Appendix 1. Details of quantification of ecosystem services at three scales.

MUNICIPAL SCALE

Information for crops, pork and maple syrup was taken from the 2001 Canadian Agricultural Census, which provides data at the level of municipalities. In the Agricultural Census, these are called Census Consolidated Subdivisions (CCS). CCS represent single municipalities, or in some cases the consolidation of several municipalities if the municipalities in question are judged to have too few farms to allow the privacy of individual farmers to be protected. In order to extract information on individual municipalities from CCS, ES values were estimated for individual municipalities by weighting the CCS values by area of the consolidated municipalities.

1. Crops (% of municipal land dedicated to crop production)

Crop production was estimated using 2001 Canadian Agricultural Census data (Statistics Canada 2001a). The category 'Land under Crop' gives the amount of hectares under cultivation. Land under crop was chosen as an indicator because crop yield values were less comparable across the two watersheds due to differences in crop plants. Land under cultivation is an indicator of how important agriculture is to each municipality, in terms of how much land in total is dedicated to this economic activity.

2. Pork (number of pigs produced per km^2)

Pork production data were taken from the 2001 Canadian Agricultural Census (Statistics Canada 2001c). Due to privacy protection laws, in some cases the number of pork-producing farms was available, but the number of pigs produced on these farms was not. In these cases, the average number of pigs per farm in all of the surrounding municipalities (those that touched the municipality in question) was used to estimate the number of pigs per farm, and thus the total number of pigs produced.

3. Drinking water (rank 1-5, including non-integers where average values were calculated from more than one sampling station)

The provision of drinking water was estimated from a provincial government water quality database (MDDEP 2008). The majority of water for drinking in the region is harvested from surface waters where water quality testing stations are set up. We used a water quality index called the IQBP (indice de qualité bactériologique et physico-chimique) that is used by the provincial government to assess the raw water supply intended for consumption. The index is based on conventional

physicochemical and bacteriological water quality parameters and combines eight variables: phosphorus, fecal coliforms, turbidity, ammonia nitrogen, nitrates/nitrites, chlorophyll a, dissolved oxygen, and pH.

Long-term water quality data from the government database was available throughout the watershed, but only on the main stems of rivers and their major tributaries. Values for 2001 were estimated by calculating the average of all water quality samples taken in that year. To estimate water quality values for municipalities that touched rivers where samples were taken, IQBP values from stations falling within each municipality were used. If more than one sampling station fell within a municipality, the average values of water quality across sampling stations was calculated. In cases where municipalities did not touch a river where sampling was done, one of two methods was used to estimate a value for water quality: 1) municipalities drawing their drinking water from a known location and treatment plant were assigned water quality values for the area of river where the water is drawn from, or 2) municipalities not drawing their drinking water from surface water were assigned a neutral value of 3.5 (not considered to be good or bad water quality).

4. Maple syrup (number of maple syrup taps per km^2)

Maple syrup production was estimated using the 2001 Canadian Agricultural Census (Statistics Canada 2001b). This dataset gives the number of maple syrup taps and maple syrup farms for each municipality. Maple syrup taps was chosen as an indicator of production, as the size of each maple syrup farm varied widely. Due to privacy protection laws, in some cases the number of maple syrup-producing farms was available, but not the number of maple syrup taps. In these cases, the average number of taps per farm in all surrounding municipalities (those that touched the municipality in question) was used to estimate the number of maple syrup taps per farm, and thus the total number of taps.

5. Deer hunting (number of deer killed per km^2)

Hunting data was obtained from database called The Guide to Hunting and Fishing in Quebec, developed by a private mapping company (SoftMap 2001). Data from 1999 was used that identifies the location of every deer killed that year. Hunters are required to mark on a map the location where they shot the deer when they register the dead deer at their local tagging station. In ArcGIS, the number of points where deer were killed was calculated for each municipal polygon.

6. Tourist attractions (number of tourist attractions per km^2)

The number of tourist attractions per municipality was estimated using a provincial government database (MTQ 2007b). A document accompanying the database lists the criteria used to determine whether a site is included in the tourism database (criteria include factors such as having infrastructure aimed at hosting tourists, being registered with the provincial regulating body, conforming with local and provincial laws and regulations, etc, as well as more specific criteria pertaining to types of tourist sites) (MTQ 2007a). Estimations of the number of tourist attractions per municipality included only tourist attractions themselves and not related services such as restaurants and lodging.

7. Nature appreciation (number of reported sightings of rare species per km^2)

This data was collected by the MDDEP (Ministry for Sustainable Development, Environment and Parks) and the MRNF (Ministry for Natural Resources and Fauna) from 1988 to 2007 and was available as a shapefile for the region requested (CDPNQ 2007). The number of points where rare species of flora and fauna were observed was calculated in ArcGIS for each municipal polygon. This data includes observations of endangered or threatened floral and faunal species within the two study watersheds (in accordance with classifications under CITES). Observations are not considered to represent an accurate portrait of rare and endangered species in the region, but rather a reflection of areas that have been frequented by scientists and nature enthusiasts and where these species were observed.

8. Summer cottages (tax value of cottages per km^2)

Data for estimating values of summer cottages was taken from a provincial database on property taxes by category of lodging (MAMR 2007). The summer cottage category of housing (category K – chalet) was available by municipality. Additional data on the number of summer cottages per municipality was collected from each municipality by calling all municipal offices, in order to check whether the tax value data reflected the extent of this land use. Tax value of cottages and number of cottages were highly correlated, but the tax value was used because it was considered to better reflect the value or importance of this ES across municipalities.

9. Forest recreation (% of municipal land covered by forest)

Forest recreation was assessed using forest cover as an indicator. Forest cover was estimated from land cover maps (BDTQ 2005), joined to a layer of municipal boundaries. The areas of all forest fragments were calculated for each municipality in ArcGIS, and resulting values were outputted into a spreadsheet and added to obtain the total forest area per municipality. This value was divided by the area of the municipality.

10. Above-ground carbon sequestration (kgC per km^2)

Above-ground carbon sequestration values were calculated from MODIS satellite data representing net primary productivity values (LPDAAC 2001). MOD17 produces gross primary production of vegetation every day, and sums to net primary production at 8-day intervals. The product is computed with daily MODIS landcover, FPAR/LAI and global GMAO surface meteorology at 1km for the global vegetated land surface. These variables provide the initial calculation for growing season and carbon cycle analysis, and are used for agriculture, range and forest production estimates.

Two tiles of 2001 data were order from NASA to cover the area of land within the Richelieu and Yamaska watersheds for every 8-day period in 2001. The files were converted to file formats compatible with IDRISI and then 'windowed' to extract the relevant study area. All pixels classified as water or urban (32761 and 32766) were reclassified as 0. Missing data, presumably caused by cloud cover, was a problem during the months of June and July (classified as 32767), and thus we calculated 'summer' and 'non-summer' totals separately. June and July maps where many pixels were assigned the value of 32767 (n=11) were reclassified to correct for missing values. This was done by taking the average value of NPP for each pixel over the weeks in June and July, only counting the values that were not 32767. This average value was then multiplied by 11 to find the summer total NPP for those missing 11 8-day periods. Nearest neighbour reclassification was not appropriate in this instance as the missing data pixels were aggregated together in large areas.

The total non-summer NPP was calculated by adding up all the values for each pixel over the year. The total non-summer NPP was added to the total summer NPP to get total NPP values for 2001 at a 1X1 km resolution. This map was resampled for municipalities using 'zonal' statistics in ArcGIS to obtain an average NPP value per municipality.

Crop yields were calculated for each municipality using the 2001 agricultural census (Statistics Canada 2001d). The amount of carbon present in the portion of cultures that is removed from fields was calculated using average values of C per crop plant published for Quebec crops (ISQ 2007), multiplied by the percentage of each crop that is typically removed from the field (Whalen et al. 2003). Final amount of C that were removed from fields per municipality were subtracted from the NPP totals per municipality to get the final value of carbon sequestration.

11. Phosphorus retention in soil (%)

Soil samples were taken by the provincial government on every farm in the province, between 1995 and 2001 (MAPAQ 2001). A total of 22,984 soil samples

were taken within the two study watersheds. Average values for soil retention of phosphorus for each municipality were available via a government online database (MAPAQ 2001). These values only represent the phosphorus saturation values on agricultural land and not across all land covers.
The retention of phosphorus in the soil is indicated by the phosphorus saturation index, which measures the degree to which soil phosphorus (P) sorption sites have been filled (Kleinman and Sharpley 2002). For Quebec soils of the type found in these two watersheds, values above 12 % phosphorus saturation are considered to be at high risk for run-off into waterways (Beauchemin and Simard 2000).

12. Organic matter in soil (%)

Soil samples were taken by the provincial government on every farm in the province, between 1995 and 2001 (MAPAQ 2001). A total of 22,984 soil samples were taken within the two study watersheds. Average values for organic matter in soil for each municipality were available via a government online database (MAPAQ 2001). These values only represent the organic matter in soil on agricultural land, and not across all land covers. Organic matter in soil is widely thought to have a critical level of 3.4%, below which the productive capacity of agriculture is compromised by a deterioration in soil physical properties and the impairment of soil nutrient cycling mechanisms (Loveland and Webb 2003).

SMALLER SCALES ($1km^2$, $9km^2$)

Ecosystem services were calculated in the same manner for the $1km^2$ and $9km^2$ spatial scales. Grids were constructed in ArcGIS at these spatial grains to sample the data.

1. Crops (% of land dedicated to crop production)

Crop production was estimated from land cover maps (BDTQ 2005) joined to the grid layers at both spatial grains. The areas of all croplands were calculated for each grid cell in ArcGIS, and resulting values were outputted into a spreadsheet and added to obtain the total cropland area per grid cell. Land under crop was chosen as an indicator because crop yield values were less comparable across the two watersheds due to differences in crop plants. Land under cultivation is an indicator of how important agriculture is to each municipality, in terms of how much land in total is dedicated to this economic activity.

2. Pork (number of pork farms)

Pork production data were taken from unpublished GIS maps created by the Centre de la Nature Mont Saint-Hilaire from data collected from the 15 relevant

municipalities. Pork production facilities were mapped in point data form and resampled using the grids of both spatial grains.

3. Maple syrup (% of land covered by sugar maple stands)

Maple syrup production was estimated from unpublished land cover maps produced by the Centre de la Nature Mont Saint-Hilaire joined to the grid layers at both spatial grains. The areas of all sugar maple (*Acer saccharum*) stands were calculated for each grid cell in ArcGIS, and resulting values were outputted into a spreadsheet and added to obtain the total area per grid cell covered by maple stands. This service was estimated in this way because agricultural census data on number of maple syrup taps or exploited maple stands were not available at small scales.

4. Deer hunting (number of deer killed)

Hunting data was obtained from database called The Guide to Hunting and Fishing in Quebec, developed by a private mapping company (SoftMap 2001). Data from 1999 was used that identifies the location of every deer killed that year. Hunters are required to mark on a map the location where they shot the deer when they register the dead deer at their local tagging station. In ArcGIS, the number of points where deer were killed was calculated for each grid cell.

5. Tourist attractions (number of tourist attractions)

The number of tourist attractions per municipality was estimated using a provincial government database (MTQ 2007b). A document accompanying the database lists the criteria used to determine whether a site is included in the tourism database (criteria include factors such as having infrastructure aimed at hosting tourists, being registered with the provincial regulating body, conforming with local and provincial laws and regulations, etc, as well as more specific criteria pertaining to types of tourist sites) (MTQ 2007a). The addresses of the tourist attractions were used to locate them on a GIS map in order to sample the number of points within each grid cell.

6. Nature appreciation (number of reported sightings of rare species)

This data was collected by the MDDEP (Ministry for Sustainable Development, Environment and Parks) and the MRNF (Ministry for Natural Resources and Fauna) from 1988 to 2007 and was available as a shapefile for the region requested (CDPNQ 2007). The number of points where rare species of flora and fauna were observed was calculated in ArcGIS for each grid cell. This data includes observations of endangered or threatened floral and faunal species within the two study

watersheds (in accordance with classifications under CITES). Observations are not considered to represent an accurate portrait of rare and endangered species in the region, but rather a reflection of areas that have been frequented by scientists and nature enthusiasts and where these species were observed.

7. Forest recreation (% of municipal land covered by forest)

Forest recreation was assessed using forest cover as an indicator. Forest cover was estimated from land cover maps (BDTQ 2005), joined to the grid layers at both spatial grains. The areas of all forest fragments were calculated for each grid cell in ArcGIS, and resulting values were outputted into a spreadsheet and added to obtain the total forest area per grid cell.