Scientific Information in Support of Water Resource Management of the Big River Area, Rhode Island

Introduction

The Rhode Island Water Resources Board (RIWRB) is concerned that the demand for water may exceed the available public water supply in central and southern Rhode Island. Although water is often assumed to be plentiful in Rhode Island because of abundant rainfall, an adequate supply of water is not always available everywhere in the state during dry periods. Concerns that water demand may exceed supply are greatest during the summer, when lower water levels and increased drought potential combine with seasonal increases in peak water demand (Rhode Island Water Resources Board, 2012). High summer water demands are due to increases in outdoor water use, such as lawn watering and agricultural irrigation, and to increased summer population in coastal areas. Water-supply concerns are particularly acute in central and southern Rhode Island, where groundwater is the primary source of drinking water.

The Big River and Mishnock River Basins (fig. 1) are subbasins of the South Branch of the Pawtuxet River Basin in central and southern Rhode Island. These basins—referred to together as "the Big River area" for the purposes of this report—are undeveloped relative to other nearby areas and provide a potential source of high-quality public drinking water for central and southern Rhode Island.

Major Findings

- Three subbasins in the Big River area (the Big, Carr, and Mishnock River Basins) function as a single connected groundwater resource.
- Withdrawals in one subbasin have the potential to deplete streamflows in—or intercept groundwater that would have discharged to—another subbasin.
- Groundwater and stream systems are hydraulically connected.
- Groundwater withdrawals would reduce streamflows. Informed management of the location, magnitude, and timing of withdrawals can reduce the depletion of critical streamflows.
- Groundwater and wetlands are hydraulically connected.
- Groundwater withdrawals have the potential to alter the seasonal duration of inundation and saturation of the wetlands.
- The influence of withdrawals on wetlands depends upon the proximity of wetlands to pumped wells and streams and the connection between the aquifer and the wetland.
- The amount of groundwater that is available for withdrawal is dependent on geology, the annual pattern of water-supply demands, the timing and amount of withdrawals from multiple wells, and the requirements for maintaining streamflows and water levels in wetlands.

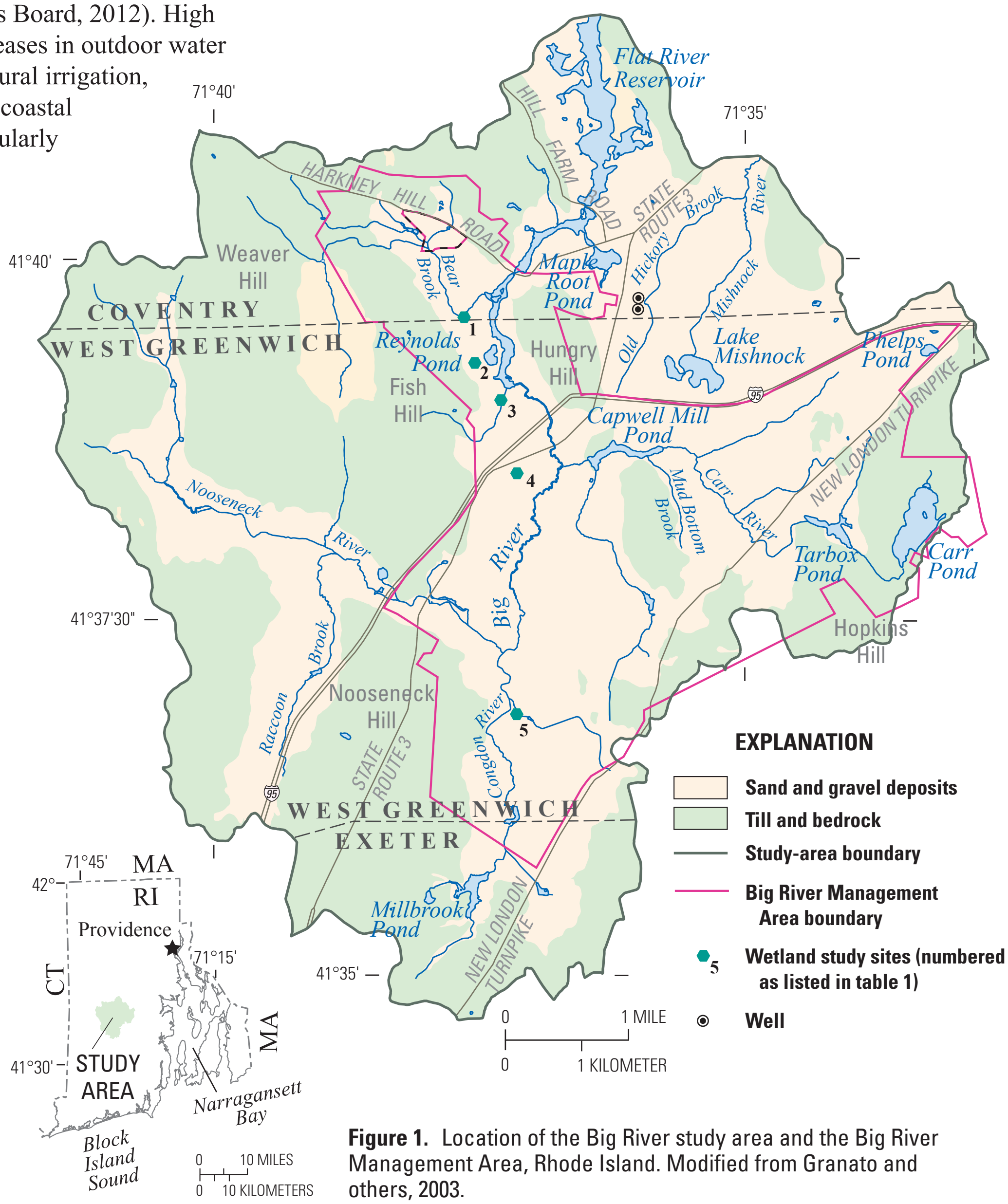

Figure 1. Location of the Big River study area and the Big River Management Area, Rhode Island. Modified from Granato and others, 2003.

After the severe drought of the 1960s, the State of Rhode Island acquired land in the Big River area with the intention of building a water-supply reservoir. The reservoir was not built because of concerns over potential environmental impacts and projected statewide water-supply needs (U.S. Environmental Protection Agency, 1989). The land acquired for the reservoir (13.4 mi^2), called the Big River Management Area (BRMA), is currently managed by the RIWRB as a future source for public water supply and as open space. In the 1980s, the RIWRB began to consider whether the BRMA could supply water from its aquifers (groundwater). Groundwater withdrawals for public or other water-supply needs can alter the hydrologic conditions and ecologic communities of surrounding rivers, lakes, and wetlands by removing water from these systems. Consequently, the RIWRB was interested in determining optimal amounts of groundwater that could be withdrawn from the BRMA for public supply while minimizing the effects on rivers, lakes, streams, and wetlands that also rely on this water.

For nearly two decades, the RIWRB has conducted a series of cooperative studies with the U.S. Geological Survey (USGS). The goals of these studies have been to (1) evaluate and characterize the water resources of the BRMA and the greater Big River area, and (2) identify sustainable levels of groundwater use that would minimize effects on water resources. This fact sheet describes the major findings of those studies.

The Big River Area

The Big and Mishnock Rivers are adjacent headwater tributaries of the South Branch Pawtuxet River. The Big River is the larger of the two, draining an area of about 30 square miles (mi^2), compared to only 4 mi^2 for the Mishnock. The Big River flows north into the Flat River Reservoir (Johnson Pond), where it merges with the Flat River. The outflow of the reservoir, called the South Branch Pawtuxet River, is joined by the Mishnock River about 1.5 miles downstream. The South Branch Pawtuxet River then flows east toward Narragansett Bay (Granato and others, 2013).

The landscape in the Big River area consists of rolling hills and valleys. The natural land cover is mostly forest and wetlands and includes several unique habitats, such as Atlantic white cedar swamps (fig. 2) and pitchpine/scrub oak barrens that are classified as Natural Heritage Areas (Rhode Island Geographic Information System, 2014). The BRMA is protected land, similar to the watershed-protection areas around large reservoirs such as those bordering the Quabbin Reservoir in Massachusetts and the Scituate Reservoir in Rhode Island. Developed land in the Big River area is clustered in areas adjoining major highways (State Route 3 and U.S. Interstate 95) and the Flat River Reservoir and Lake Mishnock.

Streamflows in the Big and Mishnock Rivers vary seasonally and are lowest in summer. The headwater tributaries and upper reaches of the Big River have relatively natural flows that support native aquatic species including brook trout (fig. 2). Streamflows and water levels in the downstream reaches of the Big River are altered because of impoundment by the Flat River Reservoir and the annual drawdown and refilling of the reservoir during winter and spring. Most homes in the Big River area have private water wells and onsite septic systems. Water supplies in portions of the towns of Coventry and West Greenwich north of Interstate 95 are served by the Kent County Water Authority.

Figure 2. *A,* Atlantic white cedar swamp, and *B*, brook trout stream, Big River area, Rhode Island.

The only large-scale groundwater withdrawals in the Big and Mishnock River Basins are from wells in the Mishnock River Basin owned and operated by the Kent County Water Authority.

Science in Support of Water-Resource Management

The cooperative studies by the USGS and RIWRB followed a scientific process that moved from basic hydrogeologic assessment to the development of complex groundwater models. Each study built upon the work of the previous studies, addressed a series of groundwater-usage alternatives, and evaluated factors that would affect local surface-water and groundwater resources. The findings of these studies have guided management decisions regarding groundwater withdrawals in the BRMA and provide a foundation for the development of statewide policies to sustainably manage water resources in Rhode Island.

Hydrogeologic Assessments

The goal of the initial USGS investigation (Craft, 2001; Stone and Dickerman, 2002) was to collect the information needed to characterize the hydrogeology, water resources, and groundwater flow in the Big River area. The USGS installed observation wells, collected geophysical information, conducted aquifer tests, and established a monitoring network to determine the thickness, extent, and water-bearing properties of the aquifers (Craft, 2001). Groundwater and surface-water-level data were collected from July 1996 through September 1998. Groundwater-level data were collected from 27 monitoring wells, 18 aquifer-test observation wells, and 15 streambed piezometers. Stream discharge was measured at 10 partial-record stations, and surface-water-level data were collected at 8 ponds and reservoirs. Craft (2001) also provides geologic data from 80 boreholes, historical water-level data from 375 groundwater sites, and water-quality data from 31 wells. These data served as the basis for the hydrogeologic-mapping and numerical-modeling studies that followed.

Geologic maps and cross sections of the Big River area produced by Stone and Dickerman (2002) show bedrock and overlying surficial geologic deposits laid down during continental glaciation. Surficial geologic deposits include glacial till (unsorted deposits of silty sand, clay, pebbles, and boulders), fine-grained (sand and silt) glacial-lake deposits, and coarse-grained (sand and gravel) meltwater deposits. Glacial till is the predominant surficial geologic deposit in upland areas. Till is a discontinuous deposit of variable thickness—often less than 10 to 15 feet (ft) thick and on top of bedrock. Coarse-grained sand and gravel deposits and fine-grained sand and silt deposits are the predominant surficial geologic deposits in valleys. These deposits are thinnest along the edges and thickest in the middle of the valleys. Sand and gravel deposits are thickest (50 to 100 ft) in the Big, Carr, and Mishnock Valleys, where they form the major aquifers in the area. The maps and associated hydrogeologic information in Craft (2001) and Stone and Dickerman (2002) provide water-resource planners and water-supply managers with a hydrogeologic framework that can be used to identify sites favorable for potential groundwater supply.

Simulation of the Effects of Groundwater Withdrawals on Streamflow

Two USGS groundwater-modeling studies (Granato and others, 2003; Granato and Barlow, 2005) were conducted to simulate groundwater flows and determine the potential effects of groundwater withdrawals on streamflow in the Big River area. Both studies used the groundwater-modeling software MODFLOW–2000 (Harbaugh, 2005) to simulate groundwater levels and flows and streamflows. In the initial modeling study, Granato and others (2003) used surficial geologic information from Stone and Dickerman (2002) and water-level data from the monitoring networks (Craft, 2001) to develop groundwater models of average annual and average monthly conditions. The models were used to create water-table maps (fig. 3), calculate water budgets, and simulate the effects of selected water-supply options on streamflow.

In most places, the surficial aquifer is hydraulically connected to streams, ponds, and wetlands. Hydrologic data indicate that some local hydrogeologic conditions are complex. For example, although groundwater generally flows toward streams and rivers within the same basin, results indicate that some groundwater flows out of the Carr River subbasin and across the Big River Basin boundary into the Mishnock River Basin. Consequently, groundwater withdrawals from the Carr River subbasin could potentially affect streamflow and water supplies in the Mishnock River Basin.

A water budget developed from the groundwater model (Granato and others, 2003) describes the amount of water entering and leaving the Big River area (fig. 4). The water budget indicates that under predevelopment conditions (no pumping or wastewater returns), most groundwater (93 percent) ultimately exits the basins as streamflow. Additional analysis of the streamflow response to groundwater withdrawals indicated that the primary source of water to potential public-supply wells would be intercepted groundwater that would otherwise have flowed to streams. Fourteen hypothetical groundwater-withdrawal scenarios were simulated to determine the effects of groundwater withdrawals on streamflow (Granato and others, 2003). The scenarios represented a range of withdrawal options at 12 locations the RIWRB was considering as potential locations for public-supply wells. Streamflow depletions simulated by the models indicated that groundwater supplies in the Big River area cannot be developed without a reduction in streamflow. For example, Scenario 10 simulated groundwater withdrawals of 4, 2, and 1 million gallons per day (Mgal/d) from

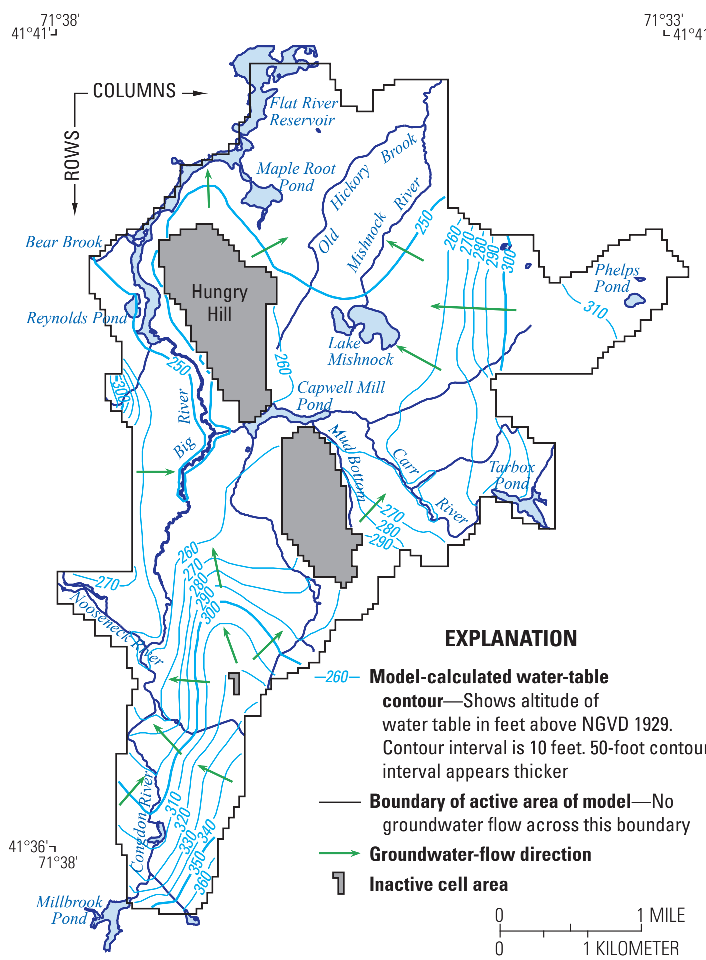

Figure 3. Water table map indicates general direction of groundwater flow is from till and bedrock uplands toward the river valleys, Big River area, Rhode Island. Modified from Granato and others, 2003.

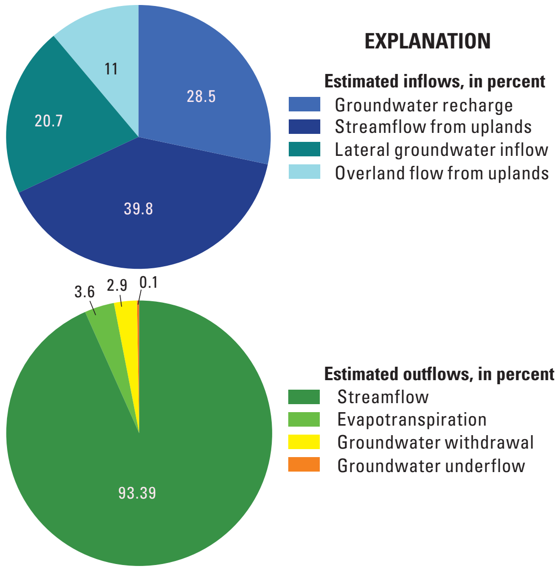

Figure 4. Groundwater inflows are from different sources, whereas outflows are mostly from streamflow, Big River area, Rhode Island. Modified from table 4 in Granato and others, 2003.

the Big, Mishnock, and Carr River Basins and determined that these withdrawals would reduce average August streamflows in those rivers by 25, 51, and 24 percent, respectively. Withdrawal strategies that balanced aquatic-habitat protection goals with water-supply needs were evaluated by comparison of model-simulated streamflows to streamflows required to sustain stream habitat in summer (0.5 $ft^3/s/mi^2$; U.S. Fish and Wildlife Service, 1981).

A subsequent study (Granato and Barlow, 2005) modeled additional scenarios to determine the effects of groundwater withdrawals on streamflows. The study used conjunctive management (combined simulation and optimization) models to determine (1) the effects of instream-flow criteria on groundwater withdrawals, (2) whether more water could be obtained from the Big River area if pumping were varied seasonally, (3) how pumping from a network of wells could be optimized to minimize streamflow depletions, (4) the effects of withdrawals on streamflow during dry periods, and (5) the influence of wastewater-return flows on water availability. The analysis focused on 13 possible locations for public-supply wells in the BRMA and evaluated 31 hypothetical groundwater-withdrawal scenarios.

The scenarios modeled by Granato and Barlow (2005) confirmed that the amount of groundwater available decreases as the minimum-streamflow criteria are increased—that is, as more water is required to be left in the streams (fig. 5). The conjunctive management models developed by Granato and Barlow (2005) allowed management options to be compared by determining the specific rates of pumping at each of the wells, the total amount of water available from the BRMA, and the streamflow depletion associated with each scenario. Analysis in Granato and Barlow (2005) also determined that the timing of water-supply demand is a critical factor influencing the total amount of groundwater that can be withdrawn from a basin over a typical year. Water demand in Rhode Island is normally highest during the summer, when streamflows are relatively low. Simulations that incorporated this pattern of increased summer demand resulted in rates of annual average groundwater withdrawals from the basin that were about one-half of the withdrawal rates in scenarios that did not consider the seasonal constraint. The analysis indicated that additional wells throughout the area with collectively managed water withdrawals would be needed to reduce the influence of pumping on streamflow during summer. Groundwater withdrawals would need to be reduced by about 1–2 Mgal/d if pumpage were not managed collectively.

Effects of Groundwater Withdrawals on Streams and Wetlands

In another USGS study of the Big River area, Borenstein and others (2012) characterized the vegetation, soils, and hydrology of selected wetlands; Masterson and Granato (2013) then modified the existing groundwater models (Granato and others, 2003; Granato and Barlow, 2005) to develop a local-scale groundwater-flow model for the northern part of the BRMA near the Flat River Reservoir and used data from the wetlands study to further refine the model. These studies were conducted to (1) investigate whether groundwater withdrawals in the BRMA could induce infiltration from the Flat River Reservoir, potentially reducing the effect of water withdrawals on surrounding wetlands and streamflow, and (2) develop a better understanding of the interactions between groundwater and surface water in riparian wetlands under changing pumping conditions.

To characterize typical hydrologic and vegetative conditions in wetlands in the Big River area, five wetlands were selected for study, and a monitoring network was established (Borenstein and Golet, 2010; Borenstein and others, 2012). Four of the study sites were forested wetlands along perennial streams, and the fifth site was adjacent to Reynolds Pond (fig. 1).

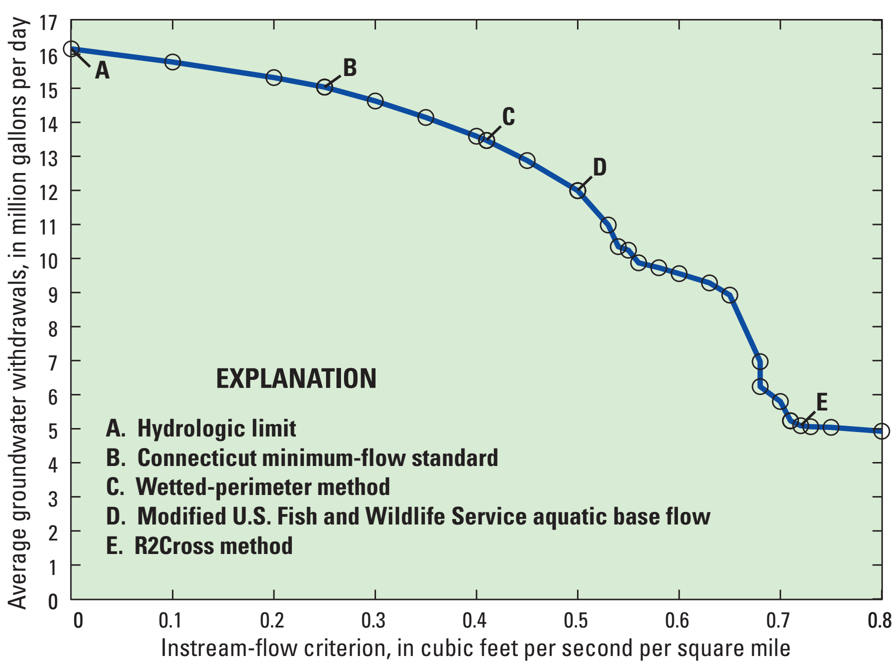

Figure 5. As the the minimum-streamflow criteria are increased, the amount of groundwater available decreases, Big River area, Rhode Island. Modified from Granato and Barlow, 2005.

The hydrology of each wetland study site was characterized during the 2009 growing season (April 15–November 30) through measurements of groundwater levels, surface-water levels in adjacent water bodies, and ponded-water conditions at the wetland land surface. Water levels indicated that the surficial aquifer is in hydraulic connection with wetlands at all five sites. The prevalence of ponded water varied among the wetland study sites. Ponding was observed throughout the growing season at the two wettest sites and for a part of the season at the remaining sites. Water levels were less than 1 ft below the ground surface for more than 80 percent of the growing season at most locations in the five sites, indicating that the shallow soil layers are wet during most of the year.

Vegetation in the wetlands was sampled as five layers—trees, saplings, shrubs, herbaceous vegetation, and mosses (fig. 6). For example, in red maple swamps—the most common wetland type studied—tree and sapling species are typically red maple and white pine, shrubs include sweet pepperbush and swamp azalea, herbaceous vegetation includes skunk cabbage and cinnamon fern, and mosses are predominantly sphagnum moss. Vegetation varied with hydrologic conditions across the five study sites and also across transects within individual sites. If the wetland soils were to become significantly drier as a result of groundwater withdrawals, the species composition of herbaceous plants and mosses would likely undergo more change at a faster rate than that of trees, saplings, and shrubs. Shallowly rooted and requiring wet conditions, herbaceous plants and mosses would likely be more sensitive to changes in soil moisture than trees, saplings and shrubs, which have a more persistent nature, relatively deep roots, and tolerance for variable soil-moisture conditions (Allen and others, 1989).

The model developed by Masterson and Granato (2013) tested several hydrogeologic factors that affect groundwater availability in the northern portion of the BRMA, including the hydraulic conductivity of fine-grained glacial-lake deposits that underlie the Flat River Reservoir and the northern part of the BRMA, the exchange of groundwater between the till uplands and the valley-fill aquifer system, and the annual drawdown and refilling of the Flat River Reservoir during winter and spring. The results indicated that fine-grained sediments underlying the Flat River Reservoir would restrict the amount of induced infiltration available from the reservoir and thereby increase the potential for decreased water levels beneath nearby wetlands.

Masterson and Granato (2013) also simulated the effects on wetland water-level declines in a five-well 2.5-Mgal/d groundwater-withdrawal scenario proposed by the RIWRB. The results indicated that the amount of dewatering of wetlands and nearby surface-water bodies is directly related to the amount of groundwater withdrawn by pumping. Average monthly water levels in wetlands near Reynolds Pond would decline 4 to 6 ft, depending on whether the Flat River Reservoir was flooded or drained (table 1). Simulated declines in water levels in the Atlantic white cedar wetland were less than 1 ft, and declines in water levels in the other study wetlands were less than 0.3 ft. The simulation results indicate that groundwater withdrawals are likely to lower water levels in wetlands and alter wetland ecology by reducing the seasonal duration of inundation and saturation of the wetlands.

Informing Water-Management Decisions

Collectively, the scientific studies conducted by the USGS in cooperation with the RIWRB have provided the foundational understanding and the numerical modeling tools needed to assess the responses of the aquifers and streams in the Big River area to future water-supply development. USGS groundwater models have been used by the RIWRB to locate test wells, develop a test-well pumping plan, and assess the effects of groundwater withdrawals on hydrologic conditions in local streams, rivers, and wetlands. These cooperative studies have improved the understanding of surface and groundwater interactions among streams, riparian wetlands, and aquifers and helped to quantify the nature and magnitude of the tradeoffs between developing groundwater supplies and protecting water resources in the BRMA. The long-term partnership between the RIWRB and USGS provides a scientific foundation for water-resource management. The studies in the Big River area continue to inform sustainable water-resources management in Rhode Island.

Table 1. Selected average monthly water-level declines at the wetland-study sites in response to continuous pumping at aquifer-test sites, Big River area, central Rhode Island.

[ID, identification. Value indicates the water-level decline between the no-pumping and pumping conditions. Wetland study sites are identified by map IDs on figure 1. Modified from Masterson and Granato, 2013, table 4]

Map ID	Wetland name	Well name	August (feet)[1]	December (feet)[1]
1	Bear Brook Swamp	COW484	0.2	0.2
2	Reynolds Swamp	WGW427	3.8	5.8
3	Cedar Swamp	WGW428	0.4	0.5
4	Scarborough Swamp	WGW426	0	0.1
5	Congdon Swamp	WGW429	0	0

[1]From March through October, control boards are typically in place, and water levels in the reservoir are raised. From November through February, control boards are typically removed, and water levels in the reservoir are lowered for weed control.

Figure 6. USGS employee sampling wetland vegetation in the Big River area, Rhode Island.

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