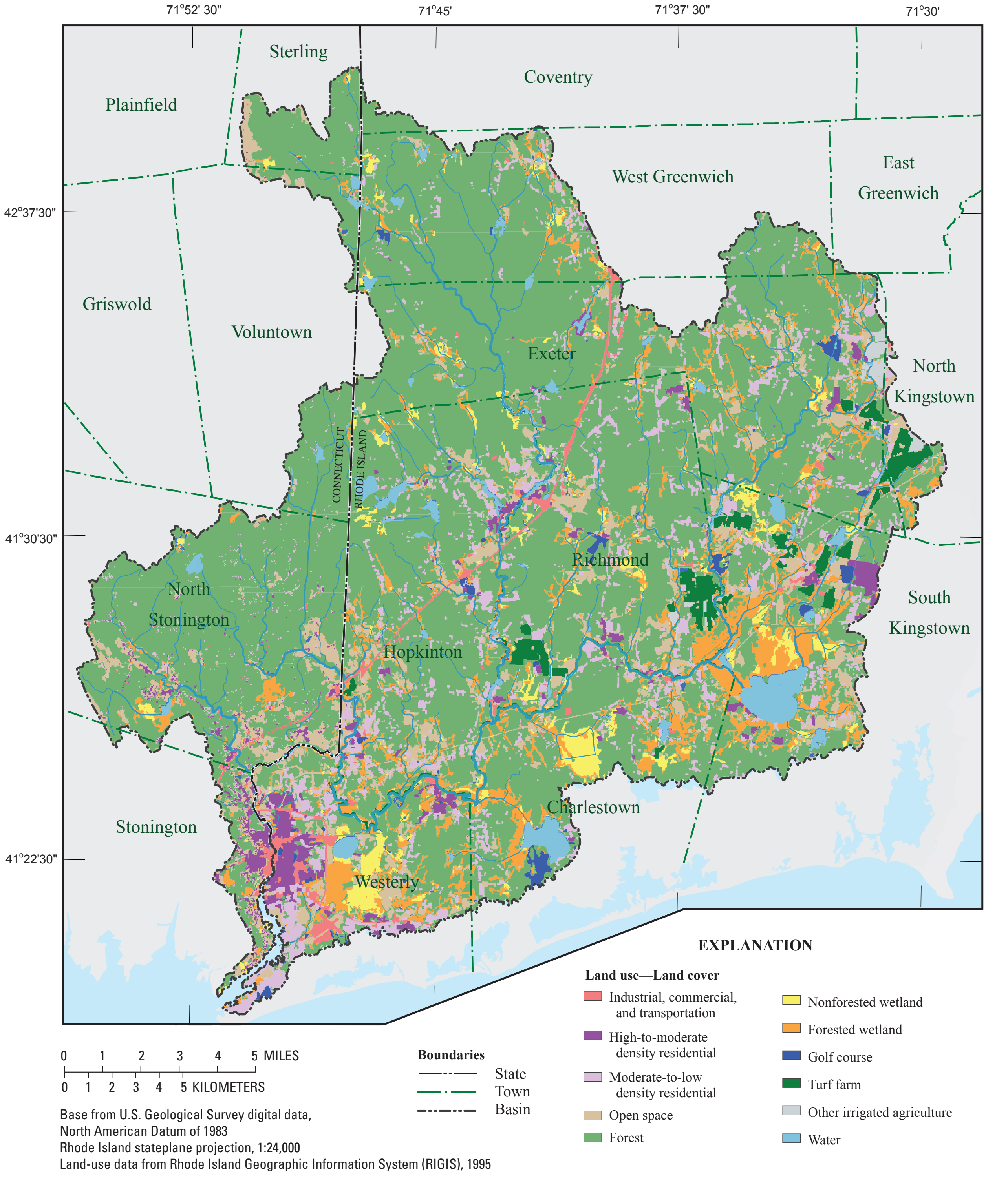


Figure I–3. Generalized land use (1995) in the Pawcatuck River Basin, southwestern Rhode Island and southeastern Connecticut.

Water-use information was compiled for the 5-year period 1995–99 by Wild and Nimiroski (2004) for the Pawcatuck River Basin. This compilation includes domestic, public, commercial, and agricultural uses. Data from that study were used to supplement the water-use information collected during the present study.

Numerous other water-resource-related studies for the Pawcatuck River Basin have been published by other Federal, State, and local government agencies, as well as universities, watershed organizations, and consulting firms. For example, Desbonnet (1999) provided a general overview of ground- and surface-water resources, water uses, and management issues in the Pawcatuck River Basin. One of the management issues discussed is the need to develop quantitative models for evaluating the effects of withdrawals on water resources.

Several statewide water-resources studies include information on the Pawcatuck River Basin. Information on groundwater-resources was provided for the basin by Allen (1953), Lang and others (1960), Lang (1961), Johnston (1988), and Trench (1991, 1995). Guthrie and Stolgitis (2000) provided information on the areal extent and bathymetry of lakes and ponds. DeSimone and Ostiguy (1999) provided hydrogeologic, water-quality, land-use, and other spatial data to identify factors that contribute to the relative vulnerability of groundwater in the basin to contamination. Information has been collected and compiled for the water use in the basin in previous studies by Horn and Craft (1991), Craft and others (1995), Korzendorfer and Horn (1995), Medalie (1996), and Horn (2000).

Hydrogeologic studies of adjacent river basins that included small areas of the Pawcatuck River Basin are those by Barlow and Dickerman (2001a,b) in the Hunt-Annaquatucket-Pettaquamscutt (HAP) Basin to the northeast and Masterson and others (2007) in the South Coastal Basin to the south. Dickerman and others (1997) and Barlow and Dickerman (2001a) determined that groundwater discharges to the HAP Basin in the upper part of the Queens Fort Brook, which is a tributary subbasin of the Usquepaug-Queen River subbasin, and in the upper part of the Chipuxet River Basin (northeastern part of Pawcatuck River Basin). Masterson and others (2007) provided detailed hydrogeologic information and developed a groundwater-flow model for the southern border of the basin in the salt-pond region of Rhode Island. The model area includes parts of the Pawcatuck River Basin—the eastern part of the Chipuxet River subbasin and area south of the Pawcatuck River, with the Chipuxet River and the Pawcatuck River as the northern model boundary. Masterson and others (2007) identified many small areas along the southern border of the Pawcatuck River Basin that contribute groundwater flow to the salt-pond region of Rhode Island. Hydrogeologic studies for adjacent river basins include those by Craft (2001), Granato and others (2003), and Granato and Barlow (2005) in the Big River Basin to the north.

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http://ri.water.usgs.gov

Bent and others—**Simulated Effects of Water Withdrawals and Land-Use Changes on Groundwater Levels in the Pawcatuck**—Scientific Investigations Report 2009–5127