Quantifying the Bellamy River Watershed Hydrologic Budget

A Hydrologic Assessment
Prepared For:

Town of Madbury
Water District Board of Commissioners

By: Thomas Fargo, C.G.

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Introduction

The Madbury Water District Board of Commissioners has expressed an interest in assessing the water or hydrologic budget within the Bellamy River watershed. The Bellamy River represents a regional water resource supplying significant portions of the water used by the cities of Dover and Portsmouth and at the same time sustaining recognized valuable water-dependent ecosystems in Dover, Madbury and Barrington. A desire has been expressed to quantify current and anticipated future water exports outside of the Bellamy River watershed and to explore what this might mean to the residents of Madbury. The Water Resources Chapter of the 2001 Town of Madbury Master Plan contains two recommendations pertaining to management of the Bellamy River watershed:

6.2 "Support the efforts of watershed associations, regional planning commission, and municipalities to coordinate water protection and management within the Bellamy and Oyster River watersheds. Incorporate actions, regulations, and policies from watershed management plans through the Planning Board, Conservation Commission, and Water District"

8.2 "Madbury should become an active and vocal stakeholder in Bellamy River watershed planning and management."

Physiographic Features of the Bellamy River Watershed

The headwaters of the Bellamy River arise in the Town of Barrington. The Bellamy River watershed encompasses nearly 21,700 acres or approximately 33.9 square miles. Portions of the watershed are located within Barrington (46%), Dover (31%), Madbury (21%), Durham and Lee (1% each). Figure 1 depicts the physiographic features of the watershed. Slightly over seven square miles (20%) of the watershed drains directly to the tidal or estuarine portion of the river and is therefore is generally unavailable for consumptive use. The Bellamy River watershed incorporates two significant bodies of water, Swains Pond in Barrington and the City of Portsmouth Bellamy Reservoir in Madbury. The Bellamy River also passes through an extensive, 450+ acre wetland between these water bodies. These wetlands are located along the western Town of Madbury boundary, south of Nute Road and east of Route 125.

Water Budget Calculations and the Hydrologic Cycle

The first step in quantifying the water budget for the Bellamy River watershed is to understand the water (or hydrologic) cycle. All water within the Bellamy River watershed is ultimately derived from precipitation. From long-term precipitation records the average annual input of water to this region is slightly over 40-inches per year. Figure 2 depicts long-term average precipitation as measured at the University of New Hampshire weather station in Durham. The non-tidal Bellamy River watershed covers approximately 17,300 acres or roughly 27 square miles. At 42-inches of precipitation per year, the total water input to the watershed is approximately 19.8 billion gallons per year.

Hydrologists are often called upon to assess how the water that enters a watershed is apportioned among the various components of the water cycle. Principal regional factors influencing this apportionment water include land cover and slope, soil permeability, and climate. Through regional studies of large watersheds, as well as detailed studies of small sub-basins, several rules-of-thumb have been developed that allow rough approximations of the components of water flow within the Bellamy River watershed. In the Bellamy River region, approximately half of the precipitation is returned to the atmosphere through combined processes of evaporation and transpiration. Hydrologists generally do not differentiate between these components. The remaining water input to the watershed is locally estimated to be approximately 21 inches per year (or 9.8 billion gallons per year over the 27 square mile non-tidal watershed). This amount would also represent the total discharge of the main stem of the river to the Great Bay estuary.

There is no long-term discharge monitoring data available for the Bellamy River. The United States Geological Survey (USGS) recently installed a short-term stage-height monitoring station on the Bellamy River in Dover. Data from this station are not yet available. The USGS does, however, maintain a gauging station on the Oyster River immediately upstream of the Route 155A bridge in Durham. Discharge data from the Oyster River were used to approximate the discharge of the Bellamy River for watershed budget estimates. Oyster River watershed data were analyzed to assess accuracy of the estimates with respect to the available long-term discharge data. Based on the Oyster River gauging data, the rough approximation for total evapo-transpiration losses in that watershed agreed fairly well with the regional hydrologic rule-of-thumb.

The Bellamy River watershed has many characteristics similar to the Oyster River watershed, with the exception of surface water bodies noted above. The presence of the two water bodies and the extensive wetlands in the Bellamy watershed would have the tendency to slow peak run-off during wet periods, but total discharge per unit area should be about the same.

It should be noted that a significant portion of the population within the Bellamy River watershed relies on individual wells and on-site wastewater disposal systems (or septic systems). From a watershed-water budget perspective, such systems do not significantly alter the availability of water unless the wells are used for large-scale irrigation projects. Water that is drawn for homeowner use generally comes from bedrock (artesian) wells and is disposed on-site through septic systems into the shallow groundwater zone. The design estimate for household water use is generally based on the number of bedrooms in a home. The NHDES uses a design flow of 150 gallons per day per bedroom for residential dwellings. At this time it is not possible to accurately estimate the number of on-site wells and wastewater disposal systems within the Bellamy River watershed.

Seasonal Variations in Water Availability

Table 1 (below) depicts the seasonality of water availability in the Bellamy River watershed. This table summarizes the average daily discharge for the Oyster River as measured at the USGS gauging station for each month during the six-year period, 1994 through 1999. These values were then divided by the area of the watershed upstream of the gauging station (12.1 square miles) to estimate the average daily discharge per square mile of watershed. An estimate of the average daily discharge of the non-tidal Bellamy River was then calculated by multiplying this value by the area of the non-tidal watershed (approximately 27 square miles). These estimates suggest an average total annual discharge for the period 1994 through 1999 of approximately 10.5 billion gallons. This is roughly seven percent greater than the 9.8 billion gallons per year estimate based on the long-term precipitation data and estimated water loss to evapo-transpiration. The total annual precipitation measured for the years 1994 through 1999 was 44.97 inches, or seven percent above the assumed long-term average of 42-inches per year. The agreement between the two estimates of total annual discharge is remarkably good. Table 1 also lists the average percentage of the total estimated discharge that occurred during each month over the six-year period, 1994-1999. These values range between greater than 21% of the discharge occurring in March, to less than 1% of the discharge occurring in August.

Table 1 – Monthly Water Availability in the Bellamy River Watershed

Month	Average Daily Discharge at Oyster River Gauging Station (gallons/day)	Estimated Daily Discharge of Non-Tidal Bellamy River (gallons/day)	Percentage of Total Annual Discharge Occurring In Each Month (1994 – 1999)
January	16,110,000	35,947,000	10.6
February	18,921,000	42,221,000	11.2
March	32,929,000	73,478,000	21.6
April	18,461,000	41,195,000	11.7
May	14,660,000	32,713,000	9.6
June	10,045,000	22,415,000	6.4
July	3,201,000	7,142,000	2.1
August	1,078,000	2,407,000	0.7
September	3,063,000	6,834,000	1.9
October	11,041,000	24,637,000	7.2
November	11,405,000	25,448,000	7.2
December	14,780,000	32,981,000	9.7

It is important to recognize seasonality and other temporal cycles influencing water availability in the hydrologic budget analyses. Long-term meteorological data indicates that, on average, precipitation is fairly evenly distributed throughout the year. However, water availability is not evenly distributed due to the high proportion of run-off that occurs following snow melt and greater rates of evapo-transpiration during the summer. In the recent years, summers have seemed to be drought-prone. For the summer period between June 1st and September 30th (in the years 1994 through 1999) only an estimated eleven percent of the average annual runoff was available for all uses.

Summer water demand often surpasses availability and seacoast municipalities have been forced to impose water use restrictions. Figure 3 depicts, graphically, the average daily water availability and municipal water demand, on a monthly basis, between 1994 and 1999. The municipal demand represents the amount of surface water pumped by Portsmouth from the Bellamy Reservoir, plus the amount of groundwater pumped by Dover from three water supply wells in aquifers located within the Bellamy River watershed. As can be seen in Figure 3, the average municipal water system demand, for the period 1994 through 1999, exceeded the average daily water availability in August by approximately 50%. It is during this period that there is typically minimal flow out of the Bellamy Reservoir.

From 1896 to 1994, actual annual precipitation measured in Durham has ranged between approximately 25 and 55 inches per year (Figure 2). Water suppliers in New Hampshire generally recall as a difficult period, the 1960s when precipitation fell below 40-inches per year for three successive years. More notable are the precipitation data measured at Durham during the years surrounding 1910 when annual precipitation rose above 40-inches only once in the thirteen years between 1907 and 1920. If such a multi-year departure below “normal” precipitation levels were to occur now, the resources of Bellamy River watershed would not be able to keep pace with regional water needs.

Groundwater and Surface Water Interactions

Water users rely on storage to meet demand during period of below-average precipitation. This storage can be engineered impoundments, such as the Bellamy Reservoir, or the natural storage capacity of groundwater aquifers. Hydrologists recognize that in local watersheds the total discharge is divided fairly evenly between direct runoff (overland flow) and water that infiltrates to become part of the groundwater flow system. The rate of infiltration of precipitation to groundwater is determined primarily by slope and soil permeability. This rate varies from over 20-inches per year in coarse sandy soils, to almost zero inches per year through heavy clay soils. Infiltration through loamy soils generally ranges from 6 to 12 inches per year in this region.

Groundwater is simply water that is present in the pore spaces of soils or unconsolidated surficial deposits, or water that is present within fractures in the bedrock. Precipitation that infiltrates to the groundwater flow system eventually discharges through seeps or springs to streams and rivers. Hydrologists call this discharge baseflow. Streams and rivers continue to flow during periods between precipitation events due to baseflow.

Manmade influences can disrupt the groundwater-surface water interactions of a natural system. One of the most widely recognized factors is the effect of impervious surfaces. Increased paving, building surface area, and replacement of native forest vegetation with lawns causes precipitation to run off more rapidly, thereby decreasing the proportion of water recharged to the groundwater system. One negative result of having more impermeable surface within a watershed is increased flood severity. In southeast NH, water suppliers and regulators are seeing decreased aquifer yield that they attribute to the effects of greater impervious surface area constructed over recent years[1]. Studies have also shown that when the amount of impervious surface becomes greater than 10 to 20% of the land area, the surface water quality within nearby streams tends to be degraded.

Large groundwater withdrawals for municipal water supplies or irrigation systems can lower the local groundwater table below the nearby stream base level and actually induce infiltration from a stream or river into the groundwater system. In the western United States such deficit pumping for irrigation systems can dramatically alter the total runoff for a region because it converts water from groundwater and surface water into water lost to evapo-transpiration. In New Hampshire, municipal groundwater supply wells are often located adjacent to streams and rivers so that they can capture a portion of the stream's flow. The City of Dover takes advantage of enhanced well production from the artificial aquifer recharge that occurs at sand and gravel washing operations adjacent to several of its municipal supply wells. The City of Dover also operates its own artificial aquifer recharge systems by pumping water from the Isinglass and Bellamy Rivers when the privately-operated gravel washing operations shut down for the winter. For most of the year, such utilization of water resources by drawing from the interaction of groundwater and surface water sources is not a problem. However, during seasonally dry periods, municipal water service demands can place a significant strain on the health of riparian ecosystems. Water resource planners are very sensitive to meeting the demand for municipal water during extended periods of drought.

Municipal Water System Demands

Figure 4 depicts the source and service areas for the three municipal water systems that impact the Oyster and Bellamy River watershed region. Two of these systems, Dover and Portsmouth, can place significant strain on the flow of the Bellamy River because these systems export water from the watershed.

<u>Portsmouth Water System</u>
The City of Portsmouth draws water from the Bellamy River reservoir located in Madbury, a wellfield located off Freshet Road in Madbury, and also several wells located in Portsmouth and Greenland. Portsmouth's Freshet Road wellfield is located within the Oyster River watershed. Portsmouth recently revised, with the assistance of the NHDES and USEPA, the source water protection area for the Freshet Road wellfield. This source area delineation extends into an area of the Pudding Hill aquifer that may draw water, in part, from the Bellamy River watershed. The groundwater flow divide between the Bellamy River and the Oyster River (Johnson's Creek) watersheds is poorly defined in this area. According to the City of Portsmouth Water System Master Plan[2], the average annual production of the Freshet Road wellfield is currently approximately 544 million gallons, or approximately 18% of the total estimated discharge of the Oyster River watershed. This water comes from the Johnson's Creek sub-watershed.

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[1] "Managing Stormwater as a Valuable Resource, A message for Hew Hampshire municipalities and water suppliers.", New Hampshire Department of Environmental Services, Publication: NHDES-R-WD-01-13, September 2001, 17 pages & eight appendices.
[2] Water System Master Plan, City of Portsmouth, New Hampshire, Earth Tech, Inc., September 2000.

The Bellamy Reservoir was constructed, by the Army Corps of Engineers, in 1960 and supplies 60% of Portsmouth's total supply[3]. This 420 acre reservoir has a 865 million gallon usable storage volume receiving water from a 22.2 square mile drainage area. Portsmouth considers the safe yield of the reservoir to be 3.9 million gallons per day. A local drainage area of 22.2 square miles should provide, on average, roughly 22 million gallons per day (8.1 billion gallons per year). Portsmouth's reported safe yield for the reservoir represents 17.5 percent of the watershed's annual runoff upstream of the reservoir dam. Actual production from the reservoir and associated water plant averages 2.25 million gallons per day[3]. This production rate is determined mainly by the capacity of the pump that transfers water from the Freshet Road treatment facilities to the Portsmouth water distribution system. During high demand periods a second pump can be activated that can increase production of the reservoir/ treatment facilities to approximately 3.5 million gallons per day, if the reservoir has sufficient available volume. According to the Portsmouth Water Supply Master Plan, "the Safe Yield of the reservoir is in question and will be reviewed in the Phase II Master Plan Study".

The Bellamy Reservoir has several levels of source protection for areas draining to the Bellamy Reservoir. NHDES Rule Env-Ws 386.58 specifies protections for the watershed upstream of the reservoir. The Federal Government also established protective deed restrictions on lands surrounding the reservoir, mostly in 1959 and 1960. Areas with such restrictions, as recorded in the State's GIS database, are denoted by the salmon-colored overprint on Figure 4. Correspondence from the Portsmouth Water Department to the Town of Madbury, dated March 1974, requested Madbury's assistance in managing activities in the reservoir's protection areas. The current level of water-quality protection measures enforcement may warrant some attention. Recent water-supply protection efforts, following the September 11, 2001 terrorist attacks, have resulted in new restrictions and inter-municipal discussions regarding limiting public access to the reservoir area.

The Phase I Portsmouth Water Supply Master Plan (September 2000) listed projected increases in water system demand through 2020. Water demand is anticipated to rise from the current level of approximately of 4.22 million gallons per day to 6.15 million gallons per day, a 31% increase over the next 20 years. The Portsmouth Water Department is clearly looking to more fully utilize the water resources of Bellamy and Oyster River watersheds in meeting the increasing demand.

Dover Water System

Dover draws water from multiple groundwater source areas, some of which cross into adjoining towns. Two of Dover's delineated groundwater source areas lie astride the boundary between the Bellamy and Oyster River watersheds. Dover's water system source areas are denoted in green on Figure 4. Over the last three years, Dover has obtained approximately 43% of its drinking water from aquifers located within the Bellamy watershed and, to a lesser degree, the Oyster River watershed area.

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[3] Town of Madbury 2001 Master Plan and Portsmouth Water Department records.

Dover has four water-supply wells in the Bellamy watershed area. The City's Ireland well is located in the Pudding Hill aquifer off Mast Road in Dover approximately 50 feet from the Bellamy River. Anecdotal information indicates that this well draws a portion of its production through induced infiltration from the river. The NHDES tested the Ireland well for the presence of water-born pathogens in 1992 but detected only green algae. From 1994 through 2000 the Ireland well supplied an average 218 million gallons annually (26% of Dover's water supply and 2.2% of the non-tidal discharge of the Bellamy River).

Dover's Griffin well was drilled into the Pudding Hill aquifer and is located in Madbury. The Griffin well draws water from a portion of the aquifer that is separated from the Bellamy River by a clay layer. Production of this well was observed to be enhanced by nearby gravel washing operations. Water used by this gravel operation is pumped, apparently without a NHDES permit, from the Bellamy River. The amount of water pumped by the gravel operation is currently not quantified. The City of Dover operates a nearby artificial groundwater recharge facility mostly when the gravel operation is shut down for the winter. Dover has a NHDES permit to withdraw 720,000 gallons per day from the Bellamy River to enhance production of the Griffin (and Ireland?) well(s). The City's operation of the Bellamy River recharge facilities has been halted during the construction of Dover's new Public Works garage. The recharge basin is being reconfigured to accommodate gravel mining at the City's Mast Road site. The Griffin well was shut down from November 1995 through January 1999 due to groundwater contamination originating at the former Madbury Metals, Inc. facility. In 1999 and 2000, the Griffin well supplied an average of 177 million gallons annually, representing approximately 21% of Dover's water supply since the well was reactivated.

Dover's Hughes well is located in the Barbados Pond aquifer located off Old Stage Road in Madbury. The Hughes well has not been utilized to its full capacity due to elevated iron and manganese concentrations. Since 1994 the well has pumped an average of only 26 million gallons annually (supplying 3 % of Dover's water supply). Historically, when the Hughes well was pumped at full capacity it caused a marked decrease in the water level of Barbados Pond. Dover is planning to more fully utilize the Hughes well once a water treatment facility is built.

Dover has recently drilled a fourth water-supply well within the Bellamy watershed off French Cross Road in Dover, near the Bellamy Reservoir. This well is known as the Bouchard well. Preliminary water quality tests indicate elevated levels of iron and manganese in water from this well. Dover's current plan is to complete the NHDES 'new source approval' permitting for this well and construct a water treatment plant for the combined production of both the Hughes and Bouchard wells.

Summary and Conclusions

The Bellamy River represents a regional water resource supplying significant portions of the water used by the cities of Dover and Portsmouth and at the same time sustaining recognized valuable water-dependent ecosystems. Water availability is determined by long and short-term climatic (precipitation) variations. During the summer months municipal water system demand typically exceeds water availability. From an inspection of Figure 4, it becomes readily apparent that two of the NH seacoast’s larger municipalities are dependent of the water resources of Madbury, primarily relying on the resources of the Bellamy and Oyster River watersheds. What is significant about the draw of these municipal water systems is that they have the potential to export large quantities of water out of a watershed, thereby potentially lowering stream flow at times of critical low flow. There is an acute need for ever-increasing inter-municipal cooperation in managing these water resources on a regional and watershed basis.

Acknowledgements

Thanks go to Mrs. Joan Schreiber, Chairman of the Madbury Water District for suggesting that this project be undertaken. Joan is also thanked for sharing information in the District’s files and for her assistance in editing the first draft of this report. The maps (Figures 1 and 4) were prepared by Strafford Regional Planning Commission.

Figure 1: Physiographic Features of the Bellamy River Watershed

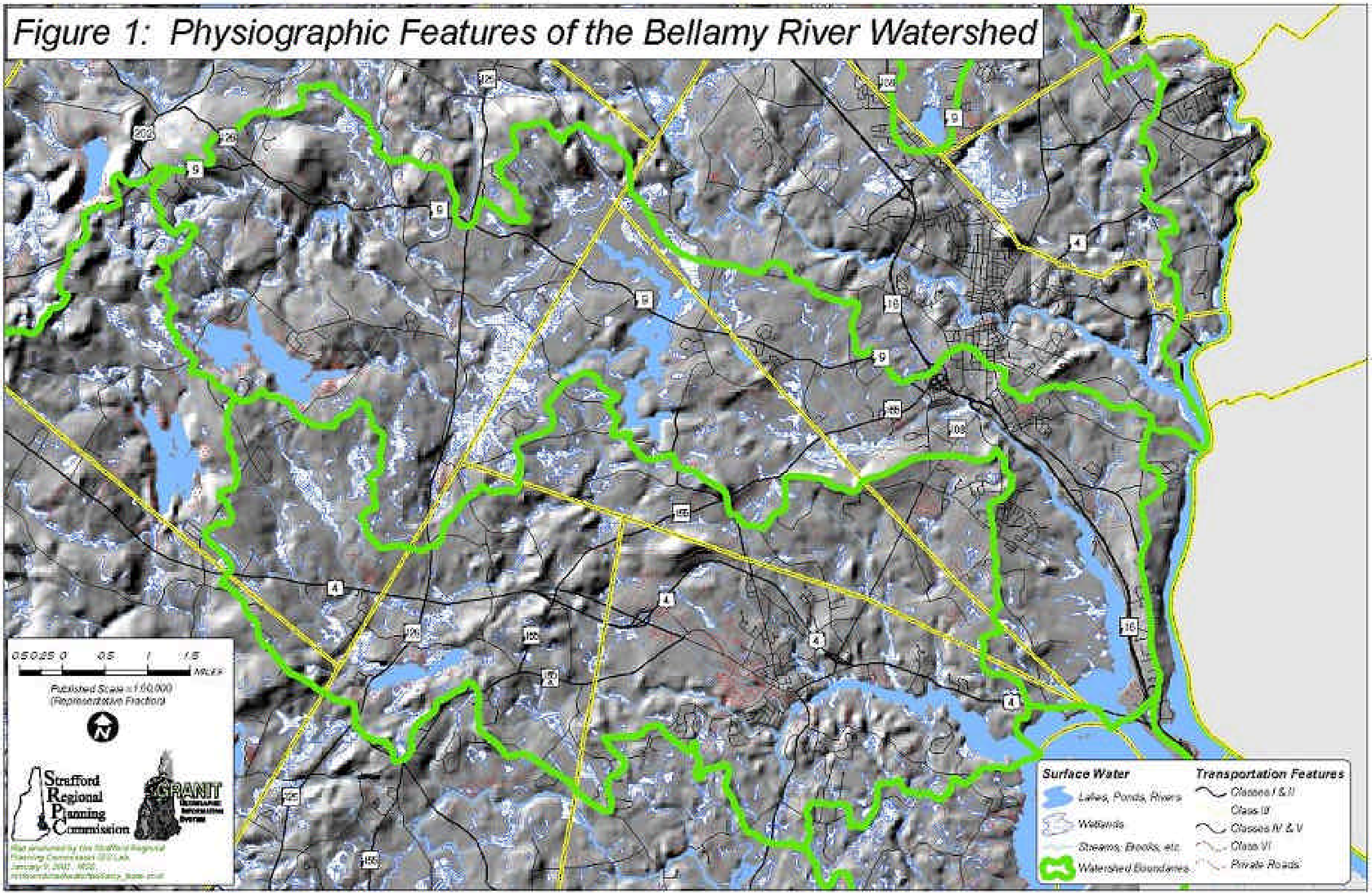


Figure 2
Long-Term Precipitation - Durham, NH

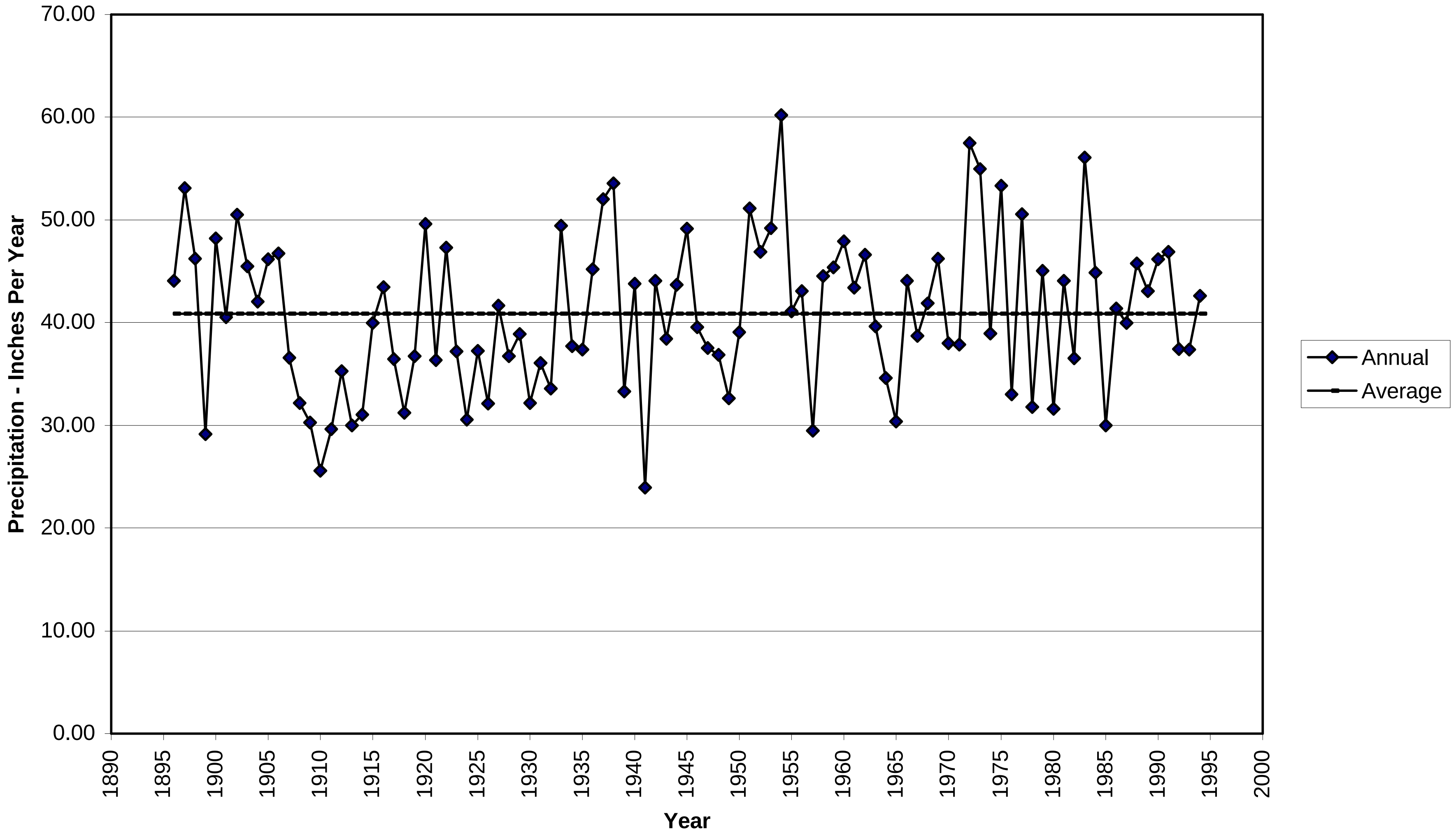
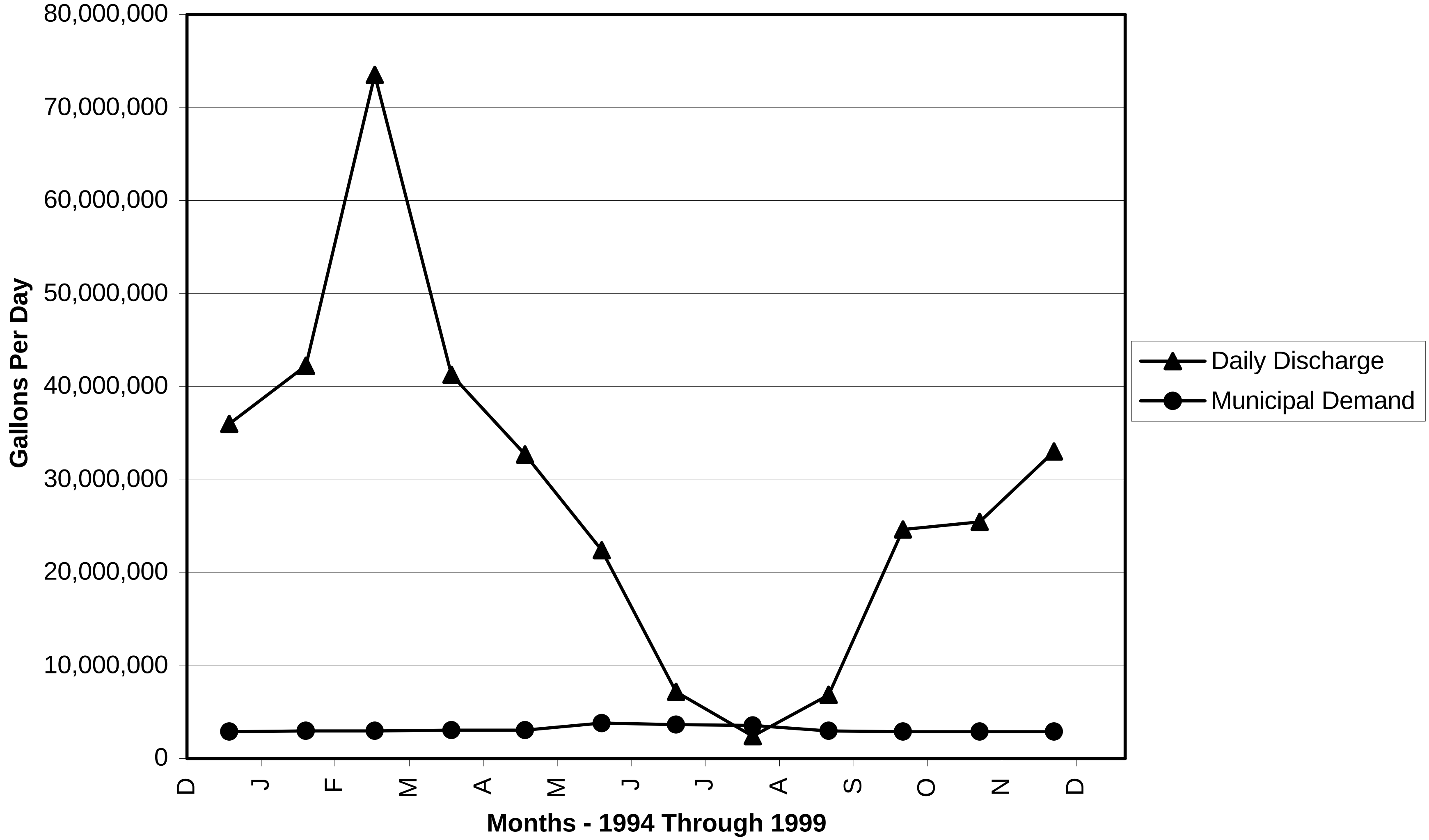


Figure 3
Average Daily Water Availability & Municipal Demand



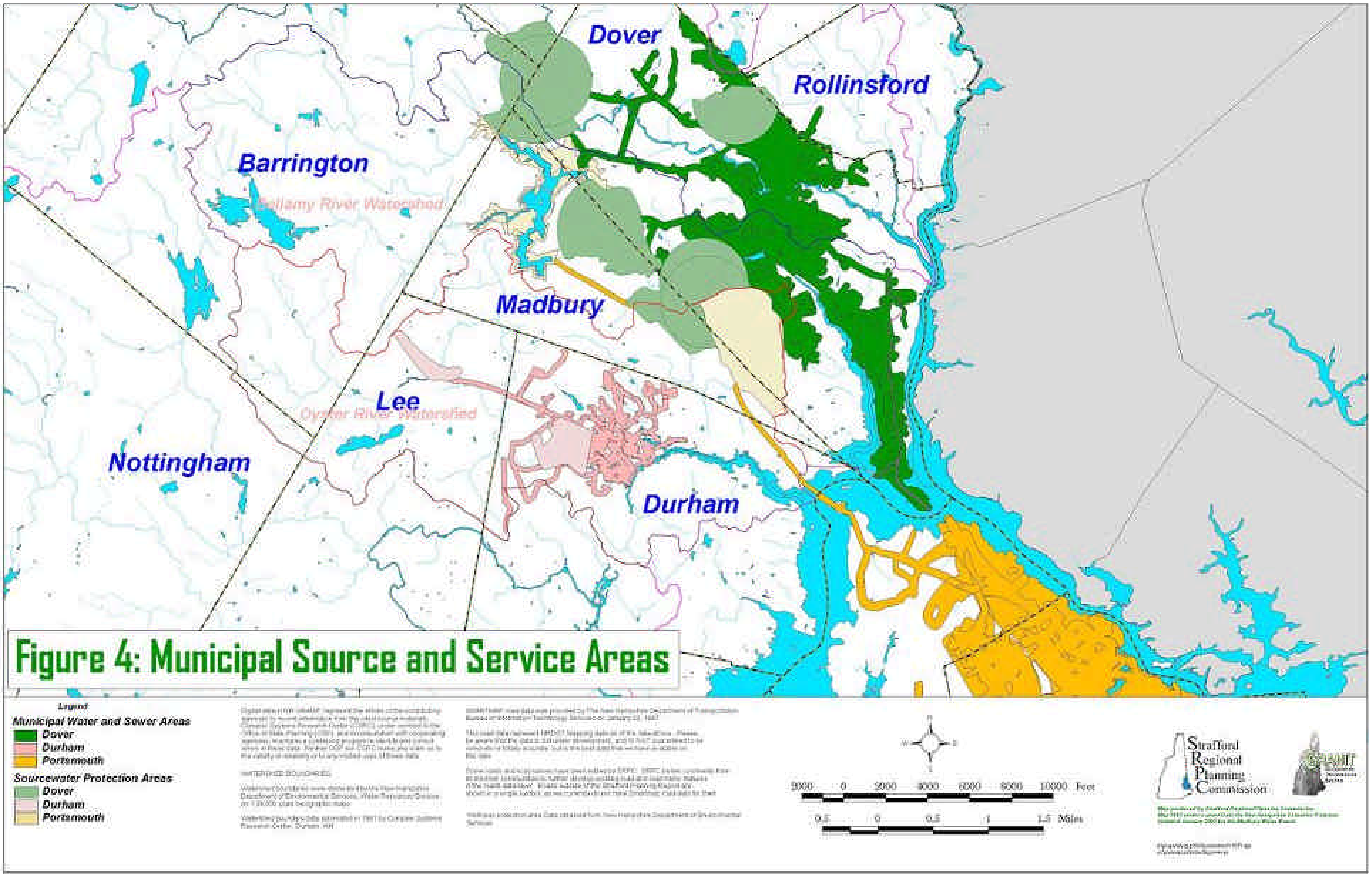


Figure 4: Municipal Source and Service Areas