Nutrient Enrichment in Estuaries from Discharge of Shallow Ground Water, Mt. Desert Island, Maine

By Charles W. Culbertson, Thomas G. Huntington, and James M. Caldwell

Prepared in cooperation with the National Park Service

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Conversion Factors, Datums, and Abbreviations

SI to Inch/Pound

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
meter (m)	3.281	foot (ft)
millimeter (mm)	0.03937	inch (in.)
kilometer (km)	0.6214	mile (mi)
	Area	
square kilometer (km^2)	247.1	acre
square kilometer (km^2)	0.3861	square mile (mi^2)
square meter (m^2)	10.76	square foot (ft^2)
	Volume	
liter (L)	1.057	quart (qt)
liter (L)	0.2642	gallon (gal)
cubic meter (m^3)	35.31	cubic foot (ft^3)
	Flow rate	
cubic meter per second (m^3/s)	35.31	cubic foot per second (ft^3/s)
liters per second (L/s)	0.03531	cubic foot per second (ft^3/s)
meter per second (m/s)	3.281	foot per second (ft/s)
	Mass	
gram (g)	0.03527	ounce, avoirdupois (oz)
kilogram (kg)	2.205	pound avoirdupois (lb)

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

$$°F=(1.8\times°C)+32$$

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

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.

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25°C).

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (µg/L).

OTHER ABBREVIATIONS USED IN THIS REPORT

DOC	dissolved organic carbon
NWQL	U.S. Geological Survey National Water Quality Laboratory
NWIS	National Water Information Systems
NPS	National Park Service
NADP	National Atmospheric Deposition Program
AIDIA	aerial infrared digital imaging analysis
USEPA	U.S. Environmental Protection Agency

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Abstract

Nutrient enrichment from atmospheric deposition, agricultural activities, wildlife, and domestic sources is a concern at Acadia National Park because of the potential problem of water-quality degradation and eutrophication in its estuaries. Water-quality degradation has been observed at the Park's Bass Harbor Marsh estuary but not in Northeast Creek estuary. Previous studies at Acadia National Park have estimated nutrient inputs to estuaries from atmospheric deposition and surface-water runoff, but the importance of shallow ground water that may contain nutrients derived from domestic or other sources is unknown. Northeast Creek and Bass Harbor Marsh estuaries were studied to (1) identify shallow ground-water seeps, (2) assess the chemistry of the water discharged from selected seeps, and (3) assess the chemistry of ground water in shallow ground-water hyporheic zones. The hyporheic zone is defined here as the region beneath and lateral to a stream bed, where there is mixing of shallow ground water and surface water. This study also provides baseline chemical data for ground water in selected bedrock monitoring wells and domestic wells on Mt. Desert Island. Water samples were analyzed for concentrations of nutrients, wastewater compounds, dissolved organic carbon, pH, dissolved oxygen, temperature and specific conductance. Samples from bedrock monitoring wells also were analyzed for alkalinity, major cations and anions, and trace metals. Shallow ground-water seeps to Northeast Creek and Bass Harbor Marsh estuaries at Acadia National Park were identified and georeferenced using aerial infrared digital imagery. Monitoring included the deployment of continuously recording temperature and specific conductance sensors in the seep discharge zone to access marine or freshwater signatures related to tidal flooding, gradient-driven shallow ground-water flow, or shallow subsurface flow related to precipitation events.

Many potential shallow ground-water discharge zones were identified from aerial thermal imagery during flights in May and December 2003 in both estuaries. The occurrence of ground-water seeps was confirmed using continuous and discrete measurements of temperature and specific conductance in selected seeps and in the adjacent estuaries that showed salinity anomalies reflecting the input of freshwater in these complex tidal systems. Analysis of water samples from shallow ground water in the hyporheic zone and from ground-water seeps indicated the presence of elevated concentrations of dissolved nitrogen, compared to concentrations in the adjacent estuaries and surface-water tributaries draining into the estuaries. These findings indicate that shallow ground water is a source of dissolved nitrogen to the estuaries. Orthophosphate levels were low in ground water in the hyporheic zone in Bass Harbor Marsh, but somewhat higher in one hyporheic-zone well in Northeast Creek compared with the concentrations in both estuaries that were at or below detection limits. Household wastewater-related compounds were not detected in ground water in the hyporheic zone. Analysis of water samples from domestic and bedrock monitoring wells developed in fractured bedrock indicated that concentrations of dissolved nitrogen, phosphorus, and household wastewater-related compounds were typically at or below detection, suggesting that the aquifers sampled had not been contaminated from septic sources.

Introduction

Coastal ecosystems are among the most valuable habitats in the United States, yet as a result of urbanization and changes in land use, these habitats also are among the most vulnerable and distressed of the natural environments. Surface and ground waters with elevated concentrations of organic and inorganic contaminants are discharging in coastal waters as a result of human activities, including the use of fertilizers and pesticides, spreading of manure on croplands, deposition of industrial emissions, disposal of wastewater, and flow of septic field leachate in watersheds near the coastal zone (Nixon, 1995; Roman and others, 2000; Cloern, 2001; Kolpin and others, 2002; Smith and others, 2003). Of particular concern to coastal environments are the inputs of the nutrient elements nitrogen and phosphorus. Nutrient enrichment in many of these ecosystems is thought to exceed even that of many agroecosystems (Nixon and others, 1986, 1996). Nutrient inputs to coastal ecosystems can result in significant environmental degradation in the form of coastal zone eutrophication, whereby plant growth is stimulated, plant community composition is affected, and the balance between production and metabolism of organic matter is disrupted

(Roman and others, 2000; Cloern, 2001). Unmitigated coastal waters eutrophication contributes to nuisance and harmful algal blooms and may ultimately result in conditions of hypoxia or anoxia.

Although the dominant means of nutrient enrichment to coastal waters in the northeastern United States is typically considered to be through surface-water transport and atmospheric deposition (Ollinger and others, 1993; Howarth and others, 1996; Carpenter and others, 1998; National Research Council, 2000; Boyer and others, 2002; Paerl, 2002), the importance of ground water as a vector in the transport of nutrients and contaminants to coastal waters needs to be considered as well (Harvey and Odum, 1990; Valiela and others, 1990; Portnoy and others, 1998; Tobias and others, 2001a; Westbrook and others, 2005). Studies conducted during the last few decades, although highly variable in terms of their findings, have demonstrated that ground water discharging into shallow coastal waters and estuaries could contain nitrate concentrations up to five orders of magnitude higher than the receiving seawater (Capone and Bautista, 1985; Valiela and others, 1990; Harvey and Odum, 1990; Tobias and others, 2001a).

Even though the inherent link between surface-water and ground-water systems is well known, interactions between these systems in estuarine environments can be unpredictable due to the large spatial and temporal variability in efficiency of transport and in the processes of nutrient transformations along specific flow paths (Westbrook and others, 2005). Hydrologic links between terrestrial sources and estuaries are influenced by freshwater and tidal hydrologic regimes, topography, hydraulic properties of soils and sediments, and the underlying surficial geology. Consequently, being able to identify the hydrologic factors that affect the transport of nutrients and contaminants to coastal waters is critical to understanding the function and capacity of estuarine ecosystems (e.g. wetlands, marshes, and mudflats) to attenuate chemical perturbations (Tobias and others, 2001b).

Acadia National Park, located on Mt. Desert Island on the central coast of Maine, is home to a rich diversity of ecosystems, including tidal marsh estuaries and many freshwater wetlands. The watersheds for these ecosystems, which lie partly outside the park boundary, are affected to varying degrees by residential and commercial development. Signs of eutrophication in Bass Harbor Marsh estuary, the largest tidal marsh estuary on the island, were first documented in the mid-1990s (Doering and others, 1995; Kinney and Roman, 1998; Farris and Oviatt, 1999), and include evidence of decreased biomass abundance of the submerged vascular plant *Ruppia maritima* (widgeon grass), associated with enhanced macro-algal growth. Northeast Creek estuary, a large tidal marsh on the northern lobe of Mt. Desert Island, does not currently (2007) show signs of eutrophication (Caldwell and Culbertson, 2007). One explanation for this difference is the extent of development within the respective watersheds. The Bass Harbor Marsh watershed is composed of several subwatersheds, the largest of which, Marshall Brook, lies outside park boundaries and is significantly affected by residential and commercial development, as well as a former landfill. Currently (2007), the Northeast Creek watershed is minimally affected by urbanization, but encroaching development outside the park boundary is increasing at an unprecedented rate and will likely increase nutrient loading. For example, from 1981 to 2001 the number of homes in the combined drainage basins of Aunt Betsey's Brook, French Hill Brook, Old Mill Brook, and Stony Brook in the Northeast Creek watershed increased from 83 to 279 (Nielsen, 2002a; Nielsen and others, 2002).

Nielsen (2002a) determined that nutrient concentrations in surface waters were relatively low in the tributaries flowing into the Northeast Creek and Bass Harbor Marsh estuaries from 2000 through 2001; however, ground-water nutrient inputs to the wetlands from the surrounding watersheds have not yet been examined. Concerns exist as to whether degrading ground-water quality, associated with increasing development on Mt. Desert Island, is at least partly responsible for the observed ecosystem changes in the Bass Harbor Marsh estuary, and whether continued development will begin to affect the Northeast Creek estuary and other wetlands. These tidal marsh systems are distinctly different with respect to the extent of urbanization. For the purposes of this investigation, the Bass Harbor Marsh estuary represents an urban-affected ecosystem and Northeast Creek estuary represents an unimpacted ecosystem. Little information is available about whether or not ground water in the underlying bedrock aquifer contains elevated concentrations of dissolved nitrogen or other wastewater-related compounds. If this deeper ground water (as distinct from shallow ground water that could discharge to estuaries at Mt. Desert Island) contained nutrients, it could be another potential source of nutrients to estuaries at Mt. Desert Island.

The primary goal of this study was to gain insight into whether shallow ground water could be a significant source of nutrient enrichment to these estuaries. To meet this objective, the U.S. Geological Survey (USGS) and the National Park Service (NPS) began a cooperative study to identify shallow ground-water discharge zones (seeps) in the Bass Harbor Marsh and Northeast Creek estuaries and to determine the potential for this ground water to contribute substantial nutrient inputs in relation to other nutrient sources to the associated estuaries. This report provides the results of analysis of aerial thermal imagery to identify temperature anomalies that indicate the presence of ground-water seeps. This report also contains continuously recorded specific conductance and temperature data that confirm the existence of these seeps. Data from water samples collected from seeps, shallow hyporheic ground water, estuaries, and bedrock wells, all of which were used to assess potential nutrient inputs and wastewater contamination, are included as well. This report includes aerial thermal imagery and (or) water-quality data collected during the period 2003 though 2005. Ancillary water-quality, water-level, and streamflow data collected during previous USGS investigations during the summer of 2001 (Stewart and others, 2002; Caldwell and Culbertson, 2007) also is presented.

The use of aerial thermal imaging for the identification of thermal anomalies (at potential shallow ground-water discharge zones) has the greatest chance of success when there is the largest temperature differential between ground water and the surface water it is discharging into. This is most likely to occur when the surface water is warm relative to cooler ground water in late summer or fall, or when surface water is cold (but free of ice) relative to warmer ground water in the spring. Tree canopies could obscure the water surface in some places in the estuary, so measurements are most likely to reveal anomalies when deciduous leaves are not present. Further discussion of the use of aerial thermal imaging for identification of ground-water seepage zones in the northeastern United States can be found in Portnoy and others (1998), Roseen and others (2002), and in Mulligan and Charette (2006).

Surface-water temperatures in upland rivers and streams in central Maine are usually near 0°C from December through late March (Morrill and others, 1983, 1984; Haskell and others, 1985). Stream-water temperature rises in April, reaches a maximum in late July, gradually declines from early August through November, and reaches 0°C in early December. Maximum values depend on local conditions including water depth, insolation, velocity, and ground-water discharge. Annual and diurnal variations in surface-water temperature in Northeast Creek and Bass Harbor Marsh are likely more complex than in upland streams because of the influence of tidal mixing. Temperature measurements in Northeast Creek from June through November in 2001 and 2002 had maximum mean daily values of 24 to 27°C (Caldwell and Culbertson, 2007). Ground-water temperature has not been measured continuously at Acadia National Park; however, previous studies suggest nearly constant values of about 7°C for ground water at depths of more than 30 m (Todd and Mays, 2005). Shallower ground water tends to have similar average annual temperatures but larger seasonal variation. For example, one site in New York had a seasonal variation of about 1°C at 13.7 m and about 10°C at 4.3 m below land surface (Todd and Mays, 2005). The amplitude in seasonal variation increases as the distance from the land surface decreases (Todd and Mays, 2005).

Description of Study Area

Mt. Desert Island (fig. 1) covers 285 km^2, making it the largest island on the Atlantic coast of the United States north of Cape Cod. Its topography ranges from gently rolling hills with slopes of around 5 percent, to mountains with slopes greater than 60 percent. Annual total precipitation is variable; for example, during a 50-year period (1944–1993) it ranged from 185 cm in 1983 to 98.8 cm in 1965 (Perrin, 1994). Over a 41-year period (1940–1980) precipitation averaged 123 cm annually. During that same period temperature averaged 8°C (Patterson and others, 1983). Acadia National Park is located in the Northeastern Coastal Zone ecoregion at 44° N latitude, and its climate is influenced primarily by maritime conditions. Summers tend to be more moist and cooler than adjacent inland areas, whereas winters tend to be somewhat warmer and experience less snowfall than inland areas (Kahl and others, 2000).

Of its total land holdings of 190 km^2, Acadia National Park covers 123 km^2 on Mt. Desert Island. Slowly weathering granites that underlie much of Acadia National Park, in combination with the absence of soil over considerable parts of the park landscape, are important characteristics of the hydrogeologic environment that lead to rapid surface runoff, flashy streamflows in response to precipitation events, and low alkalinity and nutrient concentrations in surface waters (Kahl and others, 1985, 2000). Estuarine wetlands at Acadia consist of intertidal mud flats, coarse gravel shores, salt marshes, and aquatic beds in coves and embayments sheltered from high-energy waves of the open ocean. The high tidal range at Acadia (about 3 m) has helped to create an extensive system of mud flats that are of ecological and economic importance to the region (Calhoun and others, 1994).

The Mt. Desert Island and Acadia National Park coastline includes three primary estuarine environments: Somes Sound (fig. 1), a fjord-type estuary, and two tidal marsh-dominated estuaries (the topics of this report); Northeast Creek; and Bass Harbor Marsh. Somes Sound is classified as a fjord-type estuary because of its long (8 km) and narrow (1 km) configuration, deep basins (40–50 m), and relatively shallow sill (10–12 m) (Doering and Roman, 1994). Prior research conducted on Somes Sound includes water chemistry and hydrologic studies (Folger and others, 1972; Kahl and others, 2000).

The Northeast Creek watershed is on the northern side of Mt. Desert Island (figs. 1 and 2). The outlet of Northeast Creek flows into Thomas Bay; the outlet is constricted by the remnants of an old rock dam and a bridge abutment, which are at an elevation just slightly below mean high tide. Tidal flow into and out of Northeast Creek varies as a function of the fortnightly tidal cycle. During the flooding spring tides, seawater flows over a control structure into Northeast Creek, with seaward flow during the subsequent ebbing tide. During neap tides, the estuary receives little or no seawater input and the tidal amplitude is dampened or missing. Freshwater from the inflow streams rides above the saltwater due to density stratification. The saltwater wedge extends well up into Northeast Creek during the summer low-flow period. During large runoff events, the freshwater completely flushes the saltwater out of the estuary, only to be partially displaced again by saltwater at the next tidal maximum (Caldwell and Culbertson, 2007).

The submerged vegetation in Northeast Creek consists primarily of *Ruppia maritima* (widgeon grass), a euryhaline species that is tolerant of the dramatic salinity variability throughout the system. Four perennial streams and three intermittent streams feed the Northeast Creek estuary. An area adjacent to the wetland lacking a stream-drainage network does not contribute channelized surface-water flow to the wetland or creek, but probably contributes shallow ground-water flow. The Northeast Creek watershed (26.01 km^2) is composed of several sub-watersheds. The four perennial

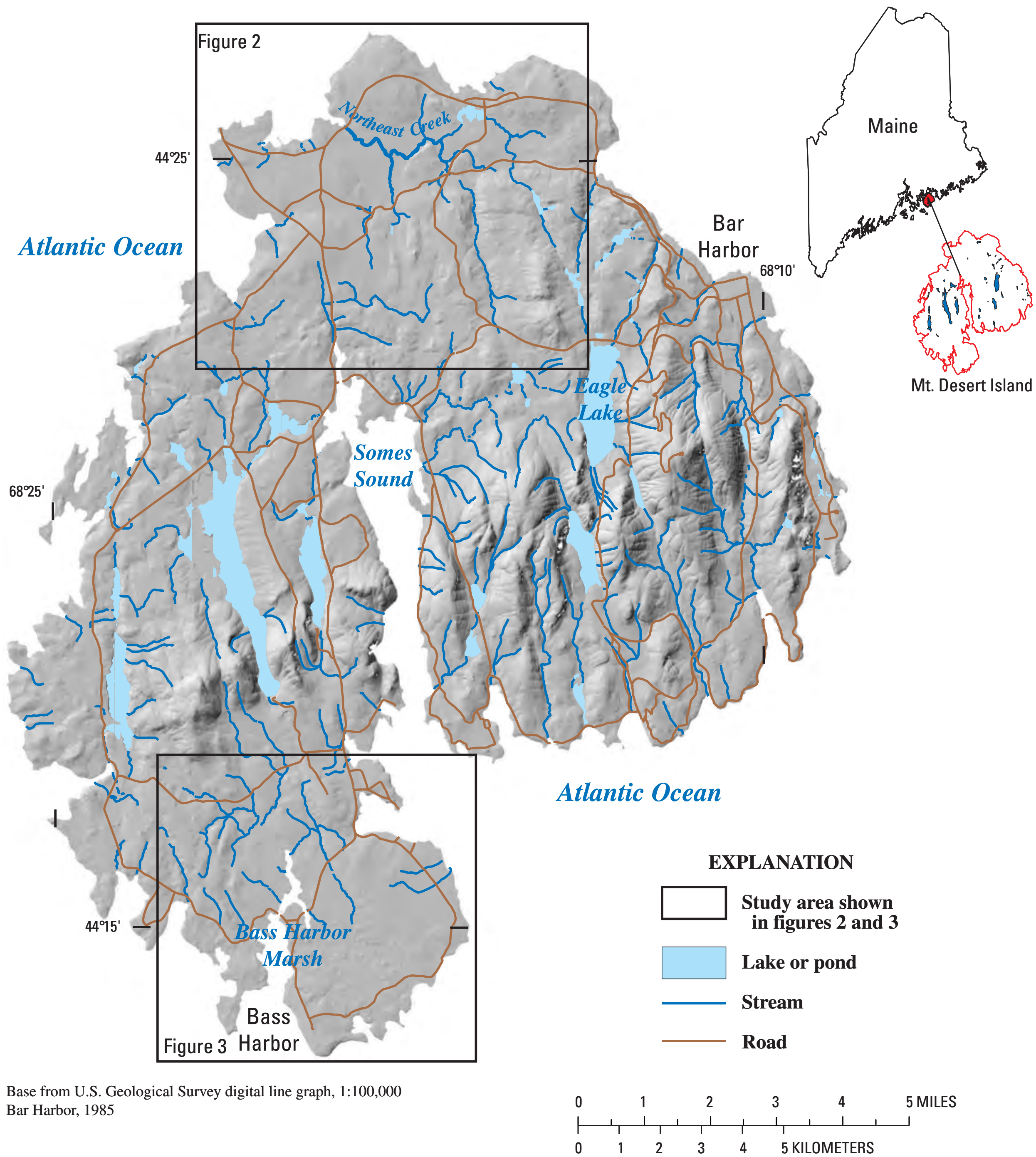


Figure 1. Locations of study areas that include Northeast Creek and Bass Harbor Marsh watersheds on Mt. Desert Island, Maine.

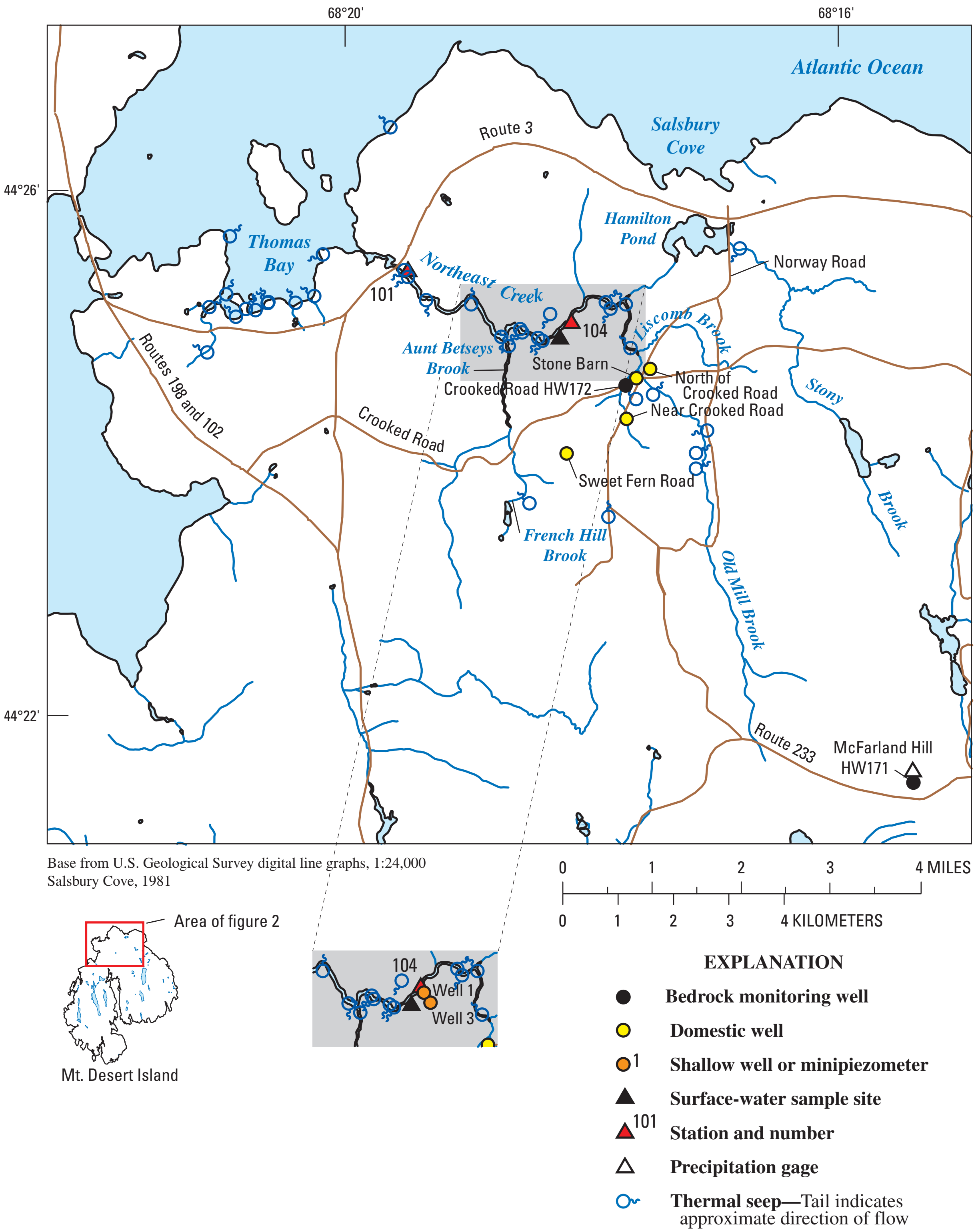


Figure 2. Locations of water-quality sampling and continuous monitoring sites in the Northeast Creek watershed on Mt. Desert Island, Maine.

streams are shown in figure 2—Stony Brook (6.73 km^2), Old Mill Brook (6.13 km^2), Aunt Betseys Brook (1.62 km^2), and French Hill Brook (1.40 km^2). The drainage basins of the three intermittent streams, including Liscomb Brook, have a total area of 3.40 km^2. Uplands immediately surrounding the wetland that are not drained by channelized surface runoff total 4.74 km^2 in area. The Fresh Meadow Wetland is within the Northeast Creek watershed and is adjacent to parts of Northeast Creek and Aunt Betseys Brook and covers an area of 1.85 km^2. The drainage areas for these tributaries to Northeast Creek are shown on a topographic map in Nielsen (2002a). The surface area covered by Northeast Creek itself (upstream from Route 3) is estimated to be 0.14 km^2.

The Bass Harbor Marsh watershed, on the southwestern coast of Mt. Desert Island, is the largest tidal marsh system on the island. It is a typical estuarine ecosystem, having direct exchange with the ocean via Bass Harbor, and freshwater input through several small streams (fig. 3). A disparity in tidal range exists between Bass Harbor (mean tidal range about 3 m) and the marsh (mean tidal range about 0.3 m) due to a bedrock sill at the mouth of the marsh. The presence of this sill creates an asymmetric tidal flux where flood tides enter the marsh for 2–3 hours, compared to a 9–10 hour ebb tide (Doering and others, 1995). The Bass Harbor Marsh watershed (21.78 km^2) consists of several sub-watersheds, the largest of which, Marshall Brook (6.52 km^2), lies outside park boundaries and is significantly impacted by residential and commercial development, several campgrounds, as well as a former landfill. Adams Brook, the second largest sub-watershed (5.01 km^2), has some limited residential development, but lies mostly within park boundaries (Doering and others, 1995). The Bass Harbor Marsh wetland itself covers an area of about 3.49 km^2.

Although estuarine waters are predominantly outside park boundaries, the NPS has sponsored water-quality research on all Northeast Creek, Bass Harbor Marsh, and Somes Sound estuaries (Doering and Roman, 1994; Doering and others, 1995; Nielsen, 2002a; Caldwell and Culbertson, 2007). Large parts of the watersheds for these estuaries are contained within the park; all receive freshwater from private and park lands.

Methods of Data Collection

Methods of data collection are described in several sections. The first section describes the aerial thermal imaging of temperature anomalies that are interpreted as shallow ground-water discharge zones (seeps). The next four sections describe methods for water-quality sampling from the hyporheic zone, estuaries, and well water from bedrock and domestic wells. The next section describes methods used for processing and analyzing water-quality samples, followed by a section that describes the procedure used to estimate nutrient loads from a shallow ground-water seep. The final section describes the ancillary measurements that were included in this report.

Aerial Thermal Imaging of Shallow Ground-Water Discharge Zones

Ground-water discharge zones (seeps) in Bass Harbor Marsh and Northeast Creek estuaries were identified using aerial infrared digital images obtained by Davis Aviation, Kent, Ohio. Aerial infrared digital imaging has been used successfully in similar studies in the northeastern U.S. to identify ground-water discharge zones (Portnoy and others, 1998; Roseen and others, 2002; Mulligan and Charette, 2006). This technique, given the altitude of the flyovers and the resolution capabilities of the digital imager, can provide sub-meter resolution of ground-water discharge. These images were obtained during low-tide conditions in May and December 2003 to capture periods of maximum temperature gradients between ground water and surface water, and maximum ground-water inputs relative to surface-water flows. Locations of ground-water discharge zones in the two estuaries were mapped for subsequent identification of sampling sites. Thermal anomalies may signal shallow ground-water seepage zones or warmer water outfalls from sources such as pipes, drains, and septic systems. Several areas of open water on Northeast Creek that were the last to freeze in December 2003 are mapped as thermal anomalies because they may indicate warmer ground-water inflows beneath the surface of the creek. Selected seeps were subsequently located using GPS, and verified by temperature, specific conductance and visual surveys in the field. One seep was monitored throughout the field season.

The aerial infrared digital imaging analysis (AIDIA) included 8.5 × 11-inch map sheets from DeLormes' map Expert 2.0, annotated USGS 7.5-minute topographic maps, a VHS videotape copy of the December 2003 original MiniDV digital videotape of infrared imagery, a MiniDV digital videotape of the May 2003 infrared imagery, and a CD-ROM with images of the 72 thermal anomalies identified during both flights. Imaging altitudes ranged from 457 to 762 m above ground level. Aerial thermal imaging can provide estimates of actual water temperatures but these data were not acquired for this study. For this study potential seeps were identified from the contrast between light and dark areas (thermal anomalies) only.

Collection of Water Samples from the Hyporheic Zone

Samples collected from three ground-water seeps in Bass Harbor Marsh were identified from AIDIA and confirmed using field measurements. Field measurements included specific conductance showing freshwater and estimation of flow that confirmed freshwater being advected from discrete seepage zones. All water-quality sampling sites, sampling dates, and analytes are listed in appendix 1. Temperature, pH, specific conductance, and dissolved oxygen were measured in situ using a YSI, Inc. 600XL multi-parameter probe immersed directly in the seeps at depths of 15 to 50 cm below

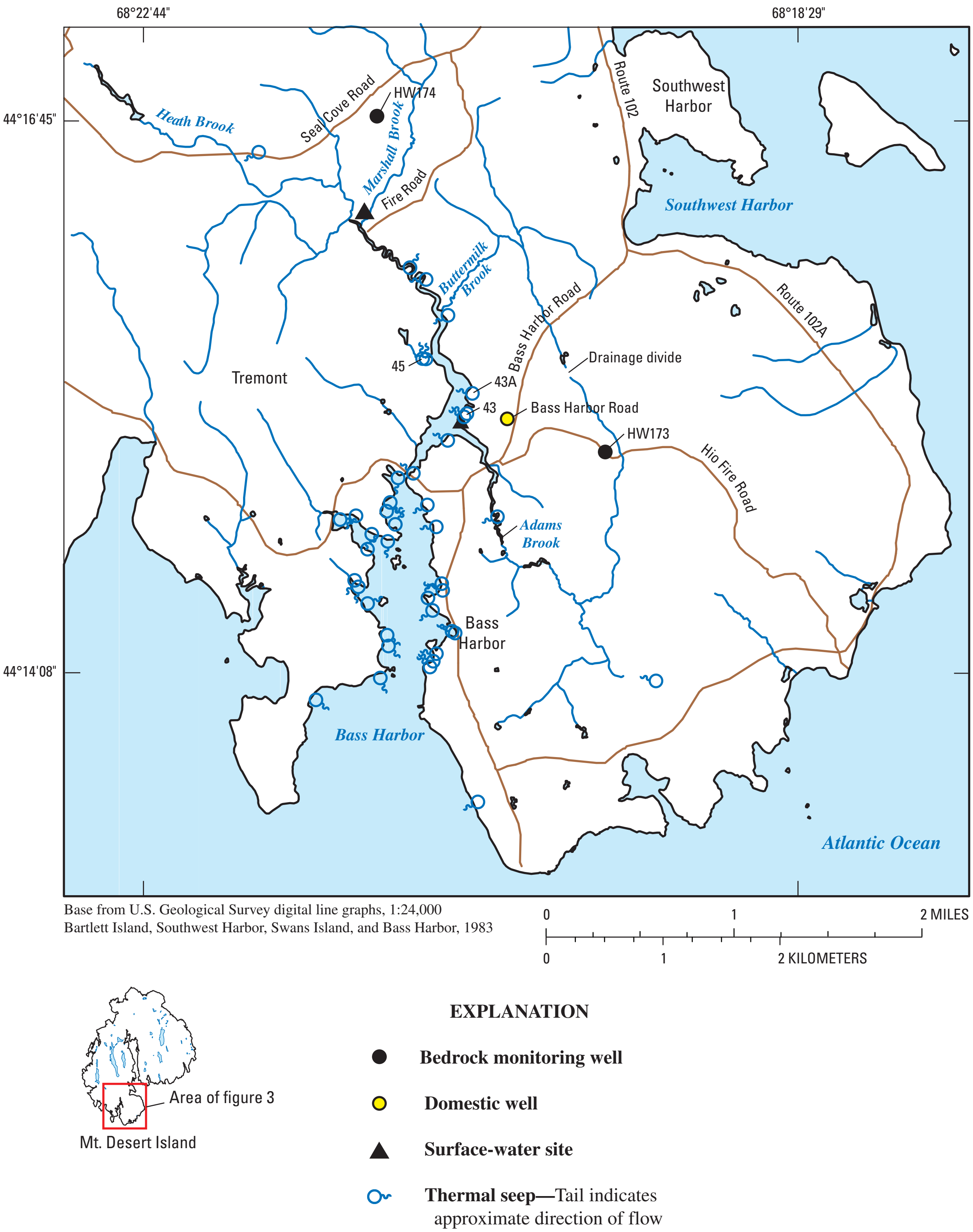


Figure 3. Locations of water-quality sampling and continuous monitoring sites in the Bass Harbor Marsh watershed on Mt. Desert Island, Maine.

the opening of the seep at the sediment surface. Samples for laboratory analysis were collected at depths of 15, 20, and 50 cm below the opening of the seep using a peristaltic pump. Samples were analyzed for dissolved inorganic nutrients (nitrate, nitrite, ammonium [reported as ammonia], orthophosphate), total phosphorus, and total and dissolved nitrogen, dissolved organic carbon (DOC) (table 1) and wastewater-related compounds (from seep 45 only) (table 2).

Three mini-piezometers (0.05 × 2 m) were installed in the riparian or hyporheic zones of marsh sediments immediately adjacent to Aunt Betsey's Brook in Northeast Creek estuary along suspected flow paths of shallow ground water that likely originated in residential areas in the uplands on October 5, 2004. Well 1 was installed 7.62 m from Northeast Creek water edge to a depth of 3.35 m, screened from 2.59 to 3.35 m. Well 3 was installed 17.62 m towards the forest from Well 1 to a depth of 1.07 m, screened from 0.335 to 0.945 m. Well 2 was not productive and, therefore, was not sampled for this study. After installation, the wells were pumped dry and then allowed to re-equilibrate overnight. Temperature, pH, specific conductance, and dissolved oxygen were measured in situ using a YSI multi-parameter probe. Samples were collected for laboratory analysis using a peristaltic pump. Samples were analyzed for nutrients (nitrate, nitrite, ammonium [reported as ammonia], orthophosphate, total and dissolved organic nitrogen, total phosphorus on June 6, 2005, only), DOC (table 1), and boron on June 20, 2005, only (table 3).

Table 1. Constituent name, U.S. Geological Survey National Water Information System parameter codes, and minimum reporting limits for temperature, specific conductance, dissolved oxygen, pH, nutrients, and dissolved organic carbon.

[ºC, degrees Celsius; na, not applicable; µS/cm, microsiemens per centimeter; mg/L, milligrams per liter; N, nitrogen, P, phosphorus]

Parameter code	Constituent name	Minimum or laboratory reporting limit
00010	Temperature, water (ºC)	0.1ºC
00095	Specific conductance, field (µS/cm at 25ºC)	1.0 µS/cm
00300	Oxygen, dissolved (mg/L)	.1 mg/L
00400	pH, field, unfiltered water (standard units)	na
00613	Nitrogen, nitrite, dissolved (mg/L as N)	.01 mg/L
00631	Nitrogen, nitrite plus nitrate, dissolved (mg/L as N)	.5 mg/L
00608	Nitrogen, ammonia, dissolved (mg/L as N)	.05 mg/L
62854	Nitrogen, total, dissolved (mg/L as N)	.01 mg/L
62855	Nitrogen, total, unfiltered (mg/L as N)	na
00671	Phosphorus, orthophosphate, dissolved (mg/L as P)	.006 mg/L
00665	Phosphorus, total (mg/L as P)	.001 mg/L
00681	Carbon, organic, dissolved (mg/L)	.5 mg/L

Collection of Water Samples from Estuaries

Samples were collected from Bass Harbor Marsh and Northeast Creek estuaries at locations adjacent to ground-water seeps (Bass Harbor Marsh) and shallow ground-water mini-piezometers (Northeast Creek) on the same dates that the seep or ground water was sampled. Temperature, pH, specific conductance, and dissolved oxygen were measured in situ using a YSI multi-parameter probe lowered to a depth of 30 to 50 cm below the water surface. Samples for laboratory analysis were collected at depths of 30 to 50 cm below the water surface using a peristaltic pump. Samples were analyzed for nutrients (nitrate, nitrite, ammonium [reported as ammonia], orthophosphate, total and dissolved organic nitrogen, total phosphorus on June 20, 2005, at Station 104 only), DOC (table 1) and wastewater-related compounds (from Bass Harbor Marsh on October 6, 2004, only) (table 2).

Collection of Water Samples from Bedrock Monitoring Wells and Domestic Wells

Four bedrock monitoring wells were installed in Northeast Creek and Bass Harbor Marsh watersheds (figs. 2 and 3) in September and October of 2003 at depths ranging from 22 to 81 m for monitoring water level and periodic water-quality assessment. Well locations, aquifer characteristics, well characteristics, and daily mean water levels are reported by Stewart and others (2006). Wells were sampled on three separate occasions at different water levels and times of the year. Prior to sample collection, at least three bore volumes were pumped from wells using a Grundfos Model 10 SQ/SQE–160 submersible pump, at a flow rate of 0.63 L/s. Water-quality samples were subsequently collected on the recovering well water using a Fultz submersible pump (Pump Head Mdl. 30575) at a flow rate of 1 L/min. Physical water-quality parameters (pH, temperature, specific conductance, and dissolved oxygen) were measured using a YSI multi-parameter probe in a flow-through chamber.

Five domestic wells in the Northeast Creek and Bass Harbor Marsh watersheds (figs. 2 and 3) were sampled once. Domestic well water samples were collected at the point-of-entry to the house, prior to the pressure tank or any water filtration system via the household well pump. Water was allowed to flow at a rate of 1 L/min until readings of physical water-quality parameters (pH, temperature, specific

Table 2. Constituent name, U.S. Geological Survey National Water Information System parameter codes, and minimum reporting limits for trace wastewater-related compounds (USGS water-quality analytical schedule 1433).

[All minimum reporting limits are in micrograms per liter]

Parameter code	Constituent name	Minimum reporting limit
62005	Cotinine	1
62052	Ethynyl estradiol	5
62063	5-Methyl-1H-benzotriazole	2
62066	Anthraquinone	0.5
62064	Acetophenone	.5
62065	Acetyl hexamethyl tetrahydronaphthalene (AHTN)	.5
34221	Anthracene	.5
34572	1,4-Dichlorobenzene	.5
34248	Benzo[a]pyrene	.5
62067	Benzophenone	.5
04029	Bromacil	.5
34288	Bromoform	.5
62059	3-*tert*-Butyl-4-hydroxy anisole (BHA)	5
50305	Caffeine	.5
62070	Camphor	.5
82680	Carbaryl	1
62071	Carbazole	.5
38933	Chlorpyrifos	.5
62072	Cholesterol	2
62057	3-beta-Coprostanol	2
62078	Isopropylbenzene	.5
62082	N,N-diethyl-meta-toluamide (DEET)	.5
39572	Diazinon	.5
38775	Dichlorvos	1
62069	Bisphenol A	1
62074	Equilenin	5
62053	17-beta-Estradiol	5
62484	Estrone	5
62091	Triethyl citrate (ethyl citrate)	.5
34476	Tetrachloroethylene	.5
34377	Fluoranthene	.5
62075	Hexadydrohexamethylcyclopentabenzopyran (HHCB)	.5
62076	Indole	0.5
62077	Isoborneol	.5
34409	Isophorone	.5
62079	Isoquinoline	.5
62073	d-Limonene	.5
62080	Menthol	.5
50359	Metalaxyl	.5
39415	Metolachlor	.5
34443	Naphthalene	.5
62054	1-Methylnaphthalene	.5
62055	2,6-Dimethylnaphthalene	.5
62056	2-Methylnaphthalene	.5
62083	Nonylphenol, diethoxy- (total)	5
62084	p-Cresol	1
62060	4-Cumylphenol	1
62085	para-Nonylphenol (total)	5
62061	4-n-Octylphenol	1
62062	4-*tert*-Octylphenol	1
34462	Phenanthrene	.5
34466	Phenol	.5
34459	Pentachlorophenol	2
62089	Tributyl phosphate	.5
62092	Triphenyl phosphate	.5
62093	Tri(2-butoxyethyl)phosphate	.5
62087	Tri(2-chloroethyl)phosphate	.5
04037	Prometon	.5
34470	Pyrene	.5
62081	Methyl salicylate	.5
62058	3-Methyl-1(H)-indole (Skatole)	1
62068	beta-Sitosterol	2
62086	beta-Stigmastanol	2
62090	Triclosan	1
62088	Tris (dichlorisopropyl) phosphate	.5

Table 3. Constituent name, U.S. Geological Survey National Water Information System parameter codes and minimum reporting limits for major ions and trace metals.

[mg/L, milligrams per liter; SO_4, sulfate; SiO_2, silica; As, arsenic; µg/L, micrograms per liter]

Parameter code	Constituent name	Minimum reporting limit[1]
00915	Calcium, dissolved (mg/L)	0.05 mg/L
00925	Magnesium, dissolved (mg/L)	.05 mg/L
00930	Sodium, dissolved (mg/L)	.05 mg/L
00935	Potassium, dissolved (mg/L)	.05 mg/L
00940	Chloride, dissolved (mg/L)	.1 mg/L
00945	Sulfate, dissolved (mg/L as SO_4)	.2 mg/L
00955	Silica, dissolved (mg/L as SiO_2)	.5 mg/L
01020	Boron	13 µg/L
01106	Aluminum	1.6 µg/L
01095	Antimony	.2 µg/L
62453	Arsenate (H_2AsO_{4-}) (mg/L as As)	.2 µg/L
01000	Arsenic	.12 µg/L
62452	Arsenite (H_3AsO_3) (mg/L as As)	.18 µg/L
01025	Cadmium	.04 µg/L
01030	Chromium	.04 µg/L
01040	Copper	.4 µg/L
01046	Iron	6.0 µg/L
01049	Lead	.08 µg/L
01056	Manganese	.2 µg/L
01065	Nickel	.06 µg/L
01075	Silver	.2 µg/L
01085	Vanadium	.1 µg/L
01090	Zinc	.6 µg/L
22703	Uranium (natural)	.04 µg/L

[1] Minimum reporting limit from U.S. Geological Survey National Water Quality Laboratory Catalog on the World Wide Web.

conductance, and dissolved oxygen) stabilized (typically 15–25 min.). Physical water-quality measurements were made using a YSI multi-parameter probe in a flow-through chamber. Once stable readings were obtained, samples were collected through a 0.45-µm Supor capsule filter, or unfiltered, depending on the analyte.

Processing and Analysis of Water Samples

All water samples collected for analysis were either filtered through a 0.45-µm Supor capsule filter, or collected unfiltered, depending on the analyte. All laboratory analyses were performed by the USGS National Water Quality Laboratory (NWQL) and entered into the National Water Information Systems (NWIS) database. Standard NWQL laboratory analytical methods were used for all analyses (Fishman, 1993). All samples were fixed according to USGS-NWQL protocols and kept on ice prior to shipment to the NWQL. Samples were shipped on ice to the NWQL within 12–24 hours of collection. Samples were analyzed for specific conductance, pH, concentrations of nutrients, and DOC (table 1), wastewater-related compounds (table 2), and major ions and trace metals, including arsenic (table 3). With the exception of arsenic, major ions and trace metals were only measured in the bedrock monitoring wells (table 1-1).

Throughout this report the notation “dissolved” in reference to laboratory determined analytes is identical to the laboratory reporting of “filtered” that is used in tables in this report that describe the NWQL analytes. Dissolved organic nitrogen was not measured directly, but rather was estimated as total nitrogen (NWQL parameter code P62854) minus nitrate plus nitrite (NWQL parameter code P00631), and minus ammonia (NWQL parameter code P00608).

Estimation of Nutrient Load

Seep 43 was observed to flow out of the ground through a narrow and relatively shallow channel and into the Bass Harbor Marsh estuary. Ten measurements of flow velocity were made over a 50-cm section of this channel on October 6, 2004. Velocity was measured by timed observation of a float over this 50-cm section (Rantz and others, 1982). The average measured velocity was 0.0763 m/s (±0.0107 m/s standard deviation (σ)). The cross-sectional area of the channel was measured in three cross sections at the upstream, middle, and outlet of this channel segment. The average cross-sectional area was 0.0101 m^2 (±0.035 m^2 σ). These measurements were used to compute an average seep discharge of 0.0077 m^3/s (±3.4×10^{-5} m^3/s σ, assuming a velocity of 0.0763 m/s). The daily load of total dissolved nitrogen from this seep was computed as the product of the streamflow rate (per day) multiplied by the measured concentration.

Ancillary Measurements

Rainfall records were obtained from the NPS at Acadia National Park. The NPS maintains a National Atmospheric Deposition Program (NADP) monitoring site that uses a Belfort tipping bucket rain gage to record daily rainfall data at McFarland Hill on Mt. Desert Island (fig. 2). The NADP program is administered by the Illinois State Water Survey, Champlain, Illinois. Data can be accessed from the URL *http://nadp.sws.uiuc.edu/*. Tidal data were obtained from National Oceanographic and Atmospheric Administration (NOAA) data files [*http://tidesandcurrents.noaa.gov*] for Frenchman’s Bay, Bar Harbor, Maine, on Mt. Desert Island. Specific conductance and water-level data for Northeast Creek during the summer in 2001 were obtained from an earlier USGS investigation (Caldwell and Culbertson, 2007).

Results and Discussion

The results and discussion are described in three sections. The first section describes identification of thermal anomalies using aerial infrared digital imaging and the confirmation of shallow ground-water discharge zones (seeps) using water-quality measurements. The second section discusses water quality in the hyporheic zone as measured in shallow ground-water seeps in Bass Harbor Marsh, in shallow ground-water wells in Northeast Creek, and in the adjacent estuaries. The third section discusses the quality of the water in domestic and bedrock monitoring wells.

Identification of Thermal Anomalies and Confirmation of Seeps

Potential ground-water discharge zones in Bass Harbor Marsh and Northeast Creek estuaries were identified from AIDIA images obtained during flights in May and December 2003. Twenty-five thermal anomalies were detected during the May flight (table 4), and 49 thermal anomalies were detected during the December flight (table 5). Temperature anomalies arise from the discharge of ground water that is colder than the surface water in the estuary in May and warmer in December.

The types of thermal anomalies identified during the two flights had quite different characteristics. During the May flight, the anomalies appeared generally to be broad and diffuse temperature variations in open water or along narrow ditches. Few small discrete anomalies were identified during the May flight. By contrast, during the December flight, numerous discrete thermal anomalies were identified in both Bass Harbor Marsh and Northeast Creek, in open water, intertidal, and onshore locations. The anomalies identified in the May flight did not appear to be from discrete ground-water seepage zones that could be validated in the field. It is likely that the temperature differences between shallow ground water and water in the estuaries were not as large in May as in December, so it is likely that the anomalies detected in December were present but not as evident in May. It also is likely that the tidal conditions and fresh surface water inputs were not as favorable for the detection of thermal anomalies during May as in December. Finally, the May flight did not include all of the area in Bass Harbor Marsh or Northeast Creek that was flown during the December flight, so some of the seeps identified during the December flight might not have been observed during the May flight.

The thermal anomalies identified during the December flight appear as discrete to diffuse variations in shading intensity (lighter colored spots of various sizes on darker backgrounds). The anomalies range in size and intensity of shading contrast compared with the background. Various types of anomalies were tentatively identified, including open water (small areas of open water surrounded by ice on Northeast Creek), a ground-water seep at water's edge or in a tidal mud flat, and a ground-water seep not at water's edge (e.g. woods, farmer's field) (table 5). The locations of many of the anomalies identified in Northeast Creek and Bass Harbor Marsh estuaries in December 2003 are shown in figures 4 and 5. The wide variation in the shape, size, and intensity (brightness contrast) of the temperature anomalies may indicate a range of different seep discharge rates and differential rates of mixing with surface water.

Measurements of specific conductance during the summer of 2001 that were reported in a previous study (Caldwell and Culbertson, 2007) are useful for the confirmation of

Table 4. Thermal anomalies identified during the flight on 5/28/2003 3:31–4:39. Municipalities included Bar Harbor, Southwest Harbor, and Tremont, Maine.

[Latitude and longitude in degrees minutes seconds (decimal seconds format). The anomalies were not classified during this flight]

Anomaly number	Latitude	Longitude
1	44 25 20.30	68 20 57.09
2	44 25 15.49	68 20 49.38
3	44 25 16.25	68 21 05.63
4	44 25 17.37	68 20 25.18
5	44 25 17.25	68 20 38.72
6	44 25 19.94	68 20 16.48
7	44 26 15.08	68 19 40.05
8	44 24 45.26	68 17 48.65
9	44 15 19.21	68 20 44.01
10	44 15 10.47	68 20 56.69
11	44 14 40.94	68 21 20.41
12	44 13 38.60	68 20 33.15
13	44 14 17.92	68 20 50.15
14	44 14 26.24	68 20 42.79
15	44 14 35.67	68 20 51.95
16	44 14 39.83	68 20 46.38
17	44 14 07.37	68 21 35.54
18	44 14 13.41	68 21 10.35
19	44 14 58.29	68 21 19.59
20	44 15 02.33	68 21 06.42
21	44 15 09.01	68 21 03.23
22	44 14 58.29	68 20 24.46
23	44 14 51.49	68 21 07.41
24	44 14 22.19	68 21 07.32
25	44 15 01.33	68 20 51.78

Table 5. Thermal anomalies identified during flight on 12/3/2003 23:45 to 12/4/2003 04:30. Municipalities included Bar Harbor, Southwest Harbor, and Tremont, Maine.

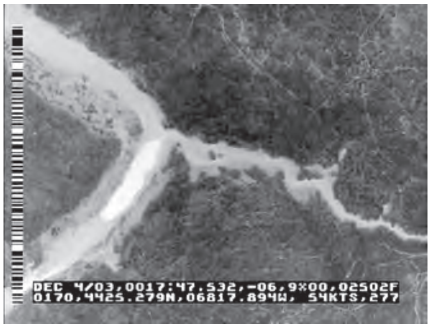
[Latitude and longitude in degrees minutes seconds (decimal seconds format). The anomalies are classified generally as GS, ground-water seep; OW, open water—a small area of open water surrounded by ice on Northeast Creek; GW, ground-water seep not exiting the ground at the water's edge; WS, water seep from the ground at the water's edge or in a tidal mud flat; or other as noted]

Anomaly number	Latitude	Longitude	Classification of thermal anomaly
1	44 24 21.99	68 17 22.59	GS, forest edge.
2	44 24 27.27	68 17 22.43	GS, forest edge.
3	44 24 34.47	68 17 15.87	GS at road/two-track.
4	44 24 46.25	68 17 42.20	GS, farmer's field.
5	44 25 02.07	68 17 51.39	Warm spots-possible minor seep—no flow visible.
6	44 24 10.23	68 18 38.46	GS in woods near road. Upper left of image. Other GS is 'headwaters' of a creek in immediate vicinity.
7	44 25 16.07	68 17 52.62	OW
8	44 25 15.78	68 18 00.25	OW
9	44 25 17.19	68 18 03.04	OW
10	44 25 05.12	68 18 31.99	OW
11	44 25 06.11	68 18 34.05	OW
12	44 25 08.22	68 18 40.44	OW
13	44 25 09.04	68 18 41.35	OW
14	44 25 03.24	68 18 47.01	OW
15	44 25 06.70	68 18 50.95	OW and GS (upper left of image).
16	44 25 16.25	68 19 05.06	GS, small.
17	44 25 19.18	68 19 25.16	OW
18	44 25 26.15	68 19 32.87	OW and small GS ~300–350 feet southeast of bridge.
19	44 25 28.55	68 19 34.67	Small GS near bridge.
20	44 25 34.06	68 20 11.84	WS at point of land.
21	44 25 17.89	68 20 37.40	WS with flow.
22	44 25 14.96	68 20 44.53	WS, several, with flow.
23	44 25 12.73	68 20 52.66	WS
24	44 25 01.48	68 21 06.30	GS, some flow over face.
25	44 25 40.92	68 20 55.94	Possible house sewage/wastewater outfall.
26	44 24 06.11	68 18 02.43	House drain/seep. First house on right on Russell.
27	44 25 34.94	68 17 00.38	GS, one small and several tiny.
28	44 20 54.97	68 24 47.41	GS, possible sewer/septic leak/seep.
29	44 16 39.97	68 21 56.05	GS at roadside, near creek.
30	44 15 54.03	68 20 43.14	WS, just below Buttermilk Brook.

Table 5. Thermal anomalies identified during flight on 12/3/2003 23:45 to 12/4/2003 04:30. Municipalities included Bar Harbor, Southwest Harbor, and Tremont, Maine.—Continued

[Latitude and longitude in degrees minutes seconds (decimal seconds format). The anomalies are classified generally as GS, ground-water seep; OW, open water—a small area of open water surrounded by ice on Northeast Creek; GW, ground-water seep not exiting the ground at the water's edge; WS, water seep from the ground at the water's edge or in a tidal mud flat; or other as noted]

Anomaly number	Latitude	Longitude	Classification of thermal anomaly
31	44 14 34.34	68 21 15.45	WS/GS at shoreline, numerous but minor.
32	44 14 38.85	68 21 18.81	WS, small at inlet.
33	44 14 55.49	68 20 48.54	WS, small at shore.
34	44 15 34.64	68 20 33.49	WS, possible, small next to and north of creek mouth.
35	44 16 04.17	68 20 51.33	Two small WS just south of sharp bend in river.
36	44 16 07.74	68 20 57.63	Two small WS at bend in river.
37	44 14 11.96	68 19 23.59	Small seep in march area.
38	44 14 16.24	68 20 51.41	Two WS next to habitation—possible outfalls.
39	44 14 19.93	68 20 48.79	Small WS on mud flats at low tide—near habitation.
40	44 14 25.61	68 20 41.59	Multiple WS at shore line.
41	44 14 31.94	68 20 50.34	Multiple WS at shore line.
42	44 14 37.74	68 20 46.42	Multiple WS on mudflats just out from shore line.
43	44 15 28.25	68 20 33.08	Warm spot on mud flats just out from shore line.
43A	44 15 27.66	68 20 33.96	GW in marsh.
44	44 14 59.71	68 21 07.85	WS at shore, near habitation—possible outfall.
45	44 15 42.20	68 20 51.82	GS/warm spot in marsh/creek short distance from main waterway.
46	44 14 25.32	68 21 07.52	WS at shore—weak.
47	44 14 49.17	68 21 14.72	WS at shore—weak.
47A	44 14 53.56	68 21 13.41	WS at shore—weak.
48	44 14 56.08	68 21 04.49	WS at shore and in mud flats—some habitations nearby.
49	44 14 57.13	68 21 25.35	WS at shore at inlet.



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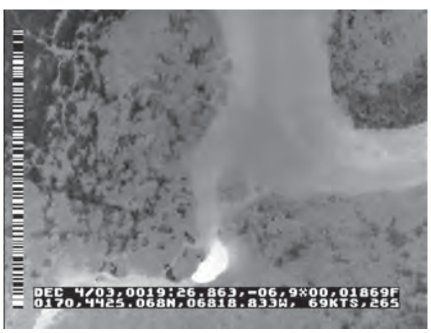

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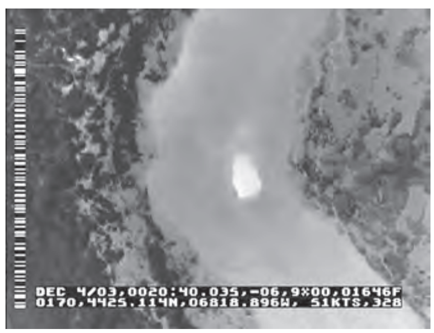

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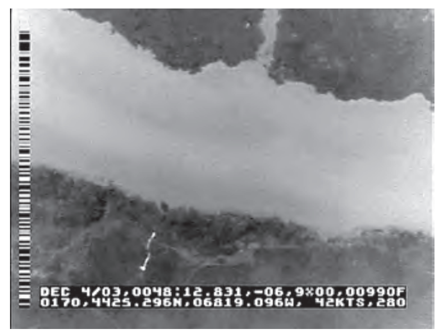

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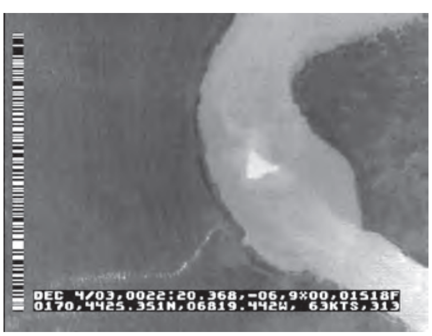

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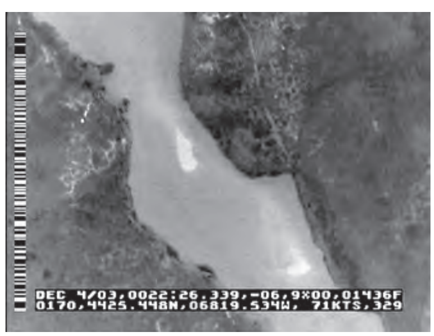

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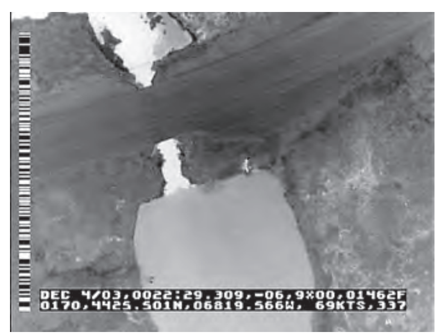

Number 19

Figure 4. Thermal seeps identified using aerial infrared digital imaging in Northeast Creek watershed in December 2003. (Seeps appear as white, or lighter colored, spots on the gray background. Numbers below photographs correspond to thermal anomaly numbers in table 5.)

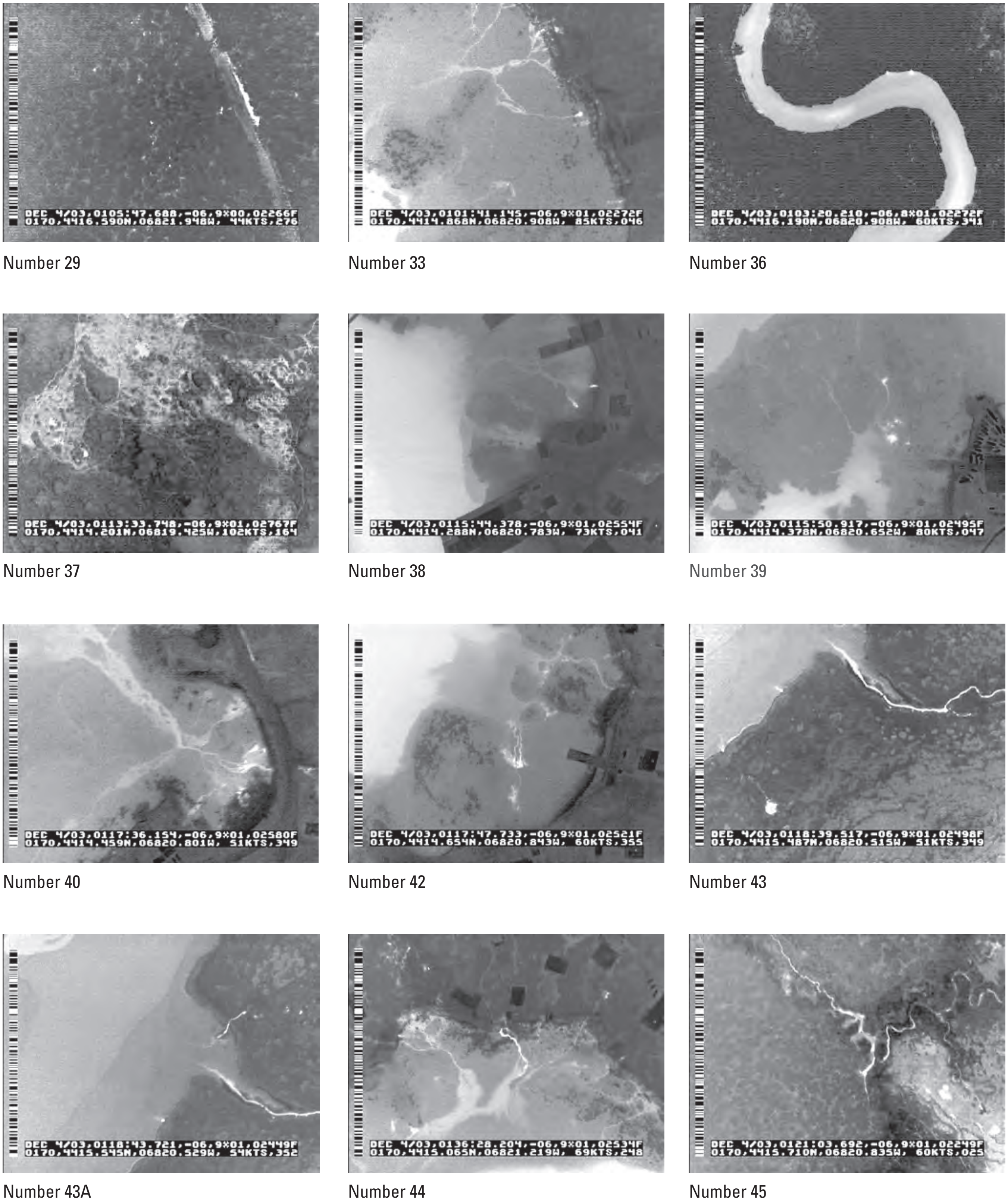

Figure 5. Thermal seeps identified using aerial infrared digital imaging in Bass Harbor Marsh watershed in December 2003. (Seeps appear as white, or lighter colored, spots on the gray background. Numbers below photographs correspond to thermal anomaly numbers in table 5.)

ground-water seepage into the Northeast Creek estuary during that summer. The presence of ground-water seeps in Northeast Creek was indicated by continuous specific conductance recorded at various stations in the estuary (Caldwell and Culbertson, 2007). At station 104 (USGS Station ID 442509068181901; latitude 44º25'09" (DMS), longitude 68º18'19"), upstream from the confluence of Northeast Creek and Aunt Betsey's Brook specific conductance was measured at 20 and 45 cm above the bottom. The methods used in obtaining continuous specific conductance in Northeast Creek during the summers of 2000 and 2001 are reported by Caldwell and Culbertson (2007). The influence of ground-water seeps on specific conductance in Northeast Creek would likely be greatest closest to the bottom and during periods when surface-water inputs were lowest. Typically streamflows in this area are lowest during late summer during extended periods with average or below average rainfall.

The summer of 2001 was a dry period, and on the basis of streamflow records, 2001 was one of the driest years of record in southeastern Maine (Lombard, 2003). For example, during the period July 20, 2001, through September 12, 2001, precipitation measured at Acadia National Park was only 3.96 cm, and this amount fell in a series of small storms, none of which exceeded 1 cm (fig. 6A). Streamflow was correspondingly low during the summer of 2001 as measured at USGS stream gages in this region (Stewart and others, 2002). No stream gages were in operation on perennial streams at Acadia National Park during 2001, but streamflow at continuously monitored sites in southeastern Maine were consistent with low flow conditions. During the period of record (1948–2004) for the Narraguagus River at Cherryfield (USGS station ID 01022500), both the August and the combined July through September streamflows in 2001 were the second lowest flows observed. Streamflow for the period July 20, 2001, through September 12, 2001, for the Narraguagus River at Cherryfield is plotted with specific conductance at station 104 in Northeast Creek (fig. 6B). In addition, during the summer of 2000, which was wetter overall than 2001, the estimated surface-water inputs to Northeast Creek upstream from station 104 were estimated to be low (Nielsen, 2002a). Streamflow at Hadlock Brook near Cedar Swamp Mountain, near Northeast Harbor (USGS station ID 01022860) (at Acadia National Park on Mt. Desert Island) is not perennial. Again, there was no gage record for the Northeast Creek tributaries during 2001, but flow at Hadlock Brook, which has been shown to be highly correlated to flows on tributaries to Northeast Creek (Nielsen, 2002a), was virtually dry during the period July 20, 2001, through September 12, 2001, averaging 0.30 m^3/day (0.0085 ft^3/s) (Stewart and others, 2002).

The tidal cycle in Northeast Creek is complex and reflects the regional semi-diurnal cycle, the influence of a sill and constriction near the outlet, and the influence of impounded freshwater. The constriction, remains of an old rock dam and existing bridge culvert, is at an elevation slightly below mean high tide. Northeast Creek receives tidal inputs during most of the lunar cycle, but intense flooding of the estuary occurs only during the perigean spring tides (when the moon's proximity to the earth in orbit coincides with the new or full moon). The tidal cycle for station 101 is shown in figure 6C. The overall pattern in specific conductance reflects the tidal cycle in the Northeast Creek estuary, showing that saltwater inputs increase quickly and reach a maximum within about 1 week (at the perigean spring tide) and then decline more gradually, reaching a minimum approximately 3 weeks later, completing the cycle (figs. 6B and 6C) (Caldwell and Culbertson, 2007).

During most of the first tidal cycle, specific conductance in the deeper water was equal to or greater than the specific conductance in the shallower water (fig. 6B). This would be expected if freshwater inputs from surface-water sources were the dominant source of freshwater in the estuary, because the lower density freshwater typically is advected out of the estuary over saltier and denser underlying water. Towards the end of this first tidal cycle on August 8, 2001, specific conductance became greater in the shallow water of the estuary and remained greater for most of the remainder of this and the subsequent tidal cycle. The inference is that ground-water seepage became the dominant source of freshwater during this dry period, when surface runoff was low. During this period, ground water appears to be largely responsible for the difference in specific conductance between saltwater (about 50,000 µS/cm) and the measured values in the estuary. The underlying saltwater wedge has been shown to migrate upstream in Northeast Creek as fresh surface-water inputs diminish during the onset of summer low-flow conditions (Caldwell and Culbertson, 2007).

Temperature and specific conductance also were measured continuously in seeps 43 and 43A in Bass Harbor Marsh during 2004, and these time series are consistent with fresh ground-water seepage into the estuary. Data in this report include only those from seep 43A. The elevation of seep 43 is slightly below mean high tide. Seep water temperature increased from late spring to early September (fig. 7A). Daily total precipitation during the period June 1 through September 15, 2004 at McFarland Hill shows four storms with rainfalls greater than 2 cm per day during this period (fig. 7B). Seep water temperature also was correlated with the tidal cycle such that temperature was higher during spring tides and lower during neap tides (fig. 7C). This relation between seep water temperature and tide could be explained by cold seep water that is warmed when the seep is flooded (from tidal inundation) and warmed to the greatest extent during the highest spring tides. The temperature of the estuary water adjacent to seep 43 (water depth = 20 cm) (21.7°C) was substantially warmer than that measured in the seep adjacent to the continuously recording temperature sensor on July 1, 2004 (14°C). The corresponding specific conductances on this date were 43,500 µS/cm in the estuary and 37,000 µS/cm in the seep. The continuous specific conductance data time series from seep 43 (fig. 7A) shows the influence of semidiurnal tidal cycle that brings saltwater into the estuary. The specific conductance in the seep never gets to levels as high as those

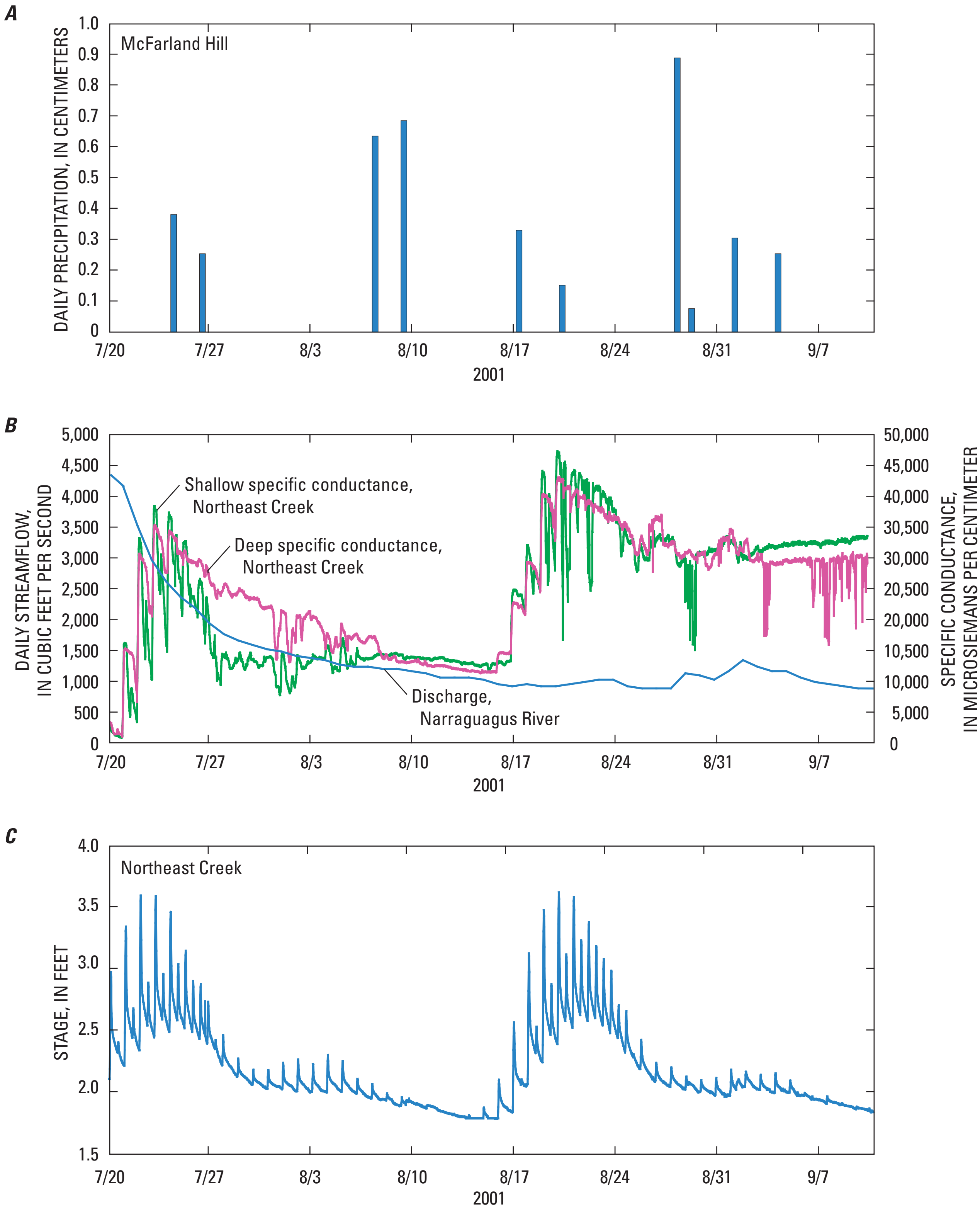

Figure 6. Precipitation, streamflow, specific conductance, and stage from July 20 through September 12, 2001. *(A)* Precipitation (rainfall) at McFarland Hill, Acadia National Park, Mt. Desert Island, Maine; *(B)* daily streamflow for the Narraguagus River near Cherryfield, Maine, plotted with specific conductance at station No. 104 in Northeast Creek; and *(C)* stage (tide) at station No. 101 in Northeast Creek, Maine.

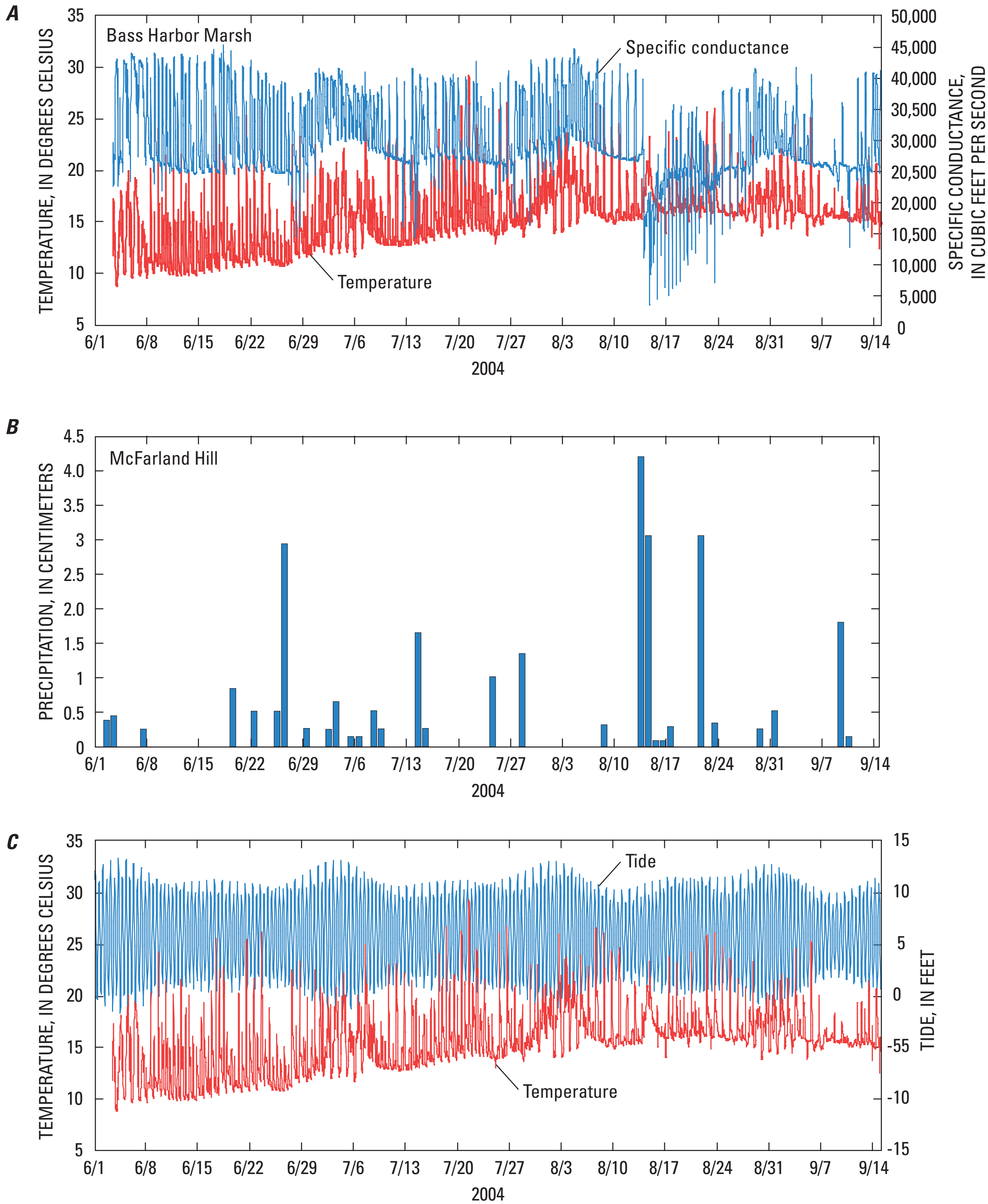

Figure 7. Seep water quality, precipitation, and ocean tide and water temperature for the period June through September 2004. *(A)* Temperature and specific conductance at 50 cm below sediment surface in seep 43a Bass Harbor Marsh; *(B)* rainfall at McFarland Hill, Acadia National Park, Mt. Desert Island, Maine; and *(C)* tide at Bar Harbor, Maine, and water temperature at 50 cm below sediment surface in seep 43a Bass Harbor Marsh.

measured in the estuary itself (comparable to saltwater). After tidal recession, the specific conductance rapidly declines to levels from 25,000 to 30,000 μS/cm. The freshening effect of a rainfall from August 13–14, 2004, (totaling 7.2 cm) (fig. 7B) is evident following this mid-August storm when the specific conductance in the seep decreased to its lowest measured values of 10,000 to 20,000 μS/cm (fig. 7A). This decrease in specific conductance persisted for several tidal cycles and was likely a result of increased freshwater inputs from ground water. Other storms, larger than about 2 cm, produced smaller but noticeable depressions in seep specific conductance (figs. 7A and 7B).

The identification of thermal anomalies in the Northeast Creek estuary could be evidence for shallow ground-water-flow paths (through soils, till, and peat) or deeper flow paths (through fractured bedrock and through overlying marine clay and peat). Further investigations would be necessary to resolve the proportional contributions from these two sources. This distinction between sources is important for understanding nitrogen loading from ground water to the estuaries at Acadia National Park.

Water Quality in the Hyporheic Zone and Adjacent Estuary

Dissolved organic nitrogen (estimated as total dissolved nitrogen, P62854, minus dissolved nitrate plus nitrite, P00631, and minus ammonia, P00608) was the dominant form of nitrogen in shallow ground water measured in wells adjacent to the estuary in Northeast Creek (table 6), in shallow ground-water seeps measured in Bass Harbor Marsh (table 7), and in the adjacent estuaries (table 8). Concentrations of ammonium (reported as ammonia) in seeps in Bass Harbor Marsh ranged from 0.17 to 0.87 mg/L, nitrate plus nitrite (P0063) was below detection at seeps 43 and 43a, but ranged from 0.57 to 0.91 at seep 45 (table 7). Concentrations of ammonium (reported as ammonia) were higher in shallow ground water collected adjacent to Northeast Creek (0.71 to 6.97 mg/L) than those measured in Bass Harbor Marsh seeps. Nitrate concentrations were below detection in all samples collected from wells in Northeast Creek and in the Bass Harbor estuary and Marshall Brook (tables 7 and 8). Total dissolved nitrogen in Bass Harbor Marsh seeps ranged from 0.66 to 1.57 mg/L compared with 0.98 to 7.42 mg/L in the shallow hyporheic zone wells in Northeast Creek. The lower concentrations of total dissolved nitrogen in Bass Harbor Marsh seeps compared with those in Northeast Creek hyporheic zone water may reflect dilution from tidal inputs, which will be discussed in more detail later in this report. Total dissolved nitrogen concentrations in the estuaries and in Marshall Brook (0.23 to 0.52 mg/L) were lower than those measured in adjacent hyporheic zone waters and similar to those reported for streams draining into Bass Harbor Marsh (Doering and others, 1995) and Northeast Creek (Nielsen and others, 2002).

Water-quality measurements from this and earlier studies have assessed total dissolved nitrogen chemistry of various locations and water types in Northeast Creek and Bass Harbor Marsh (fig. 8, tables 6, 7, 8). Total dissolved nitrogen concentrations were elevated compared to what might be expected in more “pristine” hyporheic shallow ground water and river water (Valiela and others, 1997, 2000; Valiela and Bowen, 2002) or water leached from upland forest soils (Johnson and Lindberg, 1992; Lajtha and others, 1995; Fernandez and others, 1999). Septic effluents leaching through soils into shallow ground water have highly elevated total dissolved nitrogen, and published average values for septic effluent range from 44 to 100 mg/L (average = 60) (Whelan and Titamnis, 1982; Nizeyimana and others, 1996; Valiela and others, 1997; Townshend, 1997; Bunnel and others, 1999; Fetter, 1999; Harrison and others, 2000). Elevated total dissolved nitrogen concentrations in hyporheic zone wells adjacent to the Northeast Creek estuary and Bass Harbor Marsh seeps compared with adjacent surface waters in Northeast Creek and Bass Harbor Marsh estuaries may be indicative of contamination from septic sources. The highest total dissolved nitrogen concentrations in hyporheic zone wells adjacent to the Northeast Creek estuary are comparable to those measured at most of the shallow ground-water sites in the Northeast Creek estuary as reported by Caron (2005).

An estimate of total dissolved nitrogen inputs from ground-water seepage into the estuaries on Mt. Desert Island would be useful for evaluating the relative contribution of septic sources, compared to atmospheric and surface-water sources, to the estuarine nitrogen budget. Data collected for this project, including total numbers of seeps, data on total dissolved nitrogen concentration from two seeps, and a single estimate of seep discharge, can provide a simplistic “order of magnitude” indication of potential inputs of total dissolved nitrogen to ground water. Using seep discharge and total dissolved nitrogen concentration measured on October 6, 2004, the daily load of nitrogen (input to the Bass Harbor Marsh estuary) of total dissolved nitrogen from seep 43 was estimated to be 0.105 kg/day. Assuming the discharge rate was the same on July 1, 2004, when a lower total dissolved nitrogen concentration was measured (table 7), the estimated daily load of nitrogen was 0.057 kg/day. To obtain a rough estimate of total seep contribution of total dissolved nitrogen to the daily total dissolved nitrogen load to the Northeast Creek and Bass Harbor Marsh estuaries, the average of these two daily values was multiplied by the number of seeps identified in each estuary watershed in December 2003. There were 27 seeps identified in Northeast Creek (thermal anomalies 1–27 in table 5) and 23 seeps identified in Bass Harbor Marsh (thermal anomalies 29–49, including 43A and 47A, in table 5). This extrapolation assumes that the discharge rates from each seep are equivalent to that measured for seep 43 and that the total dissolved nitrogen concentrations also are equivalent. With these assumptions, the total seep loading of total dissolved nitrogen to the estuaries would be in the range of 1–3 kg/day for Northeast Creek and 1–2 kg/day

Table 6. Water quality in the hyporheic zone in wells in Northeast Creek.

[<, less than; nd, not determined]

Dates	Times sample start time	P72008 Depth of well, feet below land surface datum	P00025 Barometric pressure, millimeters of mercury	P00300 Dissolved oxygen, water, unfiltered, milligrams per liter	P00400 pH, water, unfiltered, field, standard units	P00095 Specific conductance, water, unfiltered, microsiemens per centimeter at 25 degrees Celsius	P00010 Temperature, water, degrees Celsius	P00608 Ammonia, water, filtered, milligrams per liter as nitrogen	P00631 Nitrite plus nitrate, water, filtered, milligrams per liter as nitrogen	P00613 Nitrite, water, filtered, milligrams per liter as nitrogen	P62854 Total nitrogen (nitrate + nitrite + ammonia + organic-N), water, filtered, analytically determined, milligrams per liter as nitrogen	P62855 Total nitrogen (nitrate + nitrite + ammonia + organic-N), water, unfiltered, analytically determined, milligrams per liter as nitrogen	P00671 Orthophosphate, water, filtered, milligrams per liter as phosphorus	P00665 Phosphorus, water, unfiltered, milligrams per liter	P00681 Organic carbon, water, filtered, milligrams per liter	P01020 Boron, water, filtered, micrograms per liter
442509068181902 Northeast Creek Station 104, Well 1																
Oct 6 2004	1705	11	768	4.3	6.7	3,100	9.7	6.97	<0.06	<0.008	7.42	nd	0.779	nd	8.1	nd
Jun 20 2005	1300	11	nd	5.2	6.5	2,570	18.6	6.48	<.06	<.008	6.6	6.92	.845	0.86	6.8	181
442509068181904 Northeast Creek Station 104, Well 3																
Oct 6 2004	1720	3.5	nd	nd	nd	900	nd	1.86	<0.06	<0.008	2.47	nd	0.174	nd	nd	nd
Jun 20 2005	1125	3.5	nd	nd	nd	nd	nd	.71	<.06	<.008	0.98	2.76	.006	0.18	5.4	nd

Table 7. Water quality in the hyporheic zone in seeps in Bass Harbor Marsh.

[All constituents in the suite of household wastewater-related compounds (table 2) analyzed for Seep 45 were determined to be below detection limits; <, less than; E, estimated, but below minimum reporting limit]

Dates	Times sample start time	P00025 Barometric pressure, millimeters of mercury	P00300 Dissolved oxygen, water, unfiltered, milligrams per liter	P00400 pH, water, unfiltered, field, standard units	P00095 Specific conductance, water, unfiltered, microsiemens per centimeter at 25 degrees Celsius	P00010 Temperature, water, degrees Celsius	P00608 Ammonia, water, filtered, milligrams per liter as nitrogen	P00631 Nitrite plus nitrate, water, filtered, milligrams per liter as nitrogen	P00613 Nitrite, water, filtered, milligrams per liter as nitrogen	P62854 Total nitrogen (nitrate + nitrite + ammonia + organic-N), water, filtered, analytically determined, milligrams per liter as nitrogen	P00671 Orthophosphate, water, filtered, milligrams per liter as phosphorus	P00681 Organic carbon, water, filtered, milligrams per liter
441528068203601 Seep 43 at Bass Harbor												
Jul 1 2004	1740	766	1.6	6	37,600	14	0.43	<0.06	<0.008	0.86	E0.004	7.9
Oct 6 2004	1300	768	1.3	6	33,600	13.8	.87	<.06	<.008	1.57	.053	E8.9
441530068203401 Seep 43A at Bass Harbor												
Jul 1 2004	1830	766	0.4	6	35,100	16.3	0.17	<0.06	<0.008	0.66	E0.003	10.1
Oct 6 2004	1415	768	.4	5.9	29,200	13.4	.29	<.06	<.008	.76	.018	E8.0
441543068205701 Seep 45 at Bass Harbor												
Jul 1 2004	1520	765	11.9	6.2	6,900	12.5	<0.04	0.57	<0.008	0.68	<0.006	1.3
Oct 6 2004	1115	768	5.9	6.3	116	8	<.04	.91	<.008	.89	<.006	.4

Table 8. Water quality in Northeast Creek and Bass Harbor Marsh estuaries.

[All constituents in the suite of household wastewater-related compounds (table 2) analyzed for BHM estuary near Seep 43 were determined to be below detection limits; nd, not detected; <, less than; E, estimated, but below minimum reporting limit]

Dates	Times sample start time	P00025 Barometric pressure, millimeters of mercury	P00300 Dissolved oxygen, water, unfiltered, milligrams per liter	P00400 pH, water, unfiltered, field, standard units	P00095 Specific conductance, water, unfiltered, microsiemens per centimeter at 25 degrees Celsius	P00010 Temperature, water, degrees Celsius	P00608 Ammonia, water, filtered, milligrams per liter as nitrogen	P00631 Nitrite plus nitrate, water, filtered, milligrams per liter as nitrogen	P00613 Nitrite, water, filtered, milligrams per liter as nitrogen	P62854 Total nitrogen (nitrate + nitrite + ammonia + organic-N), water, filtered, analytically determined, milligrams per liter as nitrogen	P62855 Total nitrogen (nitrate + nitrite + ammonia + organic-N), water, unfiltered, analytically determined, milligrams per liter as nitrogen	P00671 Orthophosphate, water, filtered, milligrams per liter as phosphorus	P00665 Phosphorus, water, unfiltered, milligrams per liter	P00681 Organic carbon, water, filtered, milligrams per liter	P01020 Boron, water, filtered, micrograms per liter
441528068203602 Estuary at Bass Harbor near Seep 43															
Jul 1 2004	1750	766	7.2	7.3	43,500	21.8	0.08	<0.06	<0.008	0.36	nd	E0.006	nd	6.4	nd
Oct 6 2004	1500	768	6.6	7.6	40,900	12.5	<.04	<.06	<.008	.23	nd	E.005	nd	3.4	nd
442509068181901 Northeast Creek Monitoring Station 104															
Oct 6 2004	1730	765	9.2	7.4	414	12.9	<0.04	<0.06	<0.008	0.52	nd	<0.006	nd	6.5	nd
Jun 20 2005	1335	nd	8.3	6	65	21	<.04	<.06	<.008	.42	0.47	<.006	0.018	11.1	8.4
41619068211701 Marshall Brook at Fire Road near Southwest Harbor															
Jul 1 2004	1330	765	9.2	6.7	137	18.7	<0.4	0.07	<0.008	0.42	nd	<0.006	nd	10.9	nd

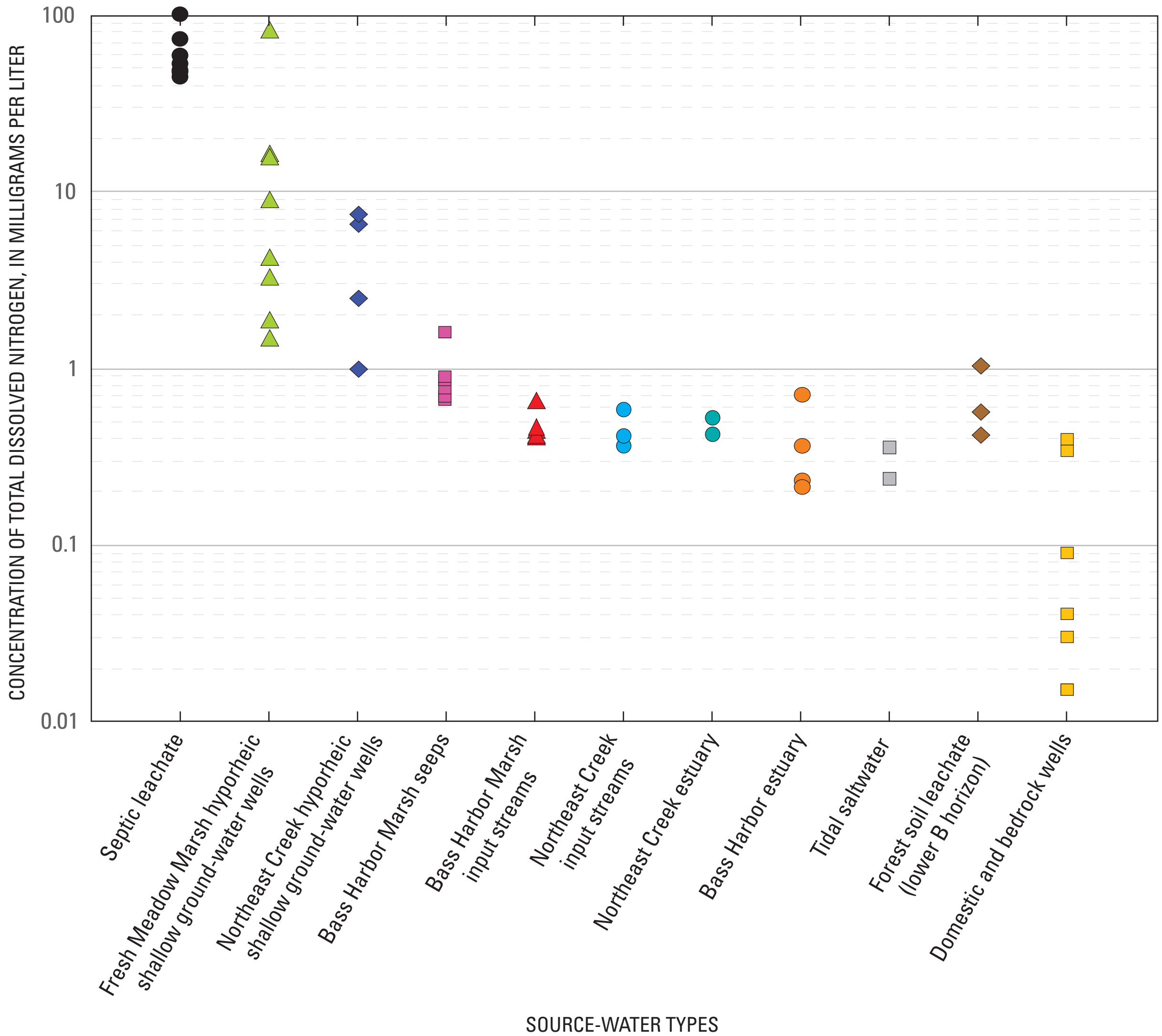

Figure 8. Total dissolved nitrogen in various waters.

for Bass Harbor Marsh. As speculative as this estimate is, it may be somewhat conservative because ground-water seepage rates in October 2004 were probably lower than the average for the period April through November based on average monthly streamflow statistics for Hadlock Brook (USGS station ID 01022860) during this period.

These potential seep loads can be compared with those estimated from the major tributaries to Northeast Creek and Bass Harbor Marsh in previously published studies. Doering and others (1995) used 19 streamflow measurements and six stream water total dissolved nitrogen concentration measurements made in the months of April through November during the years 1990 through 1992 and estimated 30 kg/day of nitrogen input to Bass Harbor Marsh estuary from five major freshwater tributaries. Nielsen (2002a) measured concentration of total dissolved nitrogen in stream water and monthly streamflow from April 1999 through September 2000. Using one continuously recording station and record extension techniques, daily streamflow was estimated from four major freshwater tributaries and ungaged streams to Northeast Creek. From these measurements a daily load of total dissolved nitrogen to the Northeast Creek estuary was estimated to be 10.7 kg/day. Although there are large uncertainties associated with extrapolating measured instantaneous loading from one seep to an entire estuary, these preliminary estimates suggest that shallow-ground-water seeps could contribute a substantial percentage of total dissolved nitrogen to the total estuary load. Nitrogen loads from shallow-ground-water seeps could be particularly important during periods of low streamflow when loads from streams are substantially reduced (Nielsen, 2002a) because ground-water seeps are likely to be less sensitive to short-term drought than streamflow.

Caron (2005) reported larger concentrations of total dissolved nitrogen in shallow ground water closest to the estuary and lower concentrations in shallow ground water further upslope and closer to inferred septic sources. More typically, concentrations of dissolved inorganic nitrogen have been found to decrease with increasing distance from septic sources (Valiela and others, 1997). One possible explanation for the pattern observed by Caron (2005) could be a suppression of the microbial uptake of nitrate in more saline waters in hyporheic shallow ground water (Sorenson and others, 1980; Koch and others, 1992; Meyer and others, 2001; Irshad and others, 2005). Such suppression, if it is occurring in these soils, could inhibit or impede denitrification and allow total dissolved nitrogen to accumulate in tidally influenced hyporheic ground water.

Concentrations of orthophosphate ranged from below the minimum reporting limit (MRL) (0.006 mg/L) to 0.053 mg/L in seeps in Bass Harbor Marsh (table 7) and from the MRL to 0.845 mg/L in shallow ground water in Northeast Creek (table 6). Orthophosphate was at or lower than the MRL in both estuaries (table 8). These concentrations of orthophosphate are much lower than what might be found in septic effluents (Canter and Knox, 1985; Weiskel and Howes, 1992). Orthophosphate is not necessarily a reliable indicator of septic contamination in waters downgradient from septic sources because of retention in soils and biotic uptake. An assessment for Narragansett Bay estuary in Rhode Island indicated that inputs of reactive dissolved inorganic phosphorus had approximately doubled since European settlement, compared with a five-fold increase for reactive dissolved inorganic nitrogen (Nixon, 1997). In Narragansett Bay, in pre-historic times, more than 95 percent of dissolved inorganic phosphorus inputs were of oceanic origin, whereas current land-derived inputs are comparable to oceanic inputs (Nixon, 1997). Nixon and others (1986) used mesocosm experiments in Narragansett Bay to show that primary production of phytoplankton was limited by dissolved inorganic nitrogen and that these findings were consistent with those reported for 10 different natural marine systems. The estuaries at Acadia National Park are likely under substantially greater risk of eutrophication resulting from anthropogenic inputs of dissolved inorganic nitrogen compared with dissolved inorganic phosphorus, as has been well documented in other northeastern U.S. coastal environments (Ryther and Dunstan, 1971). Dissolved inorganic phosphorus may be important in fresh and oligohaline parts of the Northeast Creek estuary.

Concentrations of DOC ranged from 7.9 to 10.1 mg/L in seeps 43 and 43A in Bass Harbor Marsh (table 7) and 5.4 to 8.1 mg/L in Wells 1 and 3 in Northeast Creek (table 6). These concentrations are substantially lower than those reported for tributary inputs to Bass Harbor Marsh measured in the early 1990s (Doering and others, 1995), but they are similar to those measured for tributary inputs to Northeast Creek during the period 1999 through 2000 (Nielsen and others, 2002). In contrast to these DOC concentrations, seep 45 (Bass Harbor Marsh) and Well 2 (Northeast Creek) had lower concentrations of DOC, in the range of 0.8 to 1.3 mg/L, possibly indicating deeper ground-water sources. These sources also had lower concentrations of orthophosphate and lower specific conductance (seep 45) than found in other hyporheic ground water, further suggesting a deeper ground-water source (tables 6 and 7). Specific conductance ranged from of 29,200 to 37,600 μS/cm for seeps 43 and 43A, compared with 40,900 to 43,500 μS/cm in the adjacent estuary (table 8), indicating substantial tidal influence on these sampling dates that likely resulted in a dilution of dissolved inorganic nitrogen and dissolved inorganic phosphorus in hyporheic ground water derived from terrestrial sources.

All constituents in the suite of household wastewater-related compounds (table 2) were determined to be below detection limits in seep 45 and the Bass Harbor Marsh estuary on October 6, 2004. Boron is commonly found in many household detergents and can be used also as a tracer for wastewater effluents because background concentrations are usually low and it is largely conservative in transport through natural systems (Barber and others, 1988; Repert and others, 2006). Boron concentrations measured in Well 1 (Northeast Creek) (181 mg/L), and in the Northeast Creek estuary (8.4 mg/L) (table 8) may be indicative of wastewater contamination. Boron was not detected in the Bass Harbor Marsh estuary.

Water Quality in Domestic and Bedrock Monitoring Wells

Concentrations of dissolved nitrogen species were quite low, typically below reporting limits, for the five domestic wells sampled in October 2003 (table 9). Two of the five wells had detectable concentrations of nitrate and total dissolved nitrogen in the range of 0.2 to 0.4 mg/L, and one well had detectable ammonium (reported as ammonia) at 0.08 mg/L. In most cases, these levels are consistent with the value of 0.03 mg/L nitrate-nitrogen estimated for background concentrations (uncontaminated fractured bedrock aquifer) (Nielsen, 2002b). The nitrate concentrations reported in table 9 are lower than those estimated for average nitrate concentrations in these aquifers where housing densities were used to calculate dilution based on recharge with septic-contaminated water (Nielsen, 2002b). These lower measured concentrations could be a result of denitrification, slow migration of nutrient plumes into the deep bedrock aquifers, failure to sample contaminated ground-water zones, or poor hydraulic connectivity between shallow and deep layers in the aquifer in proximal areas of surface sources of total dissolved nitrogen. Concentrations of DOC were relatively low, and concentrations of orthophosphate were below detection compared with other waters sampled for this project. The low dissolved nitrogen concentrations and DOC overall, the lack of orthophosphate, and the fact that organic nitrogen did not dominate the dissolved forms of nitrogen indicates that there is no apparent contamination of the bedrock aquifer from septic sources at the time of this investigation. All constituents in the suite of household wastewater-related compounds (table 2) were determined to be below detection limits except for phenol, which was detected in one domestic well in the Northeast Creek watershed (latitude 44º24'56", longitude 68º17'40") at a concentration of 0.7 µg/L. Arsenic (as As(III), which can occur naturally from weathering if bedrock sources are present, was detected in two wells in the Northeast Creek watershed at concentrations of 3.2 and 4.3 µg/L (table 9). The U.S. Environmental Protection Agency (USEPA) maximum concentration in drinking water for arsenic is 10 µg/L.

Concentrations of dissolved nitrogen species, orthophosphate, and DOC were at or below reporting limits, for the four bedrock monitoring wells sampled in October 2003 (table 10). All constituents in the suite of household wastewater-related compounds (table 2) were determined to be below detection limits in the bedrock wells in the Northeast Creek watershed. All household wastewater-related compounds were determined to be below detection limits in the bedrock wells in the Bass Harbor Marsh watersheds except for phenol, which was detected in HW173 at a concentration of 1.1 µg/L and in HW174 at a concentration of 0.7 µg/L. Analysis for the presence of trace metals found low levels overall; however, arsenic was detected in two wells in the Northeast Creek watershed in the range of 10.3 to 11.1 µg/L (as As(III)) in HW171, and in the range of 6.3 to 9.8 µg/L (as As(V)) in HW172 (table 10). Uranium also was detected at 8.13 to 9.82 µg/L in HW172, and in the range of 1.21 to 2.83 µg/L in HW171 and HW174. The USEPA maximum concentration for uranium in drinking water is 10 µg/L. Relatively high concentrations of manganese were measured in the Bass Harbor Marsh watershed bedrock wells: 30.6 to 72.5 µg/L in HW173 and 359 to 1,090 µg/L in HW174 (table 10).

The results of the analyses of ground water in the fractured bedrock aquifer (domestic and monitoring wells) indicated that these waters were largely free of septic nutrient contaminants during this sampling period. By comparison, the shallow ground water sampled from the hyporheic zone in both estuaries indicated concentrations of total dissolved nitrogen that were elevated larger than those for either bedrock ground water or forest leachates or what might be expected in more pristine environments (fig. 8). Taken together, these findings suggest that ground-water seepage into both Bass Harbor Marsh and Northeast Creek estuaries may more likely originate from shallow, more nutrient-rich sources rather than from the deeper aquifer system.

Future Information Needs

This study identified the presence of shallow ground-water seeps in both Bass Harbor Marsh and Northeast Creek estuaries and found elevated concentrations of dissolved nitrogen in a limited number of seeps and in the shallow ground water adjacent to the estuaries. To follow up on this study, information would be needed to determine whether seeps and shallow ground water have elevated nutrient concentrations in other locations in each of the estuaries. A monitoring program for shallow ground-water quality would be needed to determine whether these inputs may be changing over time. Information also would be needed to determine the source of the elevated nitrogen concentrations. The hyporheic zone locations that were sampled are along presumed pathways from septic sources to the estuaries, but the data collected in this study are not sufficient to determine if septic systems are the source of the elevated nitrogen. More detailed information would be needed to better quantify the rate of nutrient input from shallow ground-water seeps into the estuaries and to compare that rate with inputs from surface water. Another area of study would be the quantification of nutrients input from oceanic sources to the estuaries, which may be important in the northeastern United States. Nixon and others (1995) reported that oceanic sources contributed about 15 percent of the nitrogen input to Narragansett Bay in Rhode Island.

Table 9. Water quality in domestic wells.

[All constituents in the suite of household wastewater-related compounds (table 2) were determined to be below detection limits except for phenol, which was detected in one well (442456068174001 Norway Road north of Crooked Road) at a concentration of 0.7 µg/L. ft, feet; mm Hg, millimeters of mercury; mg/L, milligrams per liter; ºC, degrees Celsius; µg/L, micrograms per liter; <, less than; --, not measured or analyzed; E, estimated, but below minimum reporting limit]

Dates	Depth of well, feet below land surface datum (ft)	Barometric pressure, millimeters of mercury (mm Hg)	Dissolved oxygen (mg/L)	pH, water, unfiltered, field, standard units	Specific conductance, microsiemens per centimeter at 25ºC	Temperature, water (ºC)	Ammonia (mg/L)	Nitrite plus nitrate (mg/L)	Nitrite (mg/L)	Orthophosphate (mg/L)	Total nitrogen (mg/L)	Organic carbon (mg/L)	Arsenic (µg/L)
441525068201901 Bass Harbor Road													
10/30/07	270	756	0.5	7	514	10.9	0.08	E0.04	<0.008	<0.006	0.09	1	0.4
442427068181901 Sweet Fern Road													
10/30/07	300	756	8.5	6.6	81	9.6	<0.04	<0.06	<0.008	<0.006	<0.03	E.3	E.1
442438068175101 Norway Road near Crooked Road													
10/30/07	400	754	0.8	8.8	207	9.5	<0.04	<0.06	<0.008	E0.004	<0.03	E.2	4.3
442452068174801 Stone Barn													
10/30/07	300	756	0.7	7.4	389	9.9	E0.02	0.2	0.009	E0.004	0.34	3	3.2
442456068174001 Norway Road north of Crooked Road													
10/31/07	--	--	6.3	6.2	179	9.6	<0.04	0.4	<0.008	<0.006	0.39	0.8	E.1

Table 10. Water quality in bedrock monitoring wells.

[All constituents in the suite of household wastewater-related compounds (table 2) were determined to be below detection limits except for phenol, which was detected in two wells: HW173, at a concentration of 1.1 µg/L, and HW174, at a concentration of 0.7 µg/L; <, less than; E, estimated, but below minimum reporting limit; --, not measured or analyzed]

Dates	Times sample start time	P72019 Depth to water level, feet below land surface	P00025 Barometric pressure, millimeters of mercury	P00300 Dissolved oxygen, water, unfiltered, milligrams per liter	P00301 Dissolved oxygen, water, unfiltered, percent of saturation	P00400 pH, water, unfiltered, field, standard units	P00403 pH, water, unfiltered, laboratory, standard units	P90095 Specific conductance, water, unfiltered, laboratory, microsiemens per centimeter at 25 degrees Celsius	P00095 Specific conductance, water, unfiltered, microsiemens per centimeter at 25 degrees Celsius	P00010 Temperature, water, degrees Celsius	P00900 Hardness, water, milligrams per liter as calcium carbonate	P00915 Calcium, water, filtered, milligrams per liter	P00925 Magnesium, water, filtered, milligrams per liter	P00935 Potassium, water, filtered, milligrams per liter	P00930 Sodium, water, filtered, milligrams per liter
441516068194101 ME-HW173 Hio Hill near Southwest Harbor															
Sep 17 2003	1610	12.44	765	8.1	69	6.2	7.7	79	79	8.6	12	3	1.06	1.92	8.55
Dec 3 2003	1515	6.64	772	11.2	92	5.3	E6.2	49	44	7.6	4	0.58	0.65	0.31	5.98
Oct 26 2004	1015	7.66	764	10.6	89	5.4	E6.7	54	47	8	5	.86	.68	.42	6.49
441650068210801 ME-HW174 Seal Cove Road near Southwest Harbor															
Oct 28 2003	1540	5.62	760	3	25	6.8	6.9	180	172	7.4	63	19.8	3.33	0.83	11.6
Dec 4 2003	1045	4.19	769	2.8	23	6.7	6.4	132	130	7.1	47	14.3	2.62	.63	7.79
Oct 26 2004	1415	6.61	763	1.6	13	6.6	6.7	127	139	7.5	45	13.9	2.42	.76	8.93
442238068154101 ME-HW171 McFarland Hill near Bar Harbor															
Sep 18 2003	1105	25.95	757	6.6	60	9.7	8.9	103	145	10.9	57	21.5	0.72	1.16	6.41
Sep 18 2003	1110	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Dec 2 2003	1625	-1.2	747	8.9	75	9.5	8.7	134	139	7	62	23.2	.913	0.74	5.43
Oct 25 2004	1130	16.32	752	7.1	61	8.6	8.4	131	139	8	59	21.9	1.04	.66	5.45
442450068175201 ME-HW172 Crooked Road near Bar Harbor															
Sep 18 2003	1515	8.08	772	1.6	14	9.4	9.4	262	284	11.3	5	1.48	0.305	0.38	56.4
Sep 18 2003	1520	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Dec 3 2003	1005	5.32	767	1.1	9	9.8	9.2	268	280	8.6	11	3.17	.642	.69	53.3
Oct 26 2004	0800	6.73	768	1.7	14	9.4	9.3	257	286	8.4	11	3.39	.701	.55	58
Sep 18 2003	1520	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Dec 3 2003	1005	108	--	11.1	<0.2	9.91	14.8	158	<0.04	<0.06	<0.008	0.009	.04	.6	--
Oct 26 2004	0800	--	--	0.03	15.3	0.1	9.7	13.5	<.04	<.06	<.008	.011	<.06	.4	--

Table 10. Water quality in bedrock monitoring wells.—Continued

[All constituents in the suite of household wastewater-related compounds (table 2) were determined to be below detection limits except for phenol, which was detected in two wells: HW173, at a concentration of 1.1 µg/L, and HW174, at a concentration of 0.7 µg/L; <, less than; E, estimated, but below minimum reporting limit; --, not measured or analyzed]

Dates	Times sample start time	P29801 Alkalinity, water, filtered, fixed endpoint (pH 4.5) titration, laboratory, milligrams per liter as calcium carbonate	P39086 Alkalinity, water, filtered, incremental titration, field, milligrams per liter as calcium carbonate	P00452 Carbonate, water, filtered, incremental titration, field, milligrams per liter	P71870 Bromide, water, filtered, milligrams per liter	P00940 Chloride, water, filtered, milligrams per liter	P00950 Fluoride, water, filtered, milligrams per liter	P00955 Silica, water, filtered, milligrams per liter	P00945 Sulfate, water, filtered, milligrams per liter	P70301 Residue, water, filtered, sum of constituents, milligrams per liter	P00608 Ammonia, water, filtered, milligrams per liter as nitrogen	P00631 Nitrite plus nitrate, water, filtered, milligrams per liter as nitrogen	P00613 Nitrite, water, filtered, milligrams per liter as nitrogen	P00671 Orthophosphate, water, filtered, milligrams per liter as phosphorus	P62854 Total nitrogen (nitrate + nitrite + ammonia + organic-N), water, filtered, analytically determined, milligrams per liter as nitrogen	P00681 Organic carbon, water, filtered, milligrams per liter
441516068194101 ME-HW173 Hio Hill near Southwest Harbor																
Sep 17 2003	1610	16	15	--	0.02	9.1	<.2	10.7	6.4	50	<0.04	<0.06	<0.008	<0.02	--	0.4
Dec 3 2003	1515	4	--	--	--	8.1	<.2	7.06	3.8	29	<.04	<.06	<.008	<.006	<0.03	.6
Oct 26 2004	1015	--	--	--	E.01	8.34	<.1	7.83	4.4	--	<.04	<.06	<.008	<.006	<.06	.4
441650068210801 ME-HW174 Seal Cove Road near Southwest Harbor																
Oct 28 2003	1540	68	63	--	0.04	10.7	0.7	14.2	6.2	106	<0.04	E0.04	<0.008	<0.006	<0.03	0.4
Dec 4 2003	1045	46	--	--	--	9.64	.5	14.8	4.9	82	<.04	<.06	<.008	<.006	.04	.5
Oct 26 2004	1415	--	--	--	.03	9.02	.5	13.4	4.3	--	<.04	<.06	E.004	<.006	<.06	.7
442238068154101 ME-HW171 McFarland Hill near Bar Harbor																
Sep 18 2003	1105	42	54	5	E0.01	5.29	1.1	11.7	6.2	87	<0.04	<0.06	<0.008	<0.02	--	0.4
Sep 18 2003	1110	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Dec 2 2003	1625	59	--	--	--	5.04	0.9	11.8	4.5	88	<.04	E.03	<.008	E.005	0.05	E.3
Oct 25 2004	1130	--	--	--	.04	4.8	.8	10.7	4.4	--	<.04	E.04	<.008	E.005	<.06	E.3
442450068175201 ME-HW172 Crooked Road near Bar Harbor																
Sep 18 2003	1515	111	102	6	0.02	8.27	<.2	9.77	16.8	155	<0.04	<0.06	<0.008	<0.020	--	0.5
Sep 18 2003	1520	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Dec 3 2003	1005	108	--	--	--	11.1	<.2	9.91	14.8	158	<.04	<.06	<.008	.009	0.04	.6
Oct 26 2004	0800	--	--	--	.03	15.3	0.1	9.7	13.5	--	<.04	<.06	<.008	.011	<.06	.4

Table 10. Water quality in bedrock monitoring wells.—Continued

[All constituents in the suite of household wastewater-related compounds (table 2) were determined to be below detection limits except for phenol, which was detected in two wells: HW173, at a concentration of 1.1 µg/L, and HW174, at a concentration of 0.7 µg/L; <, less than; E, estimated, but below minimum reporting limit; --, not measured or analyzed]

Dates	Times sample start time	P01106 Aluminum, water, filtered, micrograms per liter	P01095 Antimony, water, filtered, micrograms per liter	P62453 Arsenate (H_2AsO_4-), water, filtered, micrograms per liter as arsenic	P01000 Arsenic, water, filtered, micrograms per liter	P62452 Arsenite (H_3AsO_3), water, filtered, micrograms per liter as arsenic	P01025 Cadmium, water, filtered, micrograms per liter	P01030 Chromium, water, filtered, micrograms per liter	P01040 Copper, water, filtered, micrograms per liter	P01046 Iron, water, filtered, micrograms per liter	P01049 Lead, water, filtered, micrograms per liter	P01056 Manganese, water, filtered, micrograms per liter	P01065 Nickel, water, filtered, micrograms per liter	P01075 Silver, water, filtered, micrograms per liter	P01085 Vanadium, water, filtered, micrograms per liter	P01090 Zinc, water, filtered, micrograms per liter	P22703 Uranium (natural), water, filtered, micrograms per liter
441516068194101 ME-HW173 Hio Hill near Southwest Harbor																	
Sep 17 2003	1610	4	<0.30	<0.3	<0.3	<0.3	E0.03	0.8	2.2	8	<0.08	72.5	7	<0.2	--	--	0.06
Dec 3 2003	1515	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Oct 26 2004	1015	59	<.20	--	<.2	--	E.02	E.5	1.3	17	.11	30.6	--	--	<0.1	3.7	.04
441650068210801 ME-HW174 Seal Cove Road near Southwest Harbor																	
Oct 28 2003	1540	E2	<0.20	<0.2	<0.2	<0.2	0.04	<0.8	E0.2	168	<0.08	359	1.89	<0.2	--	2.2	2.83
Dec 4 2003	1045	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Oct 26 2004	1415	3	<.20	--	<.2	--	.1	E.5	<.4	1,710	<.08	1,090	--	--	<0.1	2.6	1.26
442238068154101 ME-HW171 McFarland Hill near Bar Harbor																	
Sep 18 2003	1105	58	<0.30	--	10.3	<0.3	0.1	4	1	59	<0.08	1.5	1.53	<0.2	--	<1.0	8.13
Sep 18 2003	1110	--	--	11.1	11.1	<.3	--	--	--	--	--	--	--	--	--	--	--
Dec 2 2003	1625	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Oct 25 2004	1130	9	<.20	--	2	--	E.03	E.4	E.3	E6	<.08	6.4	--	--	1	<0.6	9.82
442450068175201 ME-HW172 Crooked Road near Bar Harbor																	
Sep 18 2003	1515	41	<0.30	--	8.9	5.3	<0.04	E0.6	0.3	15	E0.05	0.7	0.57	<0.2	--	<1.0	1.21
Sep 18 2003	1520	--	--	4.5	9.8	5.3	--	--	--	--	--	--	--	--	--	--	--
Dec 3 2003	1005	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Oct 26 2004	0800	32	<.20	--	6.3	--	<.04	<.8	E.3	11	<.08	2.8	--	--	1.8	E0.6	2.14

Summary

The U.S. Geological Survey, in cooperation with the National Park Service, used aerial thermal imagery and water-quality indicators to identify shallow ground-water discharge zones in two estuaries at Mt. Desert Island, Maine. The goal of this study was to assess the potential for shallow ground water to be a source of nutrient enrichment to Bass Harbor Marsh and Northeast Creek estuaries. Many potential shallow ground-water discharge zones were identified from aerial thermal imagery during flights in May and December 2003 in both estuaries. Discharge zones identified in the December 2003 flight were classified as likely ground-water seeps in sediments in the intertidal zones (not at the water's edge), water seeps at the waters edge, and open-water sites that likely reflect seeps in the streambeds. The occurrence of ground-water seeps was confirmed using continuous and discrete measurements of temperature and specific conductance in seeps and in the adjacent estuaries that showed salinity anomalies reflecting the input of freshwater in these complex tidal systems.

Water samples were collected from surface and ground-water locations, including seeps that had been identified using thermal imagery. Samples were measured for physical properties including temperature, specific conductance, dissolved oxygen, and pH, and analyzed for concentrations of nutrients, dissolved organic carbon, wastewater-related compounds, major ions, and trace metals. Water-quality measurements from ground water in the hyporheic zone indicated elevated concentrations of dissolved nitrogen compounds, particularly dissolved organic nitrogen, compared with those for the adjacent estuary. This finding indicated that shallow ground water is a source of dissolved nitrogen to the estuaries. Orthophosphate levels were low in ground water in the hyporheic zone in Bass Harbor Marsh, but somewhat higher in one hyporheic-zone well in Northeast Creek compared with the concentrations in both estuaries that were at or below detection limits. Household wastewater-related compounds were not detected in ground water in the hyporheic zone. Analysis of water samples collected from domestic and bedrock monitoring wells developed in fractured bedrock indicated that concentrations of dissolved nitrogen, phosphorus, and household wastewater-related compounds were typically at or below detection, suggesting that the aquifers sampled had not been contaminated from septic sources at the time of this investigation.

The results of this study indicate the presence of ground-water seeps in both Northeast Creek and Bass Harbor Marsh estuaries. The limited sampling of seeps and shallow ground water in or adjacent to the estuaries indicates the presence of dissolved nitrogen at concentrations higher than those measured in the adjacent estuaries. These findings provide preliminary evidence that shallow ground-water sources may contribute to water-quality impairment through nutrient enrichment in these estuaries. Furthermore, increasing rates of residential housing development within the watersheds of these estuaries pose the potential for an increase in eutrophication as development proceeds.

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Appendix 1. Sites with Water-Quality Data for 2003, 2004, and 2005 in Acadia National Park, Mt. Desert Island, Maine

Table 1-1. Sites with water-quality data for 2003, 2004, and 2005 in Acadia National Park, Mt. Desert Island, Maine.

[NU, nutrients; MI, major ions; ME, metals (trace); AS, arsenic; HW, household wastewater-related compounds; DOC, dissolved organic carbon; --, unnumbered wells or surface-water sites]

Station name	Local well number	Station number	Date of sampling	Analytes
Bass Harbor seeps and surface waters				
Marshall Brook	--	441619068211701	07/01/04	NU, DOC
Seep 43	--	441528068203601	07/01/04	NU, DOC
			10/06/04	NU, DOC
Seep 43A	--	441530068203401	07/01/04	NU, DOC
			10/06/04	NU, DOC
Seep 45	--	441543068205701	07/01/04	NU, DOC
			10/06/04	NU, DOC, HW
Estuary at Seep 43	--	441528068203602	07/01/04	NU, DOC
			10/06/04	NU, DOC, HW
Northeast Creek wells and estuary				
Station 104	--	442509068181901	10/06/04	NU, DOC
			06/20/05	NU, DOC
Station 104	Well 1	442509068181902	10/06/04	NU, DOC
			06/20/05	NU, DOC
Station 104	Well 3	442509068181904	10/06/04	NU
			06/20/05	NU, DOC
Bedrock monitoring wells				
McFarland Hill	HW 171	442238068154101	09/18/03	NU, MI, ME, HW
			12/02/03	NU, MI, DOC
			10/25/04	NU, MI, ME, DOC
Crooked Road	HW 172	442450068175201	09/18/03	NU, MI, ME, HW
			12/03/03	NU, MI, DOC
			10/26/04	NU, MI, ME, DOC
Hio Hill	HW 173	441516068194101	09/17/03	NU, MI, ME, HW
			12/03/03	NU, MI, DOC
			10/26/04	NU, MI, ME, DOC
Seal Cove Road	HW 174	441650068210801	10/28/03	NU, MI, ME, HW
			12/04/03	NU, MI, DOC
			10/26/04	NU, MI, ME, DOC
Domestic wells				
Bass Harbor Road	--	441525068201901	10/29/03	NU, DOC, HW, AS
Norway Road north	--	442456068174001	10/30/03	NU, DOC, HW, AS
Norway near Cooked Road	--	442438068175101	10/29/03	NU, DOC, HW, AS
Sweet Fern Road	--	442427068181901	10/29/03	NU, DOC, HW, AS
Stone Barn	--	442452068174801	10/29/03	NU, DOC, HW, AS

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