Characterization of the Drinking Water Source Area for the City of Medicine Hat and the Town of Redcliff

SEAWA

Prepared for:

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1 Introduction

With increased pressure due to population growth, modification of the landscape, and future climate change scenarios, the South East Alberta Watershed Alliance (SEAWA) has undertaken the present study to characterize the area of the drinking water source for the City of Medicine Hat and the Town of Redcliff. The purpose of the study is to identify and describe potential issues, sources of contaminants, and threats and risks to Medicine Hat's and Redcliff's drinking water source in terms of both quantity and quality.

The SEAWA watershed encompasses an area of approximately 19,579 km^2 in the southwestern corner of Alberta (Figure 1). It includes primarily areas within the lower South Saskatchewan River basin in Alberta, but extends at the southern boundary into the Pakowki Lake subwatershed, which is an endorheic (non-contributing) basin that discharges into the Milk River basin in times of flooding. The SEAWA watershed boundaries are based on the Water Survey of Canada National Hydro Network watershed boundaries (Government of Canada, 2023).

Because the focus of the present study is on drinking water sources and risks to the major municipal centre within the SEAWA watershed (Medicine Hat and Redcliff), the study area selected for the present study does not align directly with the SEAWA boundaries. The study area has been extended upstream to the headwaters of the South Saskatchewan River, which includes the Bow and Oldman River basins, as these areas contribute to the quantity and quality of water passing through and available at Medicine Hat. The study area also excludes the portions of the SEAWA watershed lying within the Pakowki Lake/Milk River basin, as these areas do not contribute to the source waters under consideration in this study. For completeness and because of requirements for maintenance of flows under the Master Agreement on Apportionment with Saskatchewan, the study area also includes the areas of the SSRB downstream of Medicine Hat, as well as the spatially disjointed (within Alberta) Alsask subwatershed. The total area of the selected study area is approximately 66,575 km^2.

Study boundaries are based on the Province of Alberta's Hydrological Unit Code (HUC) watershed boundaries (Alberta Environment and Protected Areas, 2023), which generally correspond closely to the Water Survey of Canada National Hydro Network watershed boundaries (Government of Canada, 2023). For the purposes of the present study and for the sake of brevity, the study area will be referred to as the South Saskatchewan River Basin (SSRB), though the area under consideration excludes the Red Deer River basin as the confluence of the Red Deer and SSRB lies downstream of the area of interest. Analysis of factors extending across the landscape (such as land cover and land use) were conducted using the 45 HUC8 boundaries included in the study area as the unit analysis (Figure 1).

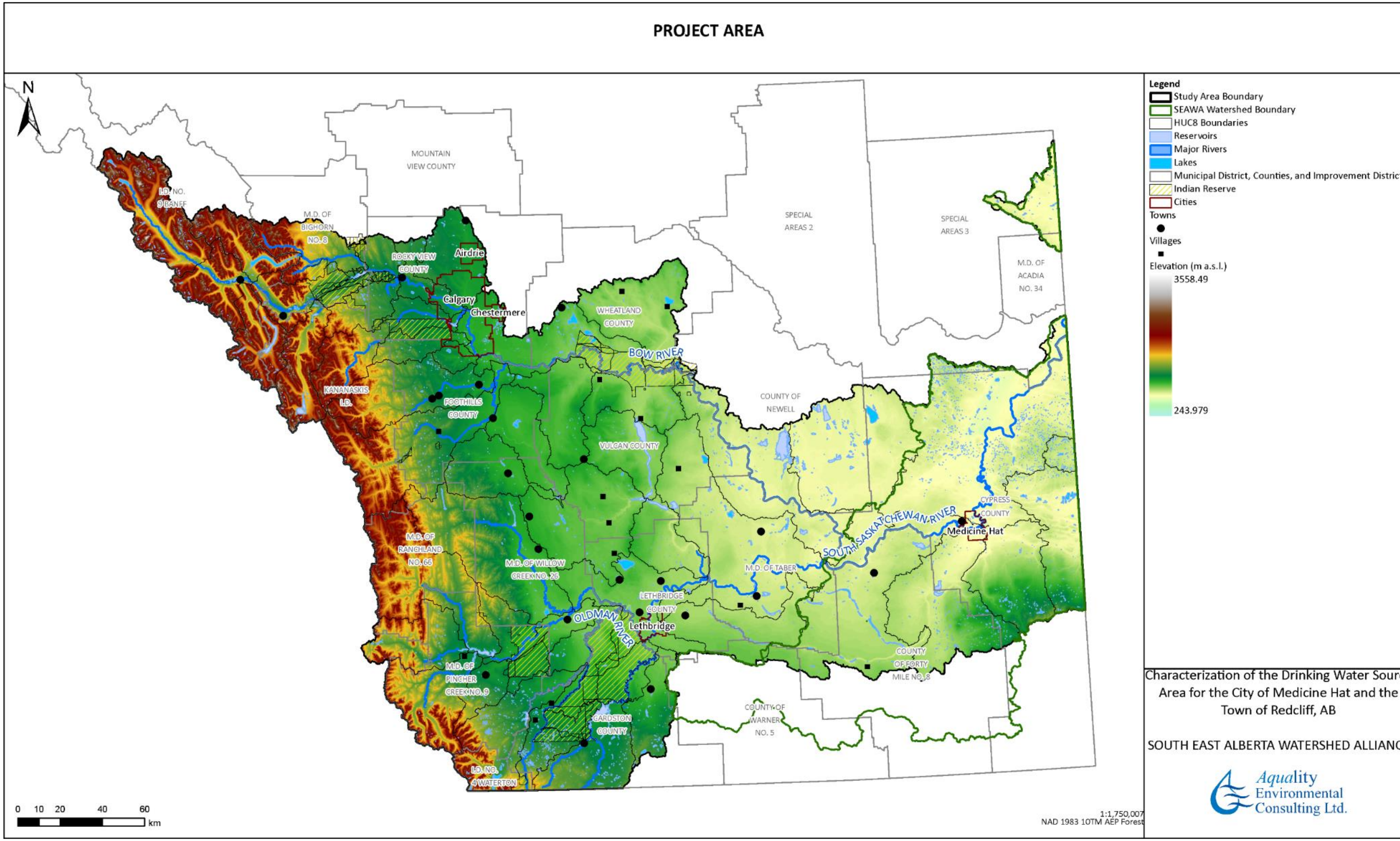

Figure 1. Study area and watershed boundaries.

2 Watershed Physiography and Human Geography

2.1 Natural Regions and Sub-Regions

Natural regions and sub-regions are driven largely by climatological patterns and surficial geology (Natural Regions Committee, 2006), with the resulting configuration strongly driving patterns of natural vegetation and human land use. The spatial pattern of the distribution of subregions manifests in many of the threats observed at a landscape level within the study area.

The distribution of natural regions and subregions closely follows trends in temperature and precipitation across the SSRB, with a general west to east gradient in precipitation, temperature, driven by elevation and the rain shadow effect of the Rocky Mountains (Figure 2). Climate norms follow a general west-to-east gradient of increasing temperatures and decreasing precipitation, with temperature also following a secondary north-to-south increasing gradient(Figure 3, Figure 4, and Table 1). Both temperature and precipitation trends are impacted by the Cypress Hills area to the southeast of the study area.

The Rocky Mountain natural region comprises 24 % of the area and dominates the high elevation areas in the west, with the Grassland natural region comprising approximately 70 % of the area and dominating in the lower elevation areas in the east (Table 1). The Foothills natural region (with 0.3 % of the area) and Parkland natural area (with 5.8 % of the area) form minor transitional components in a discontinuous band between the Rocky Mountain and Grassland natural regions.

The Rocky Mountain natural region is defined by mountainous landscapes with steep but variable topography over a range of geological forms. Vegetation is generally dominated by coniferous vegetation, but there are areas of extensive exposed bedrock and snow/ice fields. It has the coolest summers, shortest growing season, highest average annual precipitation of the natural regions within the study area. This natural region comprises the Alpine, Subalpine, and Montane natural subregions, in decreasing order of elevation and annual precipitation. It makes up approximately 24 % of the study area, but receives approximately 35 % of the total annual precipitation (Table 1).

The Grassland natural region includes the majority of the prairie landscapes in Alberta, with level to rolling terrain naturally overwhelmingly dominated by grassland vegetation, interspersed with occasional deciduous forests, shrubland, and wetlands. Human activities have extensively modified this landscape through conversion to agriculture, and the area provides some of the most productive land in Alberta for farming and ranching. The Grassland natural region is the warmest, driest natural region in Alberta, with annual precipitation only a third of that received in Alpine natural subregion. This natural region comprises Northern Fescue, Foothills Fescue, Mixedgrass, and Dry Mixedgrass natural subregions, in generally decreasing order of elevation and annual precipitation. This region makes up approximately 70 % of the study area but receives less than 60 % of the total annual precipitation.

The Foothills natural region comprises the Upper Foothills and Lower Foothills natural subregions, and the Parkland natural region comprises the Foothills Parkland and Central Parkland natural subregions. These represent transitional areas, with coniferous forests replaced by deciduous forests and then grassland/woodland mosaics along the elevation and precipitation gradient. The Foothills natural region is restricted to a small area at the northern edge of the study area, while the Parkland forms a a discontinuous band between the Rocky Mountain and Grassland region, primarily restricted to the Bow River watershed. Combined, they make up approximately 6 % of the study area and receive approximately the same proportion of the total annual precipitation.

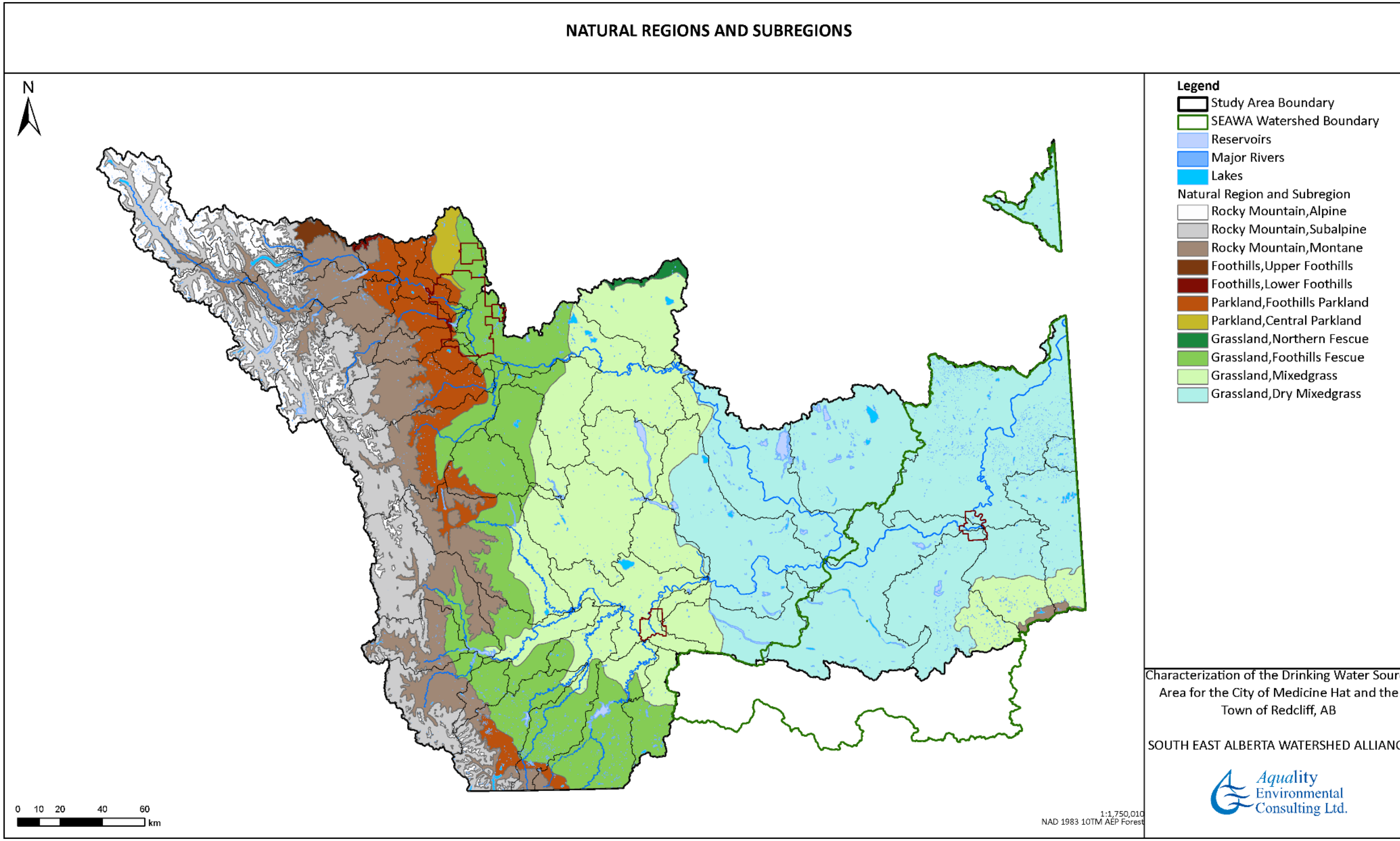

Figure 2.Distribution of natural regions and natural subregions within the study area.

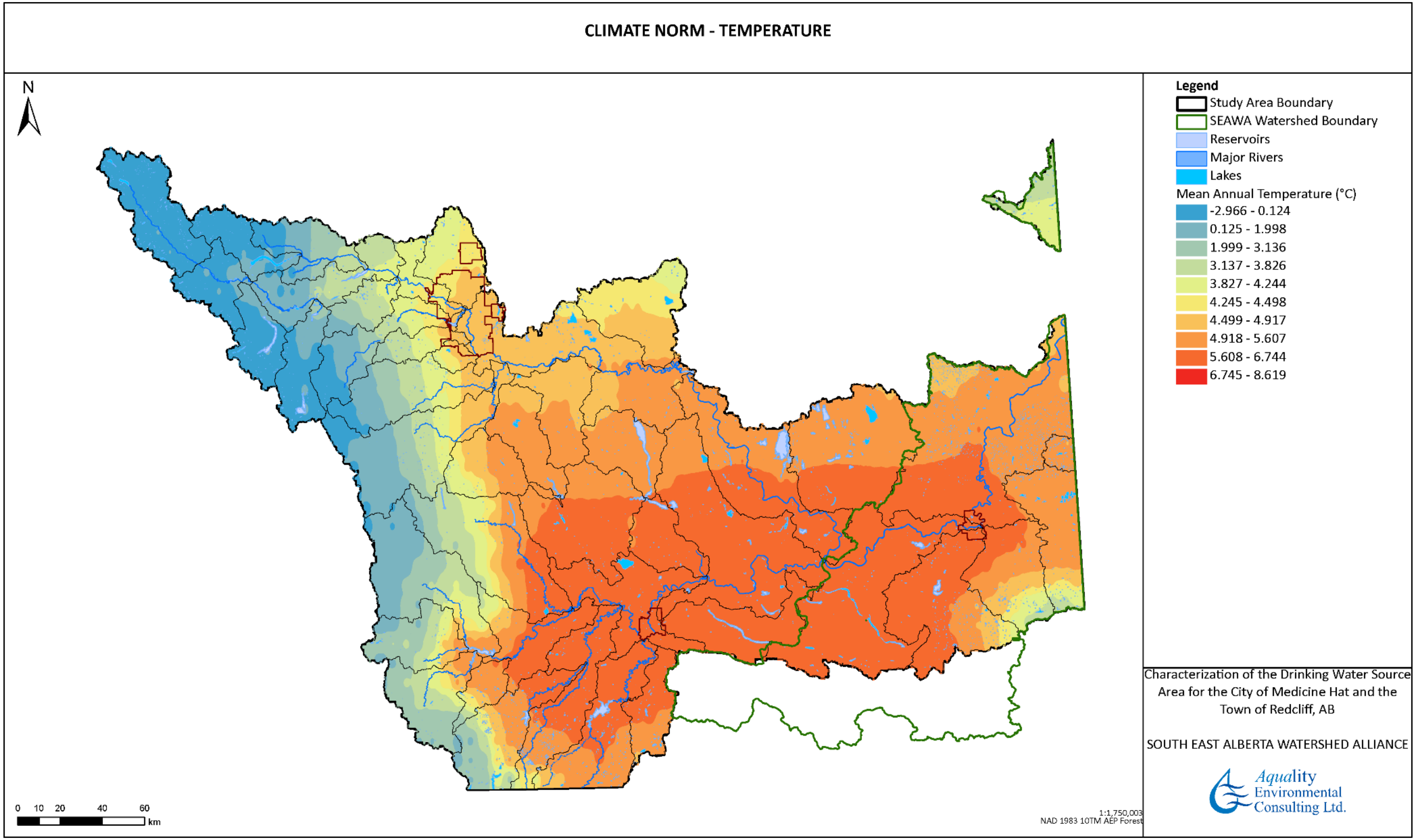

Figure 3. Climate norms for the SSRB, annual mean of daily average temperature.

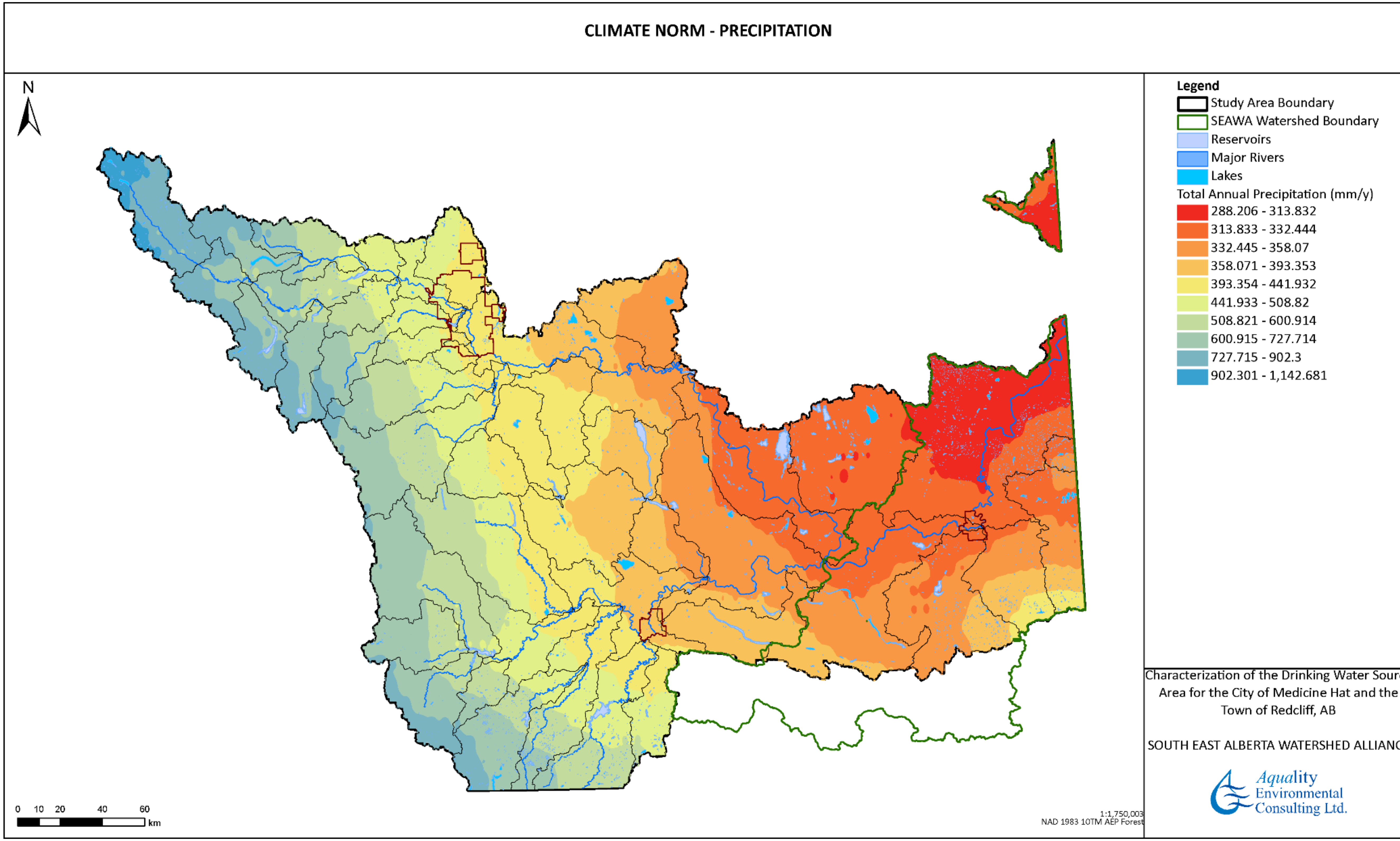

Figure 4. Climate norms for the SSRB, mean total annual precipitation.

Table 1. Areas of natural regions and natural subregions and average climate norms within the study area.

Natural Region	Natural Subregion	Area (km^2)	Area (%)	Mean Annual Temperature (°C)	Mean Total Annual Precipitation (mm/y)	Total Annual Precipitation Volume ($10^6 m^3/y$)
Rocky Mountain	Total	16006	24.0	1.38	664	10622
	Alpine	3229	4.8	-0.60	774	2500
	Subalpine	6411	9.6	0.80	699	4482
	Montane	6366	9.6	2.99	571	3635
Foothills	Total	187	0.3	2.33	537	100
	Upper Foothills	148	0.2	2.07	548	81
	Lower Foothills	40	0.1	3.33	495	20
Parkland	Total	3883	5.8	4.12	489	1897
	Foothills Parkland	3535	5.3	4.11	493	1741
	Central Parkland	348	0.5	4.20	448	156
Grassland	Total	46498	69.8	5.48	377	17541
	Northern Fescue	141	0.2	4.14	357	50
	Foothills Fescue	9548	14.3	5.08	474	4527
	Mixedgrass	14833	22.3	5.43	387	5733
	Dry Mixedgrass	21975	33.0	5.69	329	7237

2.2 Land Cover

Land cover describes the type of vegetation (or lack thereof) covering the landscape, generally classified into broad categories based on plant stature and growth habitat. Land cover is an important indicator of environmental condition, as it can reflect changes due human activities that are both direct (e.g., conversion to agricultural or residential lands) or indirect (e.g., through climate change or alteration of wildfire regimes). Land cover is generally considered separately from land use; however, certain land cover classifications such as Agriculture and Developed necessarily include some information on land use and the changes that have occurred. Land cover information used in this study is derived from the most recently available land cover data set from the Alberta Biodiversity Monitoring Institute (Alberta Biodiversity Monitoring Institute, 2010).

Land cover classifications within the study area closely correspond to the distribution of the natural subregions, with the areas within the Rocky Mountain natural region generally dominated by coniferous forest, and areas within the Grassland natural region dominated by herbaceous vegetation (Figure 5). Agricultural development has largely replaced the native mixed grass prairie within the Mixedgrass and Dry Mixedgrass natural subregions, especially in areas where surface water supplies allow irrigation, with up to 35% of the land base under irrigation in some areas of the Grassland natural region.

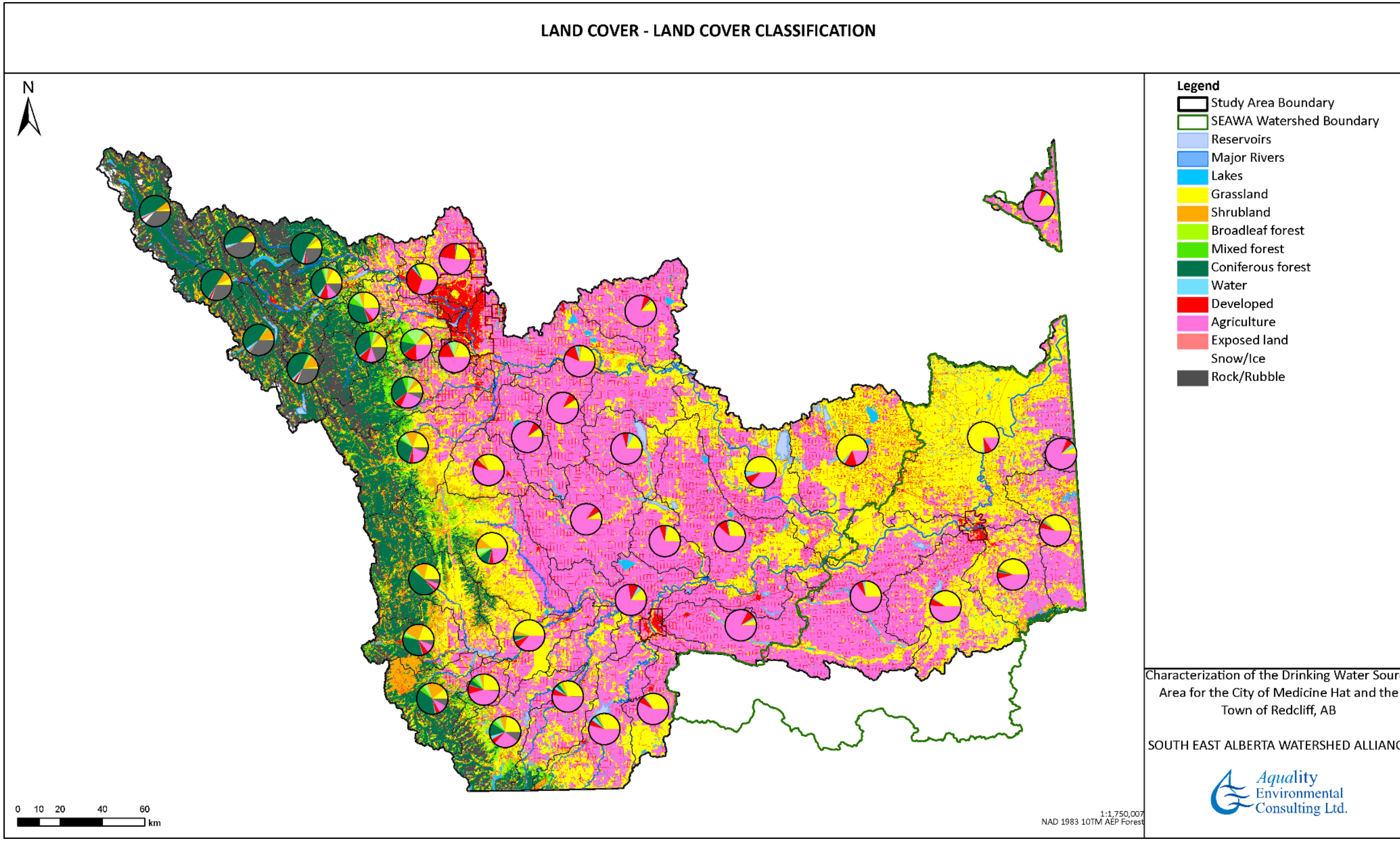

Figure 5. Land cover classification within the study area. Each pie chart indicates the relative contribution of the land cover class within each subwatershed.

2.3 Human Footprints

Human footprints are one metric for the impact that anthropogenic activities can have on the landscape. They represent the extensive physical alteration of the landscape from its natural state and conversion to an alternate land use. The Alberta Biodiversity Monitoring Institute has undertaken a program to map human footprints on the landscape, updated on an annual or semiannual basis, for the entire province (Alberta Biodiversity Monitoring Institute, 2022). Human footprints within this dataset were aggregated into 11 thematic groups, and summarized by area within each subwatershed.

Agriculture is the largest human impact to the landscape, with the highest densities concentrated on a broad corridor from Calgary to Lethbridge to Medicine Hat (Figure 6). Densities of agricultural impacts closely correspond to natural subregion boundaries, with the highest densities associated within the Mixedgrass natural subregion, driven by rich soils with sufficient precipitation for agricultural production. However, agricultural impacts are extensive throughout nearly the entire study area, extending into the Montane natural subregion and only being absent from the Alpine and Subalpine natural subregions within the Rocky Mountain natural region.

Other major impacts to the landscape include forestry, oil and gas, and residential development. Forestry impacts are confined primarily to the headwaters within the Rocky Mountain natural region, while oil and gas impacts dominate in the northern half of the Dry Mixedgrass subregion to the north of Medicine Hat. Residential development is spatially restricted to the major population centres.

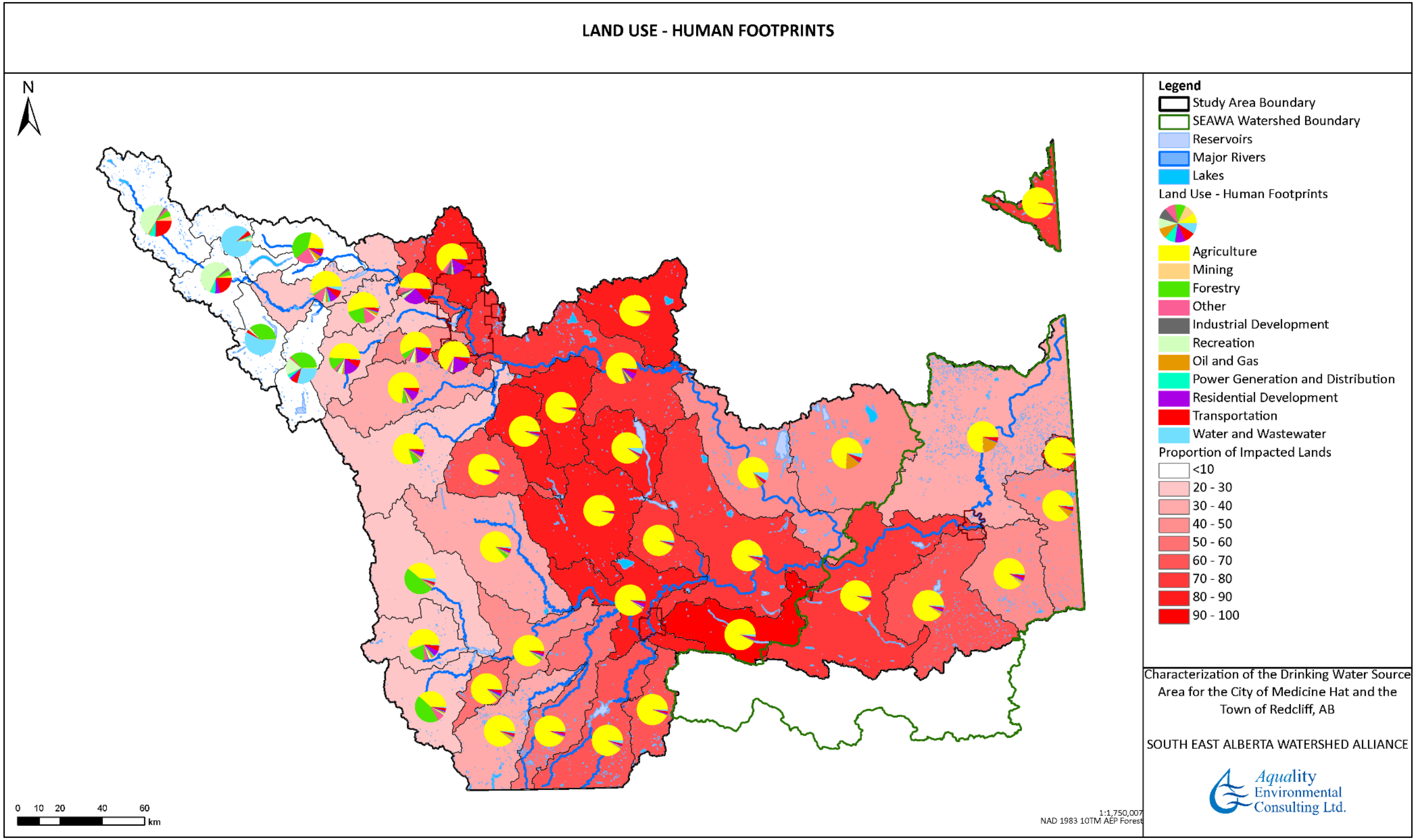

Figure 6. Distribution and classification of human footprints within the study area. Shading represents relative density of footprints, while the pie charts indicate the contribution of each thematic group to the total impacted area within each subwatershed.

2.3.1 Linear Developments

Linear developments include anthropogenic features such as roads, railways, seismic lines, pipelines, and utility right of ways. Although the total area represented by linear developments can be small, they can have an oversized impact on certain aspects of the natural environment due to the way in which they fragment the landscape. They can have significant impacts on water quality and fish and wildlife populations, including wildlife corridor interruption by roads, alteration of drainage patterns by increases in impervious or compacted surfaces, and increases in erosion and sedimentation at watercourse crossings. Linear development density in this study was derived from the ABMI Human Footprint dataset (Alberta Biodiversity Monitoring Institute, 2022).

The highest densities of linear development are associated with the Calgary region, and largely follow the Bow valley corridor from the Calgary to Medicine Hat (Figure 7). Linear developments are dominated by transportation corridors associated with urban and suburban development. There is also a pocket of high linear development density to the north of Medicine Hat, primarily associated with access for oil and gas production (see Section 3.2.1 below). There are some areas in the headwaters of the Bow River with essentially no linear developments (primarily the National Park system, but throughout the rest of the study are densities are moderate and relatively homogenous.

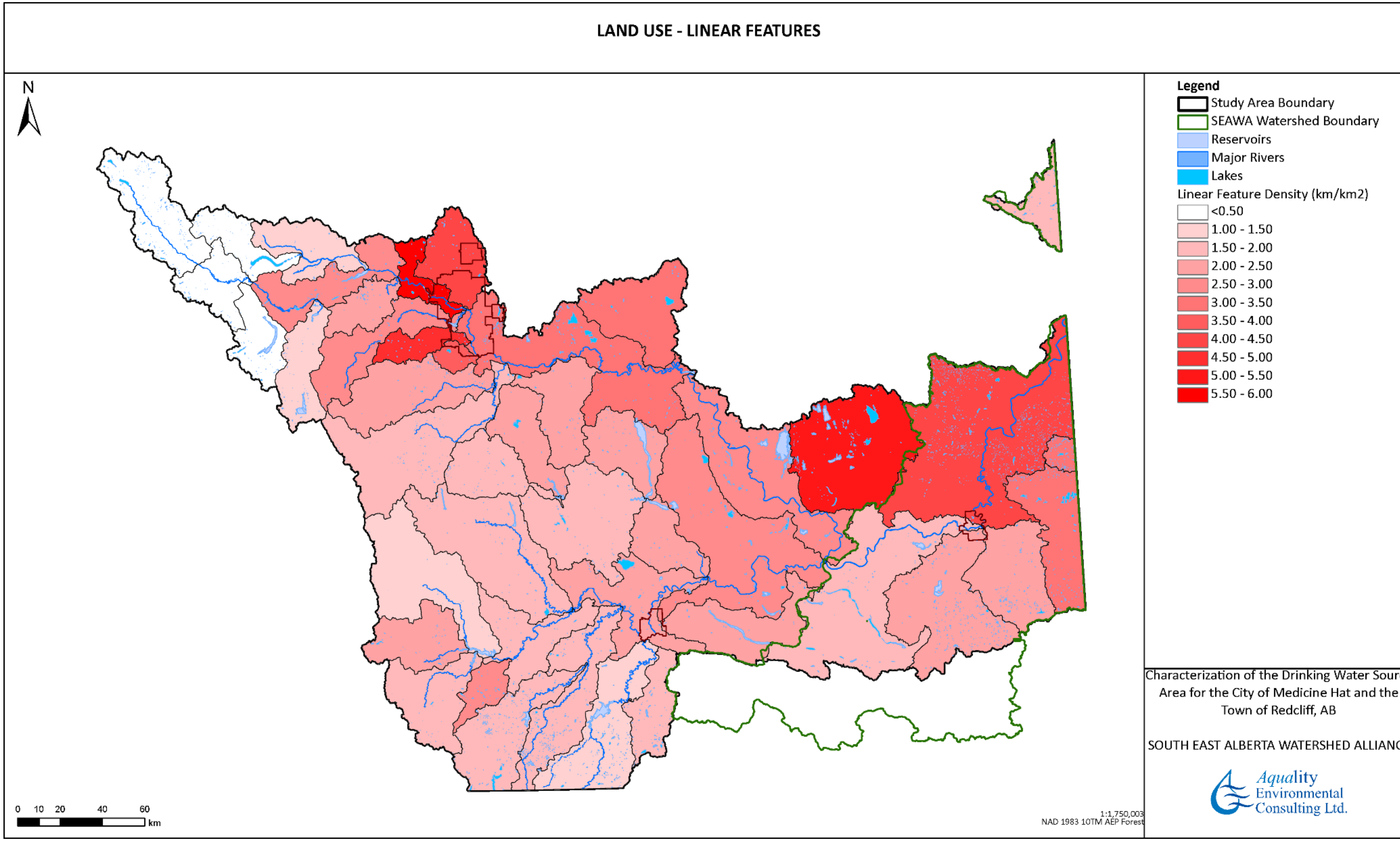

Figure 7. Density of linear developments within the study area.

2.3.2 Human Population

Human population data for the study area were derived from the 2021 Census of Population (Government of Canada, 2021). Because census subdivision boundaries generally do not align with natural boundaries such as watersheds, populations were interpolated based on the area of each reporting census subdivision falling within the study area.

The total estimated population within the study is approximately 1,850,000. The overwhelming majority of the population resides within cities (84 %), dominated by the City of Calgary. Towns comprise just under 10 % of the population, followed by Municipal Districts and Counties (5.2 %). Census subdivisions identified as Indian Reserves and Villages make up less than 1 % of the population of the study area.

The estimated population of the study area grew approximately 5.6 % from the previous census data collected in 2016.

Table 2. Human population centres and populations within the study area, based on interpolated values from the 2021 Census of Population.

Type	Name	Area within Study Area (km^2)	2021 Population
Total	Total	66547.2	1845506
City	Total	1207.8	1556020
	Calgary	843.4	1299704
	Lethbridge	124.8	98406
	Airdrie	85.6	74100
	Medicine Hat	119.8	63271
	Chestermere	34.2	20539
Town	Total	720.2	179334
	Cochrane	32.2	32199
	Okotoks	38.9	30405
	Canmore	69.4	15990
	High River	22.8	14324
	Strathmore	20.6	10415
	Taber	19.7	8862
	Coaldale	14.1	8771
	Banff	4.2	8305
	Crowsnest Pass	371.9	5687
	Redcliff	16.4	5581
	Claresholm	10.7	3804
	Cardston	8.6	3724
	Pincher Creek	10.0	3622
	Fort Macleod	23.7	3297
	Coalhurst	3.1	2869
	Black Diamond	6.9	2730
	Turner Valley	5.9	2611
	Crossfield	8.4	2487
	Magrath	6.0	2481
	Nanton	5.2	2167
	Bow Island	5.8	2036
	Picture Butte	3.0	1930
	Vulcan	6.3	1769
	Nobleford	1.9	1438
	Vauxhall	2.7	1286
	Stavely	1.8	544
Municipal District/ County	Total	61195.8	95898
	Foothills County	3670.6	23199
	Rocky View County	2028.4	21179
	Lethbridge County	2859.1	9987
	Taber	4266.6	7447
	Willow Creek No. 26	4556.4	6081
	Cypress County	10206.6	5686
	Vulcan County	5540.8	4237
	Wheatland County	2099.4	3946
	Cardston County	2636.3	3664
	Newell County	2789.4	3362
	Pincher Creek No. 9	3493.0	3239
	Forty Mile County No. 8	3658.9	1713
	Bighorn No. 8	1235.7	730
	Improvement District No. 9 Banff	3528.7	518
	Warner County No. 5	333.2	311
	Improvement District No. 4 Waterton	499.2	158
	Kananaskis	4243.5	156
	Ranchland No. 66	2637.5	110
	Special Area No. 3	505.5	85
	Special Area No. 2	356.1	68
	Acadia No. 34	51.1	23
Indian Reserve	Total	3404.3	9603
	Blood 148	1420.7	4572
	Siksika 146	711.7	3465
	Piikani 147	430.9	1550
	Peigan Timber Limit "B"	30.1	16
	Blood 148A	18.2	0
	Eden Valley 216	17.5	0
	Stoney 142, 143, 144	452.0	0
	Stoney 142B	39.2	0
	Tsuu T'ina Nation 145	284.0	0
Village	Total	19.1	4652
	Barnwell	1.5	978
	Foremost	2.2	630
	Standard	2.3	353
	Champion	0.9	351
	Barons	0.8	313
	Longview	1.1	297
	Glenwood	1.4	272
	Carmangay	1.8	269
	Cowley	1.4	216
	Arrowwood	0.7	188
	Lomond	1.2	178
	Hill Spring	1.0	168
	Hussar	0.7	164
	Milo	1.0	136
	Ghost Lake	0.6	82
	Waiparous	0.5	57

2.4 Wetland Distribution

Wetlands serve a wide variety of hydrological and biological functions on the natural landscape including drought and flood attenuation, wildlife habitat, groundwater recharge, and water quality mitigation through nutrient uptake, degradation of pollutants, and settling of suspended sediment. The loss of wetlands due to land use change can be deleterious to both the quantity and quality of surface and groundwater supplies.

The Province of Alberta has prepared a merged wetland inventory compiling several wetland inventory mosaics, using data from 2005 to 2015 (Alberta Environment and Parks, 2017). This dataset is heterogeneous as the underlying inventories were conducted using a variety of techniques and data resolutions and does not include an inventory of wetlands on federal lands. The Alberta Biodiversity Monitoring Institute has prepared an independent inventory of wetlands across the province using remote sensing techniques on satellite imagery collected from 2017 to 2018 ((Alberta Biodiversity Monitoring Institute, 2021)). The ABMI wetland inventory dataset addresses some of these shortcomings by following a single approach to wetland identification and extends the inventory onto the federal lands at the headwaters of the SSRB. The ABMI wetland dataset was therefore selected as the baseline for use in this study.

Wetland habitats comprise between 1.5 and 9 % of the land base within each subwatershed in the study area, with an average density of 3.9 % and total area of 2,555 km^2 (Figure 8, Table 3, and Table 4). Wetland densities are generally highest along the Bow valley corridor, with notably low densities in the headwaters and in the immediate vicinity of the City of Calgary. These values do not reflect wetlands that have been completely lost from the landscape (see below), so this data underestimates the natural/pre-disturbance wetland densities on the landscape.

Wetland densities naturally vary widely across the natural regions and subregions (Table 3). Areas of the Rocky Mountain subregion generally have lower densities due to the steep terrain and extensive areas of exposed bedrock, while most areas of the Grassland natural region have higher densities due to the rolling to undulating terrain left by the Pleistocene glaciation, which provide favourable topography for capturing water on the landscape (Natural Regions Committee, 2006). Densities within the Foothills and Parkland natural regions are variable due to the relatively small areas that they represent within the study area.

The study area was dominated by Marsh type wetlands, comprising more than half (56.5 %) of all wetland area (Table 4). Open Water wetlands were the next most dominant at 34.2 %, followed by Swamp (6.3) and Fen (3 %). No Bog wetlands were identified in the inventory within the study area boundaries. Note that these values likely overestimate the area of Open Water wetland habitats, as most inventories cannot determine water depth. Open Water wetlands are classified as shallow water less than 2 metres in depth under the Alberta Wetland Classification System (Government of Alberta, 2015).

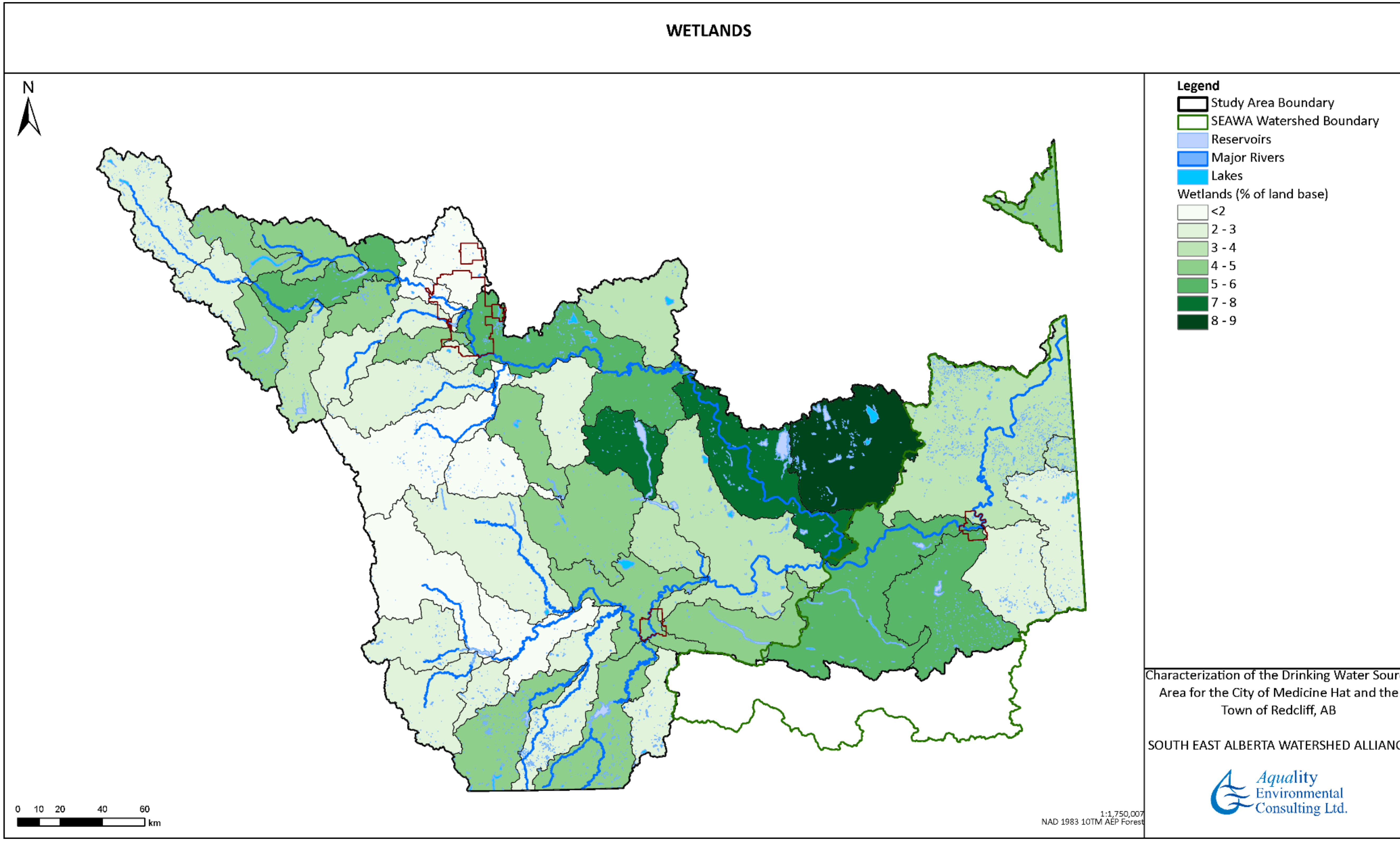

Figure 8. Distribution of wetland habitats across the study area.

Table 3. Wetland areas by natural region and subregion.

Natural Region	Natural Subregion	Total Wetland Area (km^2)	Total Wetland Area (%)
Rocky Mountain	Total	470.8	3.0%
	Alpine	14.5	0.5%
	Montane	333.7	5.2%
	Subalpine	122.6	1.9%
Foothills3 %	Total	9.3	4.9%
	Lower Foothills	0.6	1.5%
	Upper Foothills	8.7	5.9%
Parkland	Total	79.4	2.0%
	Central Parkland	2.6	0.7%
	Foothills Parkland	76.8	2.2%
Grassland	Total	1998.0	4.3%
	Dry Mixedgrass	1067.5	4.9%
	Foothills Fescue	323.8	3.4%
	Mixedgrass	601.0	4.1%
	Northern Fescue	5.7	4.0%

Table 4. Wetland classes within the study area.

Wetland Class	Wetland Area (km^2)	% of Wetland Area
Bog	0	0
Fen	77.7	3.0%
Marsh	1,443.4	56.5%
Open Water	874.4	34.2%
Swamp	160.1	6.3%

2.5 Wetland Impacts

The densities and areas of wetlands presented in the preceding section refer only to wetlands currently found on the landscape, and do not account for wetlands that have been historically lost due to infilling, draining, or other direct human activities, as well as losses from drying due to climate change. There are no datasets on historical wetland loss and impacts that include the entire study area. Current estimates of complete wetland loss within the prairie pothole region (which encompasses most of the Grassland and Parkland natural regions) are on the order of 60 to 70 % (Government of Alberta, 2013).

As a proxy of potential wetland impacts and loss, the existing wetland inventory was overlaid with the ABMI human footprints dataset, to identify areas of wetlands likely to be currently impacted by land use change and human activities. Note that this metric does not address wetlands that have been completely lost due to human activities, as these wetlands would not be identifiable in the ABMI wetland inventory.

Impacts to existing wetlands largely follow a similar pattern to the distribution of high human footprint densities from Calgary to Lethbridge to Medicine Hat, corresponding to the Mixedgrass natural subregion (Figure 9). The proportion of wetlands impacted by human activities ranges from essentially zero in some of the upper headwater regions, to nearly 70 % in the areas of highest agricultural development within the Grasslands natural region.

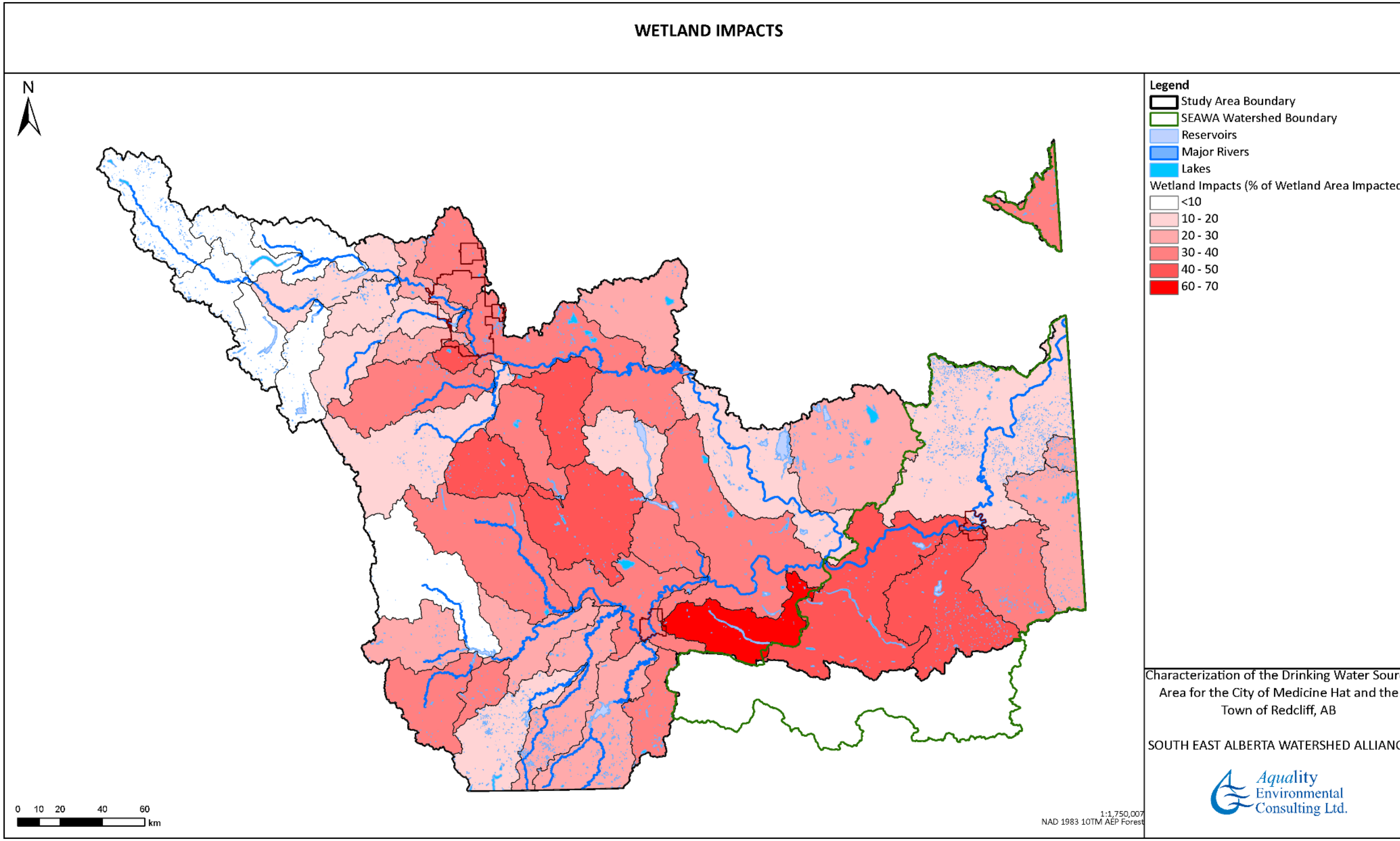

Figure 9. Distribution of impacted extant wetland habitats across the study area.

2.6 Riparian Areas

Riparian areas represent the transition between uplands and aquatic habitats, which can both influence and be influenced by associated water bodies (Clare & Sass, 2012). In the areas immediately adjacent to waterbodies, they often share many of the characteristics and functions as wetlands indicated above in section 2.4. In addition to these functions, vegetated riparian areas located along rivers and streams also serve to provide a high degree of protection of these watercourses from erosion and sedimentation, by increasing settling time for sediment laden waters and by the anchoring effect of plant root systems on the existing sediment and soils.

A complete inventory of riparian health is not available across the entire SSRB, with only minor areas of the basin having been historically assessed. As these areas may not be representative of either natural riparian areas or the pressures and impacts of human activities, they were not analyzed and extrapolated to the entire basin. A proxy for riparian impacts was derived by analyzing the proximity of waterbody and watercourse shorelines (Alberta Environment and Parks, 2023) to the closest human-modified landscape feature (Alberta Biodiversity Monitoring Institute, 2022), as the width of the riparian buffer zone is generally believed to be a good indicator of potential riparian function. For these analyses, the results are presented as the width of the undisturbed buffer, with lower values indicating higher potentials for riparian impacts.

Riparian impacts were determined based on the proximity of human modified landscapes and anthropogenic features to each point on the shoreline of every waterbody within the inventory. As a point of comparison, standard setback recommendations based on the province's "Stepping Back from the Water" BMP guide based solely on soil composition fall within the range of 20-50 metres, with modifications of these distances based on other factors like slope, land use, fish bearing status, etc. (Government of Alberta, 2012). This does not include other indirect impacts to riparian areas, such as alteration of flood/scour regimes through in-stream water management, which can negatively impact the natural recruitment of some riparian vegetation communities such as cottonwoods (Rood & Bradley, 2015).

For all waterbodies taken in aggregate, a similar pattern is seen with impacts to wetlands, though with substantially less overall impacts occurring within the Medicine Hat region. Impacts around major rivers are generally low, likely due to the restrictions and difficulties in development of steep valley sides. The apparently elevated impacts in the southern areas result from a combination of the relatively low densities of major rivers, impacts due to reservoir construction, and low topographic relief permitting development closer towards the valley floor.

Patterns of impacts to lakes and reservoirs are largely driven by the distribution of reservoirs, resulting from the management areas around them and the wide fluctuations in reservoir surface levels and the consequent disturbances to the shorelines.

Impacts to the riparian areas around smaller streams are generally concentrated in a similar pattern to wetland impacts, with limited impacts in the upper headwaters, but extensive impacts within areas of higher agricultural development.

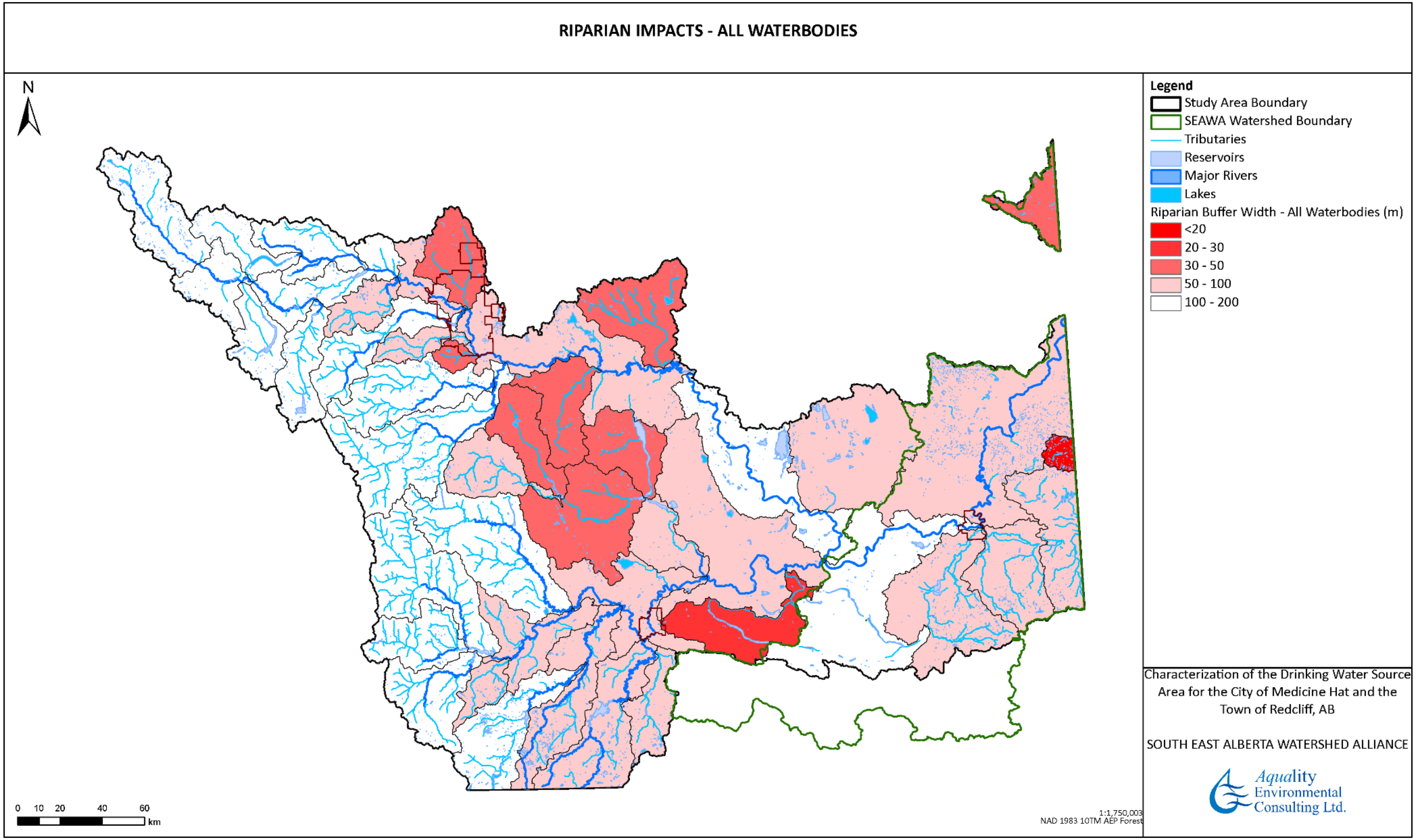

Figure 10. Riparian impacts for all mapped waterbodies in aggregate.

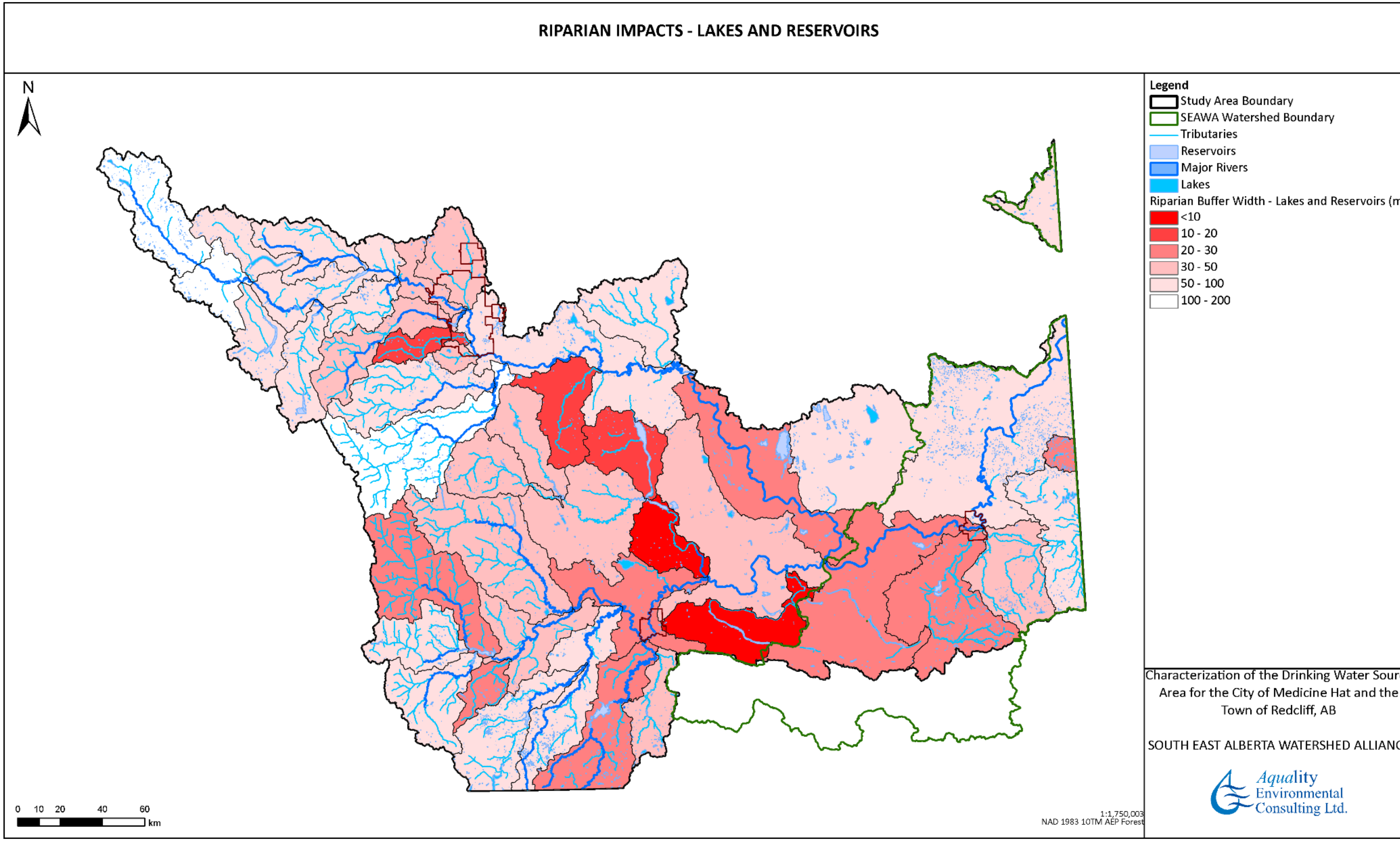

Figure 11. Riparian impacts for lakes and reservoirs.

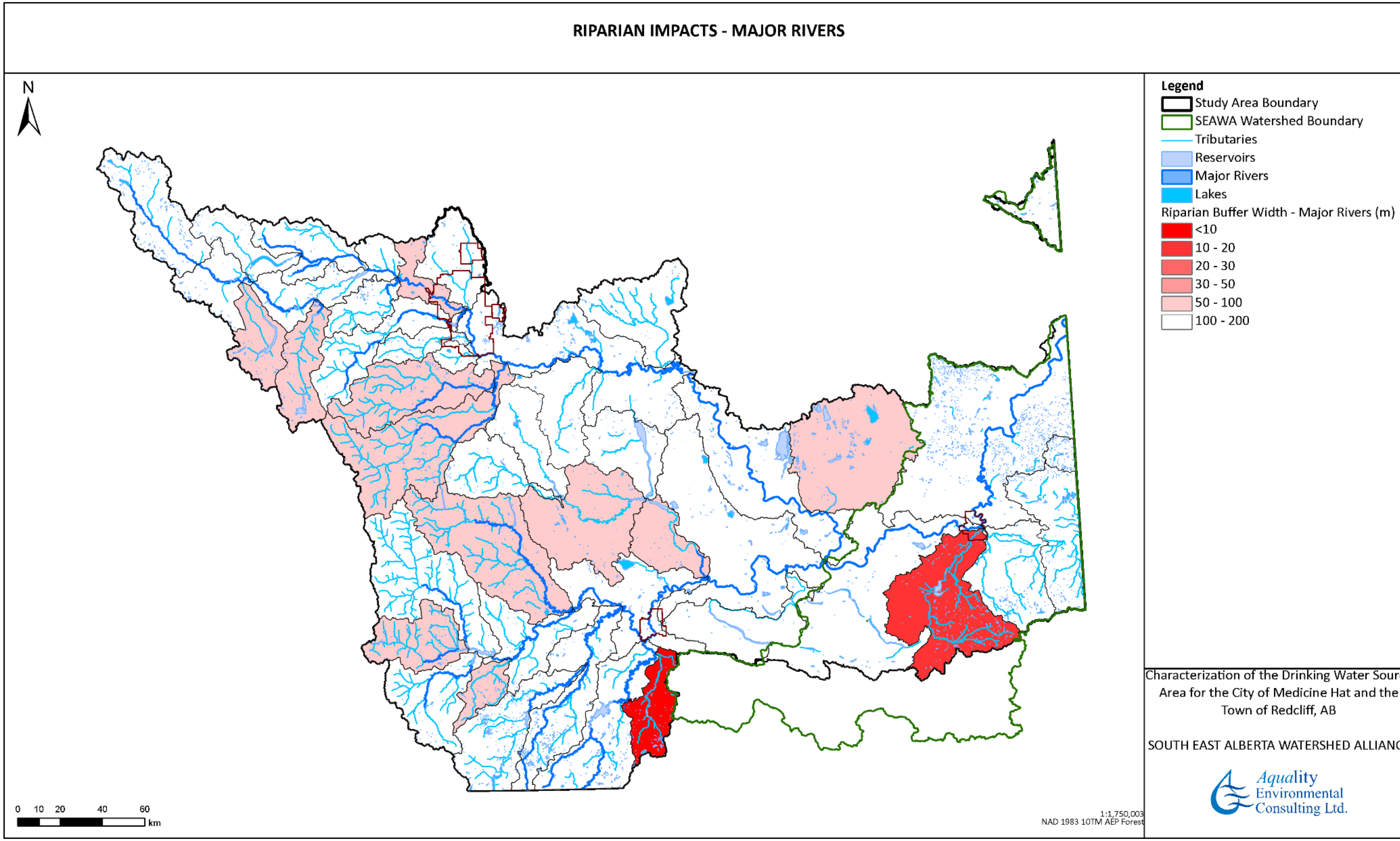

Figure 12. Riparian impacts for major rivers.

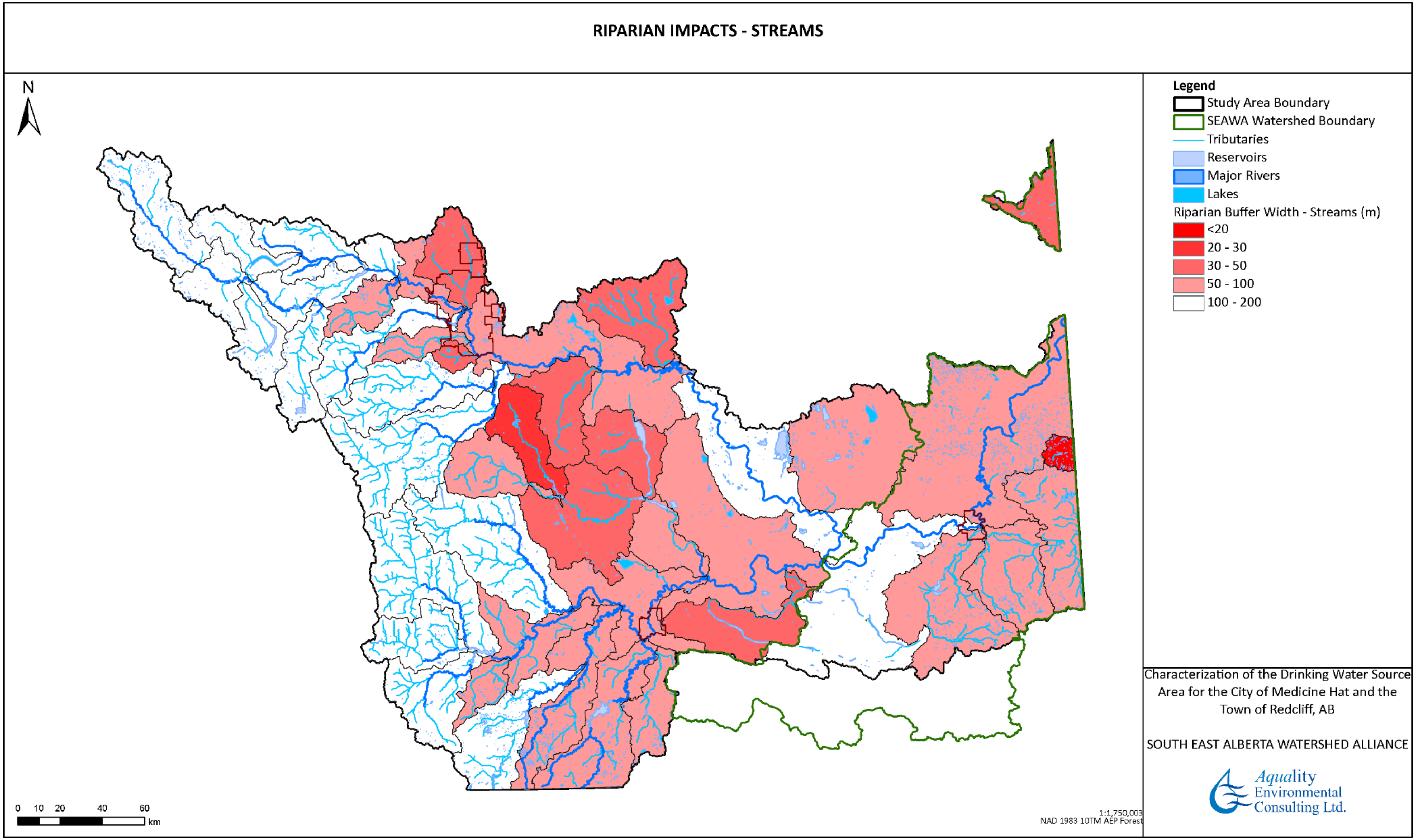

Figure 13. Riparian impacts for streams and minor rivers.

3 Drinking Water Source Threats

3.1 Agriculture

Some agricultural data are available as land cover information presented in the preceding sections, such as the relative area of the land base devoted to agricultural production of some form. More detailed data were derived from the 2016 Interpolated Census of Agriculture (Government of Canada, 2016), the most recent year for which data from the Canada Census of Agriculture were available at the time of preparation.

Metrics selected for determining risk to water supplies included the proportion of the land base under agricultural development as farms (further broken down into the proportion of cropland, improved pasture, and unimproved pasture), the proportion of the total land base to which herbicides, insecticides, fungicides, and fertilizers were applied, the proportion of the total land base under irrigation, and the production of livestock manure.

The total area turned over to farms within the study varies from essentially zero within the upper elevations of the Rocky Mountain natural region, to nearly 100% of the land base throughout much of the Grassland natural region (Figure 14). The density of farm area follows the pattern previously identified for land cover, with the highest densities occurring within the Mixedgrass subregion and southern portion of the Dry Mixedgrass natural subregions.

A similar pattern holds for cropped farmland, but with a greater concentration of cropped farmland within this corridor and with up to 70 % of the land base under crop production (Figure 15).

Pastured farmland shows a weaker spatial pattern with elevated densities in the Foothills Fescue natural subregion. Improved pasture, which is generally tilled and sown with a perennial forage crop to provide greater production, can make up to 12 % of the land base in some subwatersheds (Figure 16). Unimproved (or native) pasture is present at higher densities, occupying up to 55 % of the land base in some subwatersheds (Figure 17). Manure production does not correlate strongly with the distribution of pasture lands, and is more related to the locations of confined feeding operations (Figure 18).

Management practices related to crop production follow a similar density pattern to that of cropland distribution itself, generally varying only in the relative proportion of the land under each management practice. Across all subwatersheds within the study, insecticide application rates can be as high as 18 % of the agricultural area (Figure 19), fungicide application as high as 24 % (Figure 20), fertilizer application as high as 55 % (Figure 21), and herbicide application as high as 60 % (Figure 22). Because the western portions of the Grassland natural region experience higher levels of precipitation than the east, the density of irrigated lands departs from this spatial pattern, with a higher density of irrigation in the southern and eastern extents of high cropland densities, and with up to 35 % of the agricultural lands under irrigation (Figure 23).

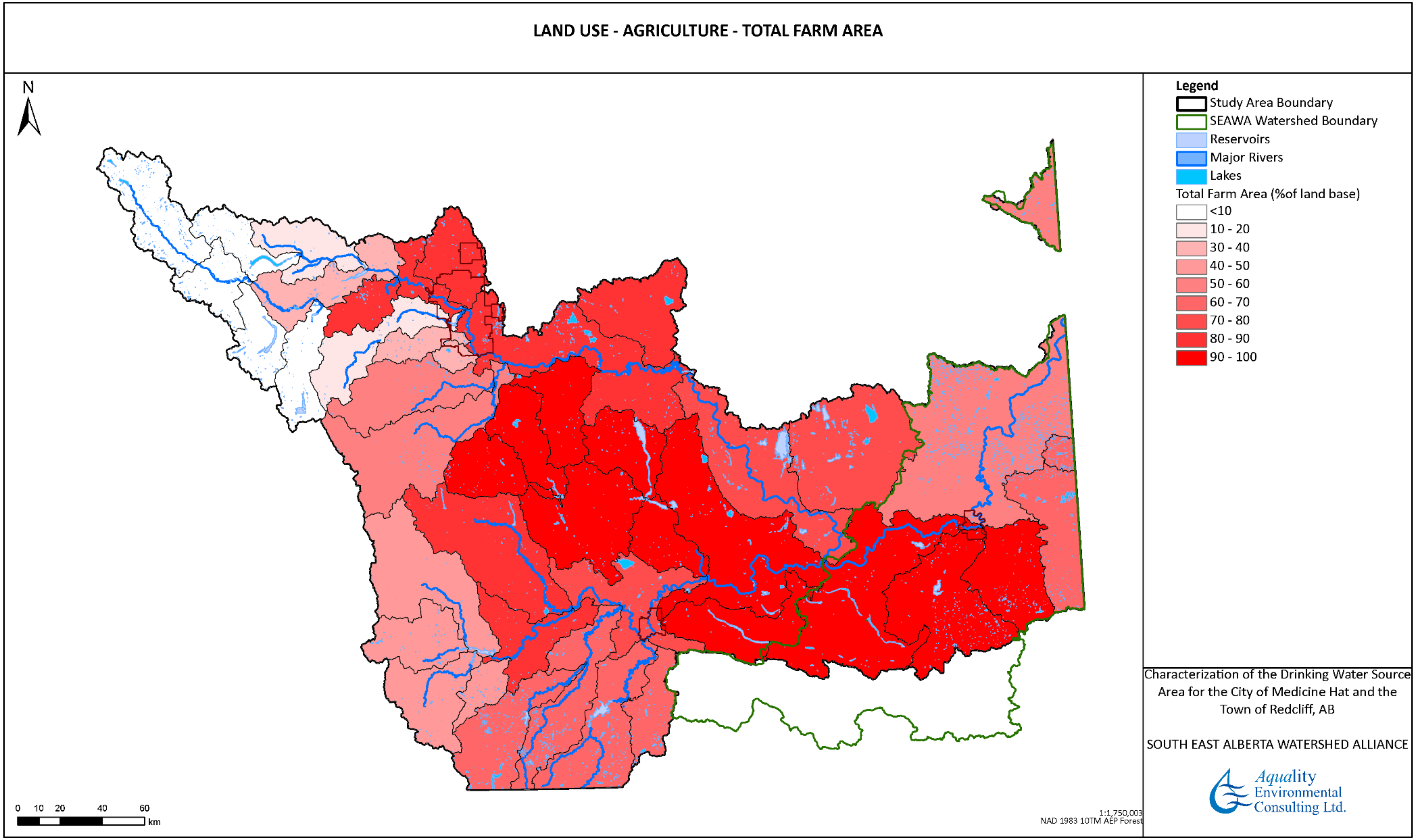

Figure 14. Total farm area as a proportion of the land base.

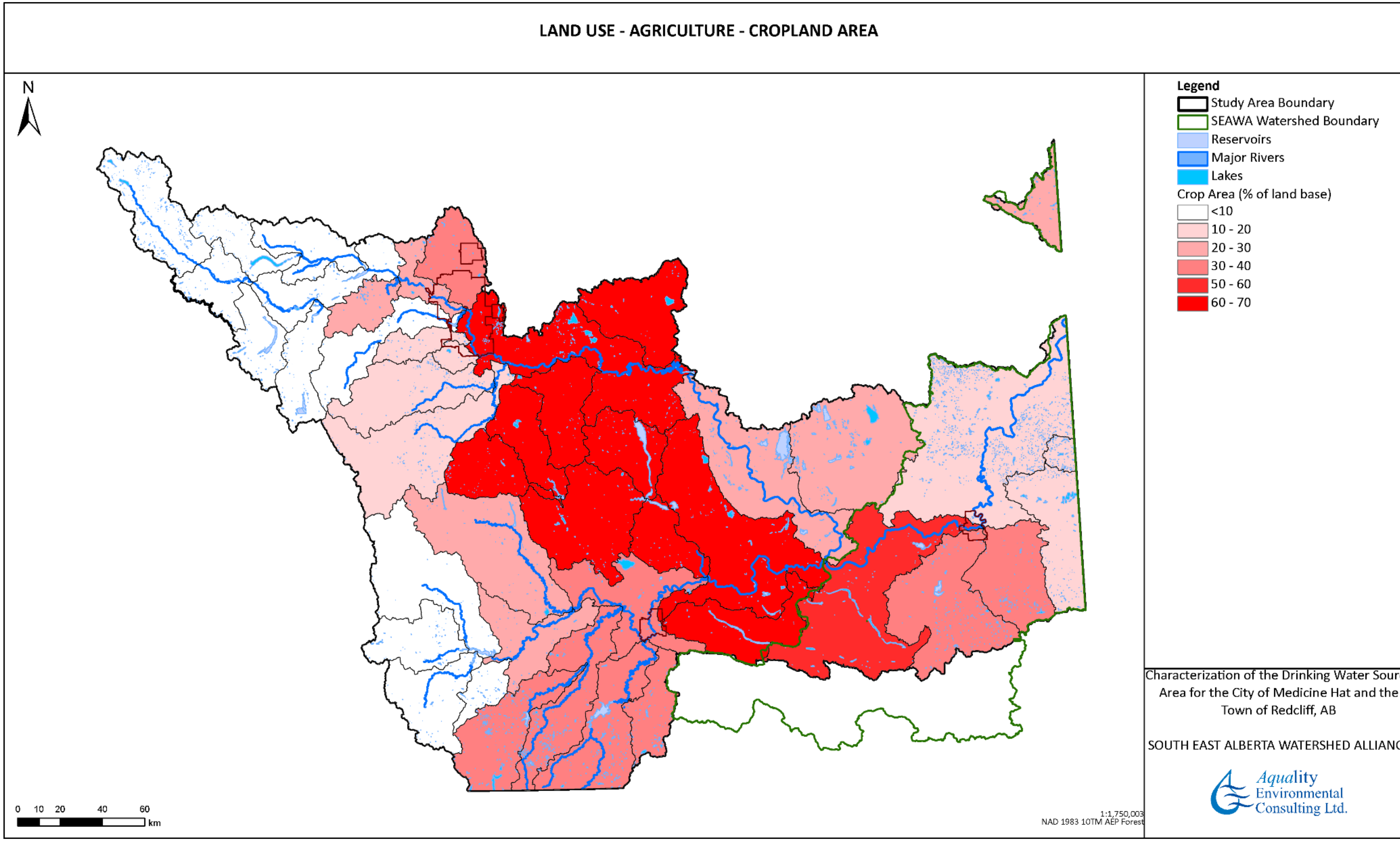

Figure 15. Total area of cropped farmland as a proportion of the land base.

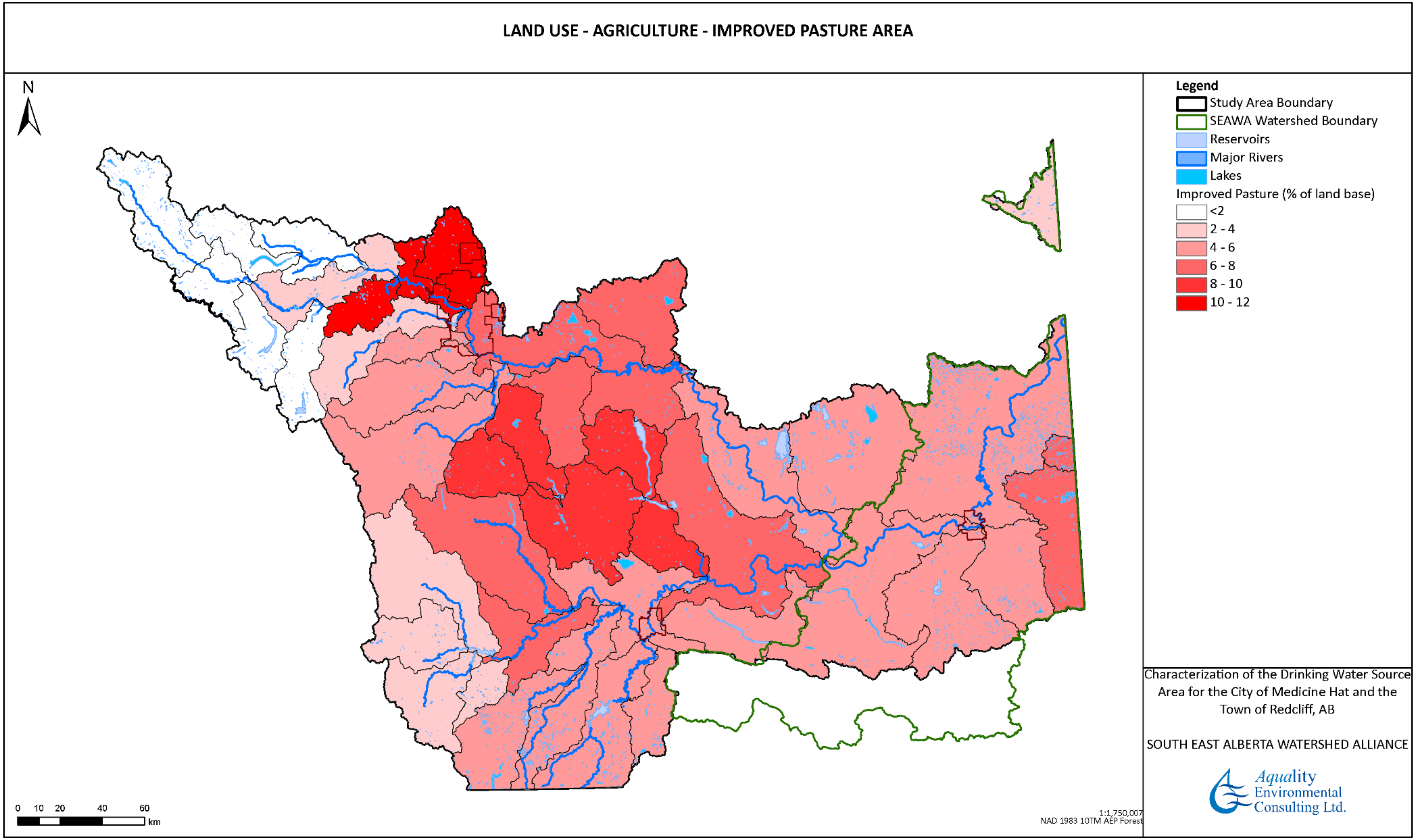

Figure 16. Total area of improved pasture as a proportion of the land base.

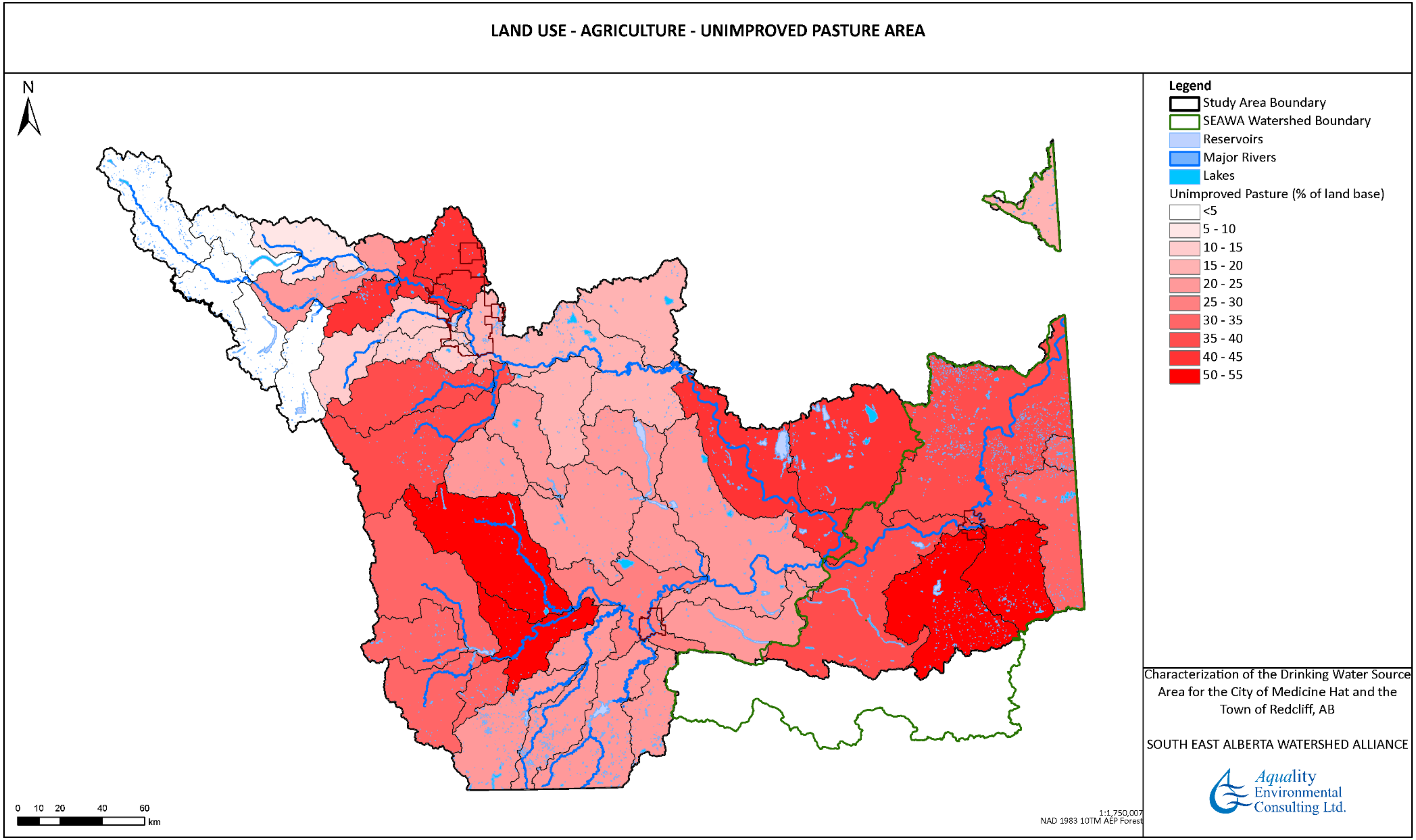

Figure 17. Total area of unimproved pasture as a proportion of the land base.

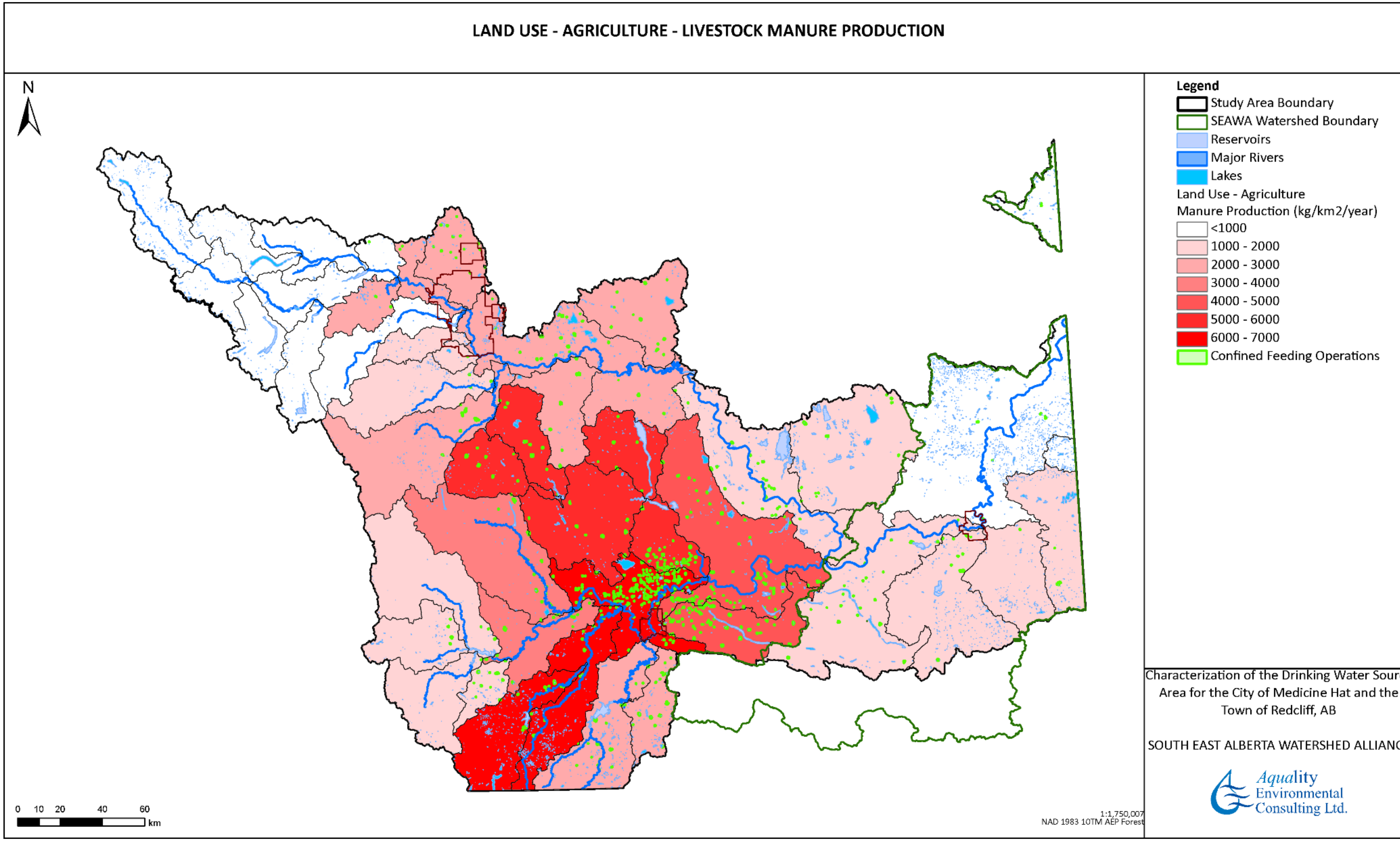

Figure 18. Total livestock manure production and the distribution of confined feeding operations.

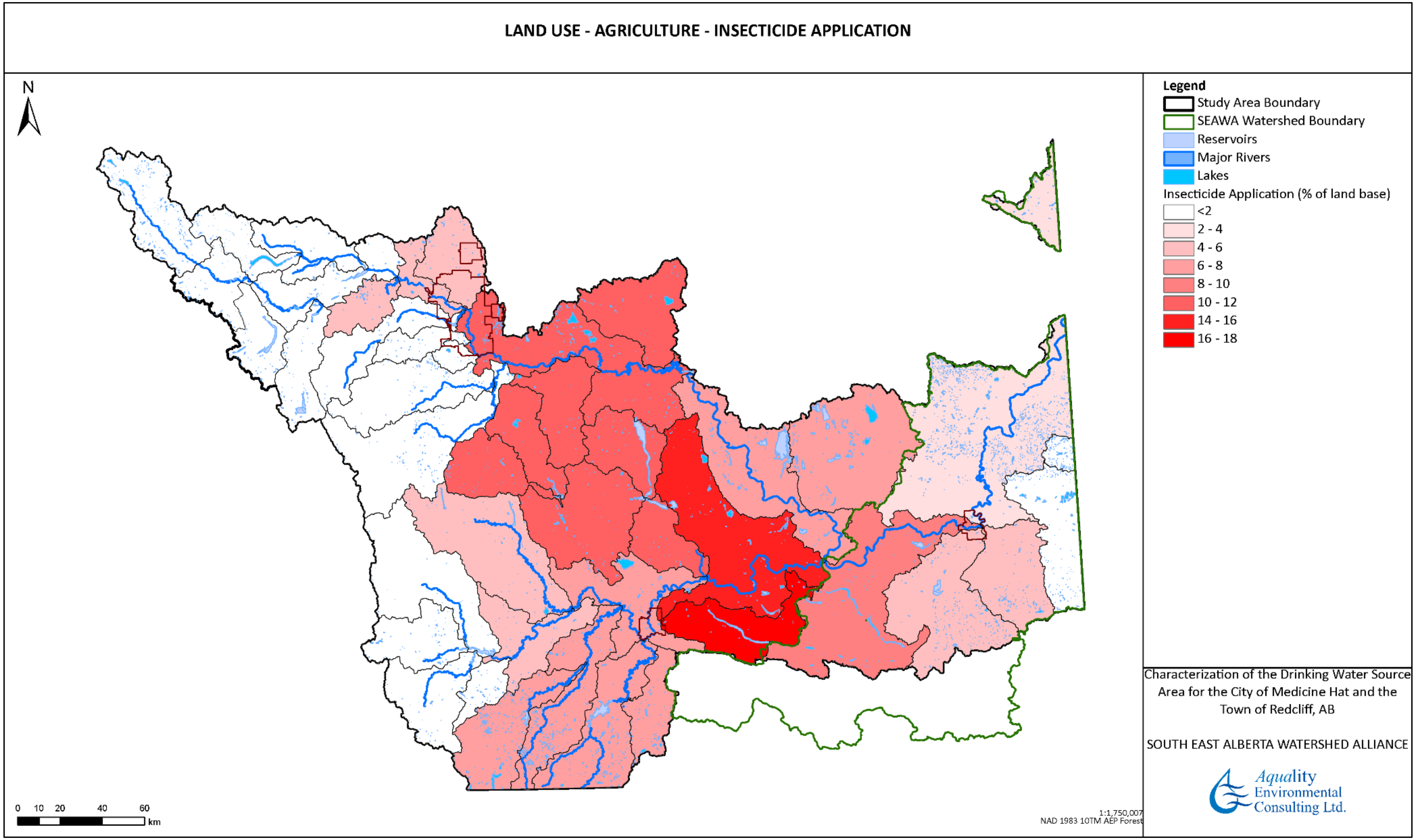

Figure 19. Proportion of agricultural lands with insecticide application.

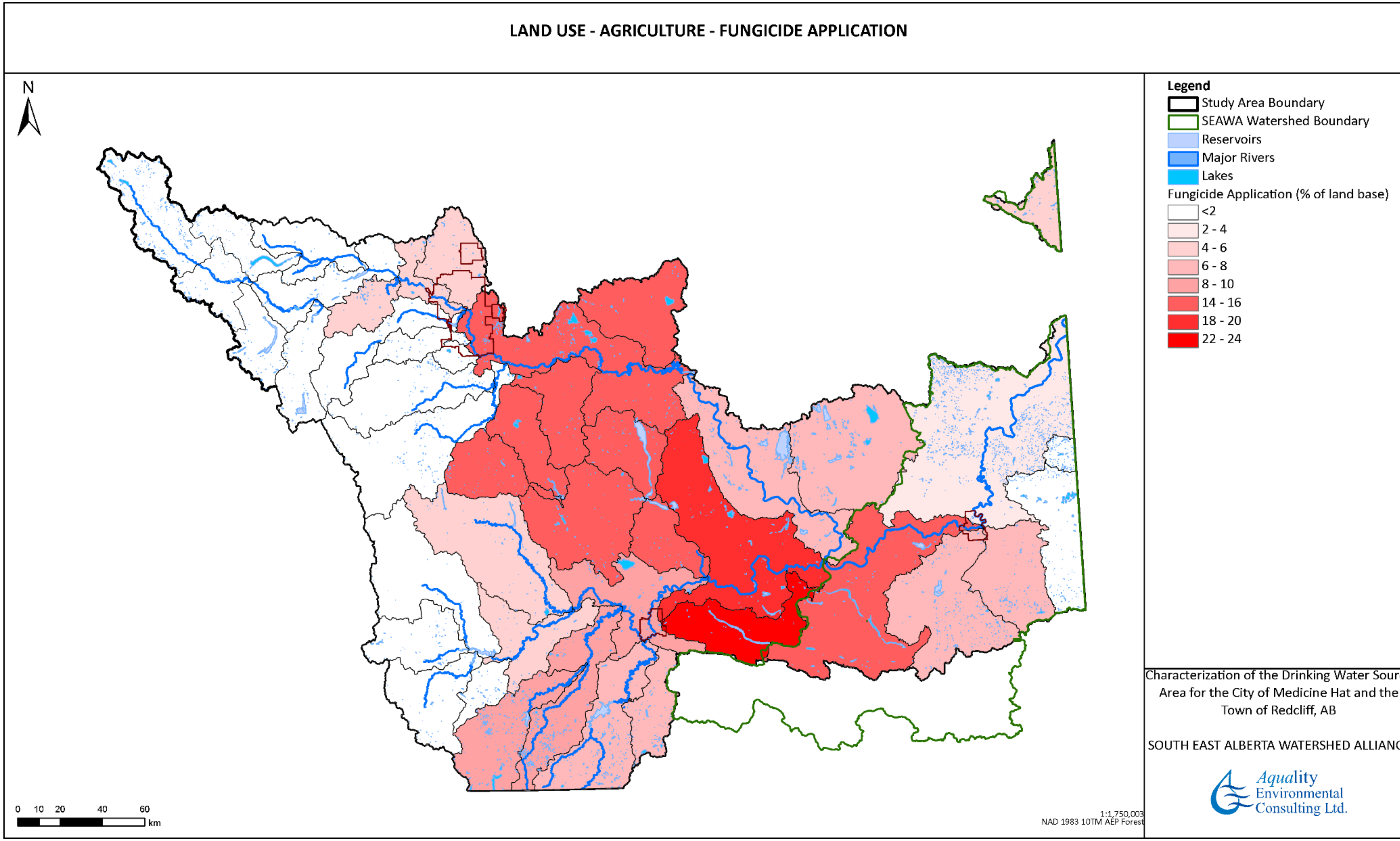

Figure 20. Proportion of agricultural lands with fungicide application.

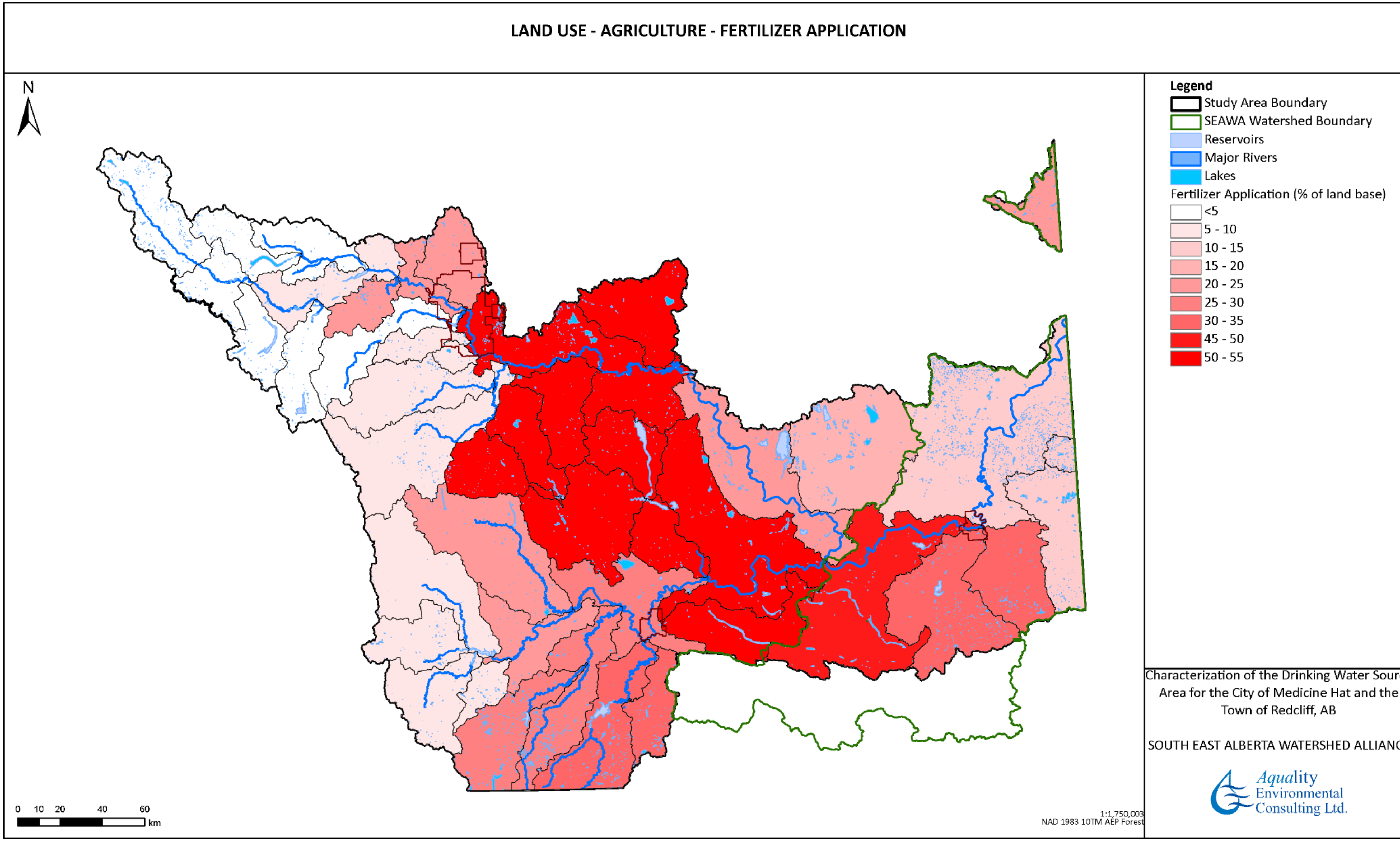

Figure 21. Proportion of agricultural lands with fertilizer application.

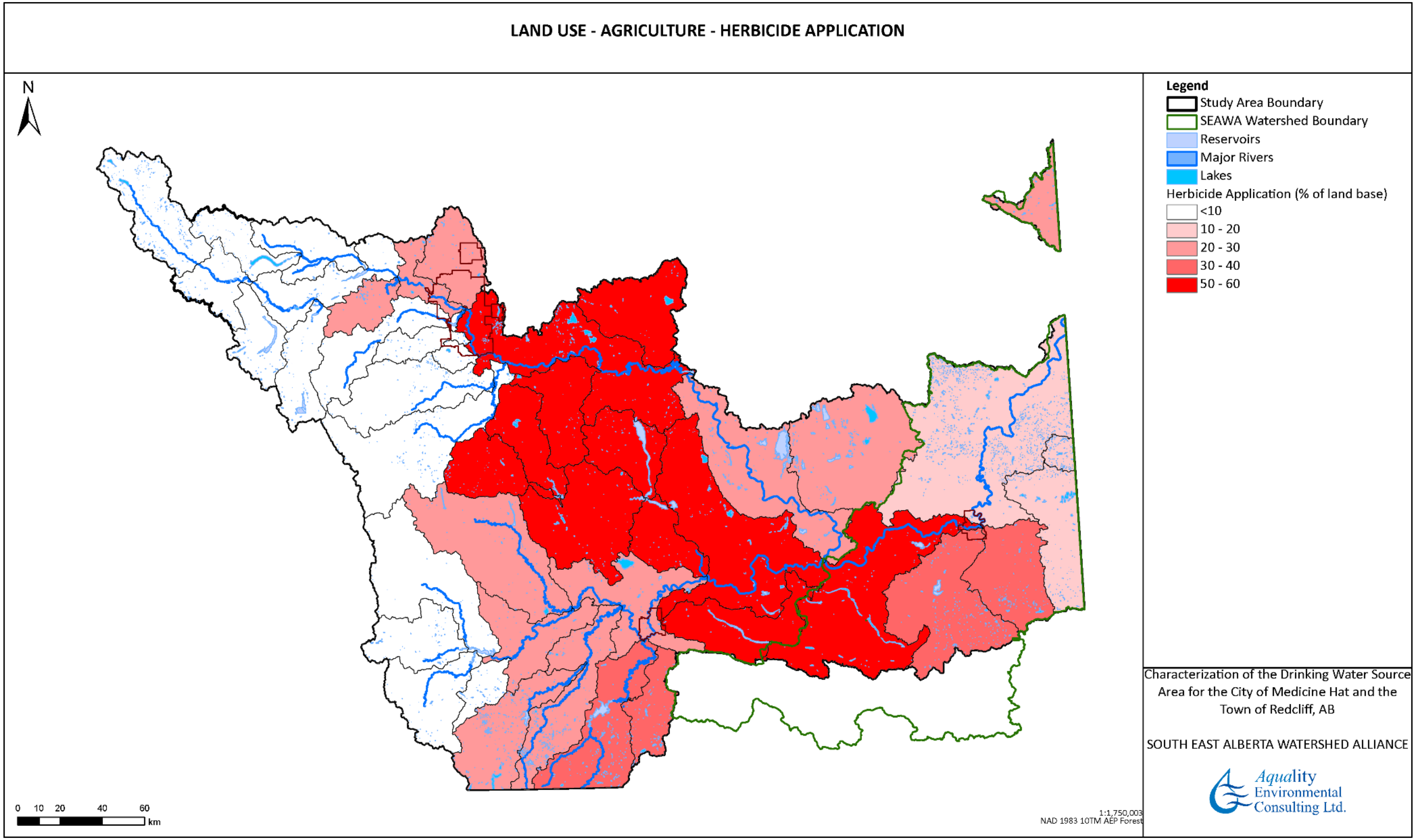

Figure 22. Proportion of agricultural lands with herbicide application.

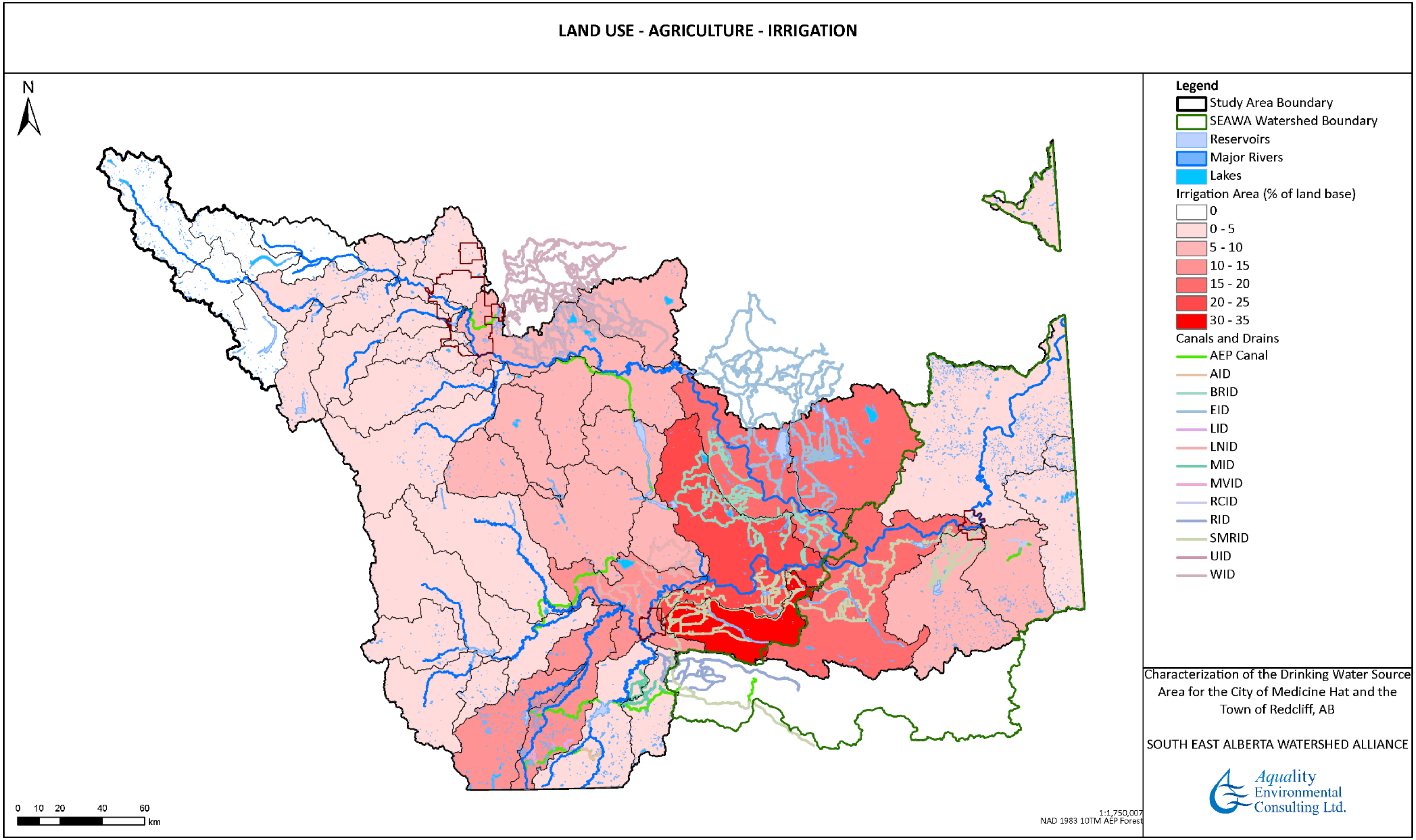

Figure 23. Proportion of agricultural lands under irrigation.

3.2 Resource Extraction

3.2.1 Oil and Gas

Oil and gas production occurs throughout much of the study area within the Grassland natural region, with densities of wells and related facilities of up to 2 per km^2 in most such subwatersheds. However, the overwhelming majority of such activity is concentrated in the Dry Mixedgrass natural subregion to the north of Medicine Hat, within the Medicine Hat-Hatton gas field. In this area, well densities are more than double that value. The impacts of oil and gas activities are also seen in the distribution of linear developments required for the installation and maintenance of these facilities (see Figure 7 in Section 2.3.1 above).

The natural gas wells dominant in the east are likely to pose a greater threat to water quality and quantity due to the high levels of landscape impacts required for installation and maintenance, as well as potential interactions and interference with groundwater bearing geological formations due to drilling activities. Threats from oil extraction activities, concentrated more in the western portion of the study area, carry some of these same risks, but also an increased risk of water quality impacts due to unintentional releases of hydrocarbon products.

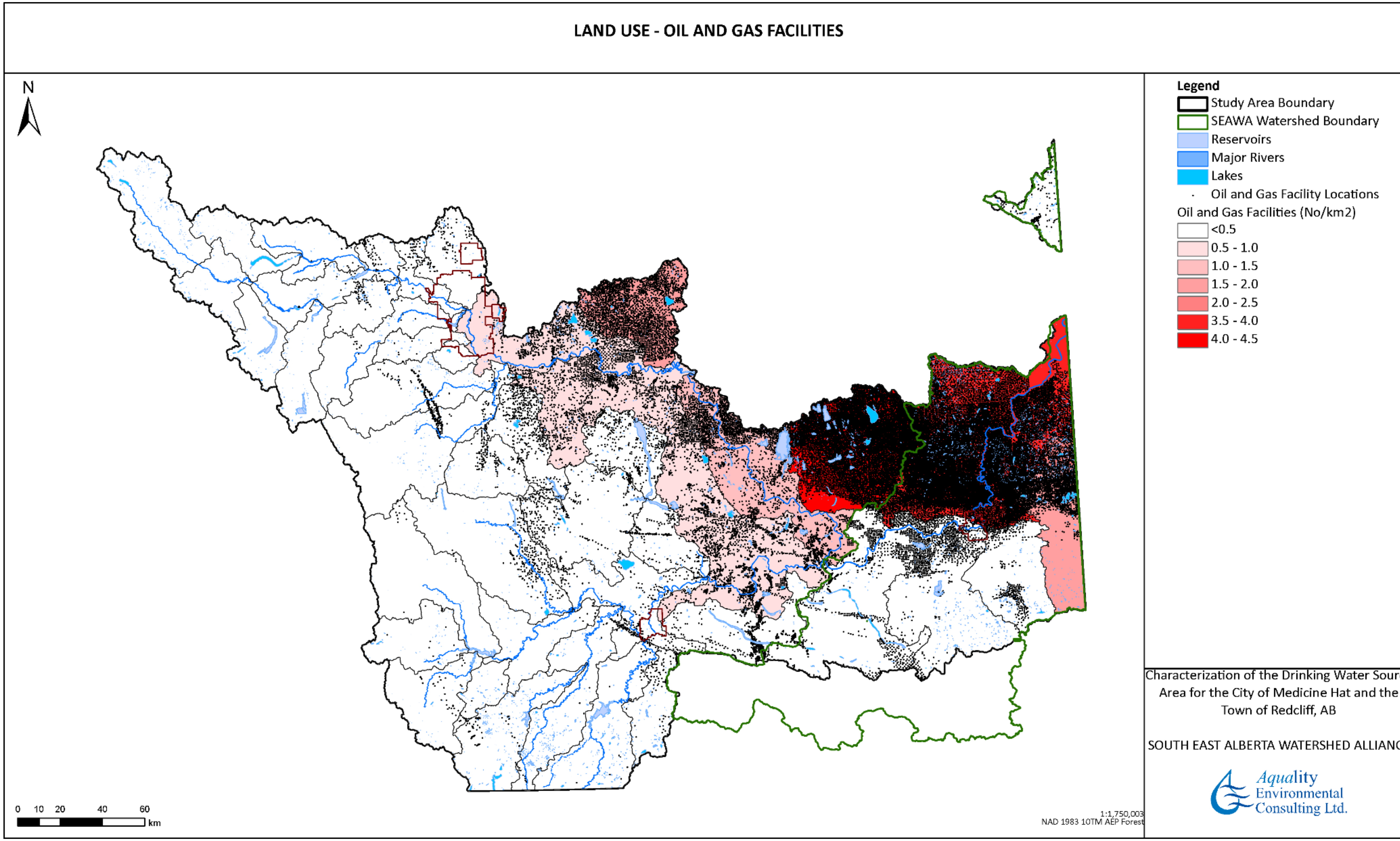

Figure 24. Oil and gas facility locations and density.

3.2.2 Forestry and Forest Fires

Forestry activities within the watershed are limited generally to the upper headwaters in the Rocky Mountain natural region where forest stand densities are highest (Figure 25). The highest densities of forestry harvest activities are located in the Oldman River headwaters, with up to 11 % of the land base given over to active and recovering harvest areas. Because of restrictions on activities within the National and Provincial Park systems, there is less forestry activity within the upper headwaters of the Bow River. There are two Forest Management Agreements in place, with Crowsnest Forest Products Ltd. holding the agreement in the Oldman basin headwaters and Spray Lake Sawmills (1980) Ltd. holding the agreement in the Bow basin headwaters outside of the Parks systems.

Wildfires have both natural and anthropogenic causes, with approximately half of all fires resulting from human activity (Government of Alberta, 2023). Wildfires also have a complicated and integrated relationship with forestry activity, as silvicultural practices may alter the location, frequency, and intensity of fires. Wildfire distributions follow a similar pattern of restriction to the forested Rocky Mountain natural region (Figure 25). However, fire epicentres also show a correspondence to the distribution of transportation corridors, emphasizing the anthropogenic nature of many wildfires.

Forestry activities and wildfires have the potential to impact water quality and to a lesser extent water quantity. Increases in exposed lands following both are expected to increase pollutants in surface runoff through elevated levels of erosion and sedimentation into watercourses. Removal of vegetation through both mechanisms may also reduce landscape retention of surface runoff, increasing the rate at which precipitation enters watercourses and resulting in increasing flashiness of surface water flows.

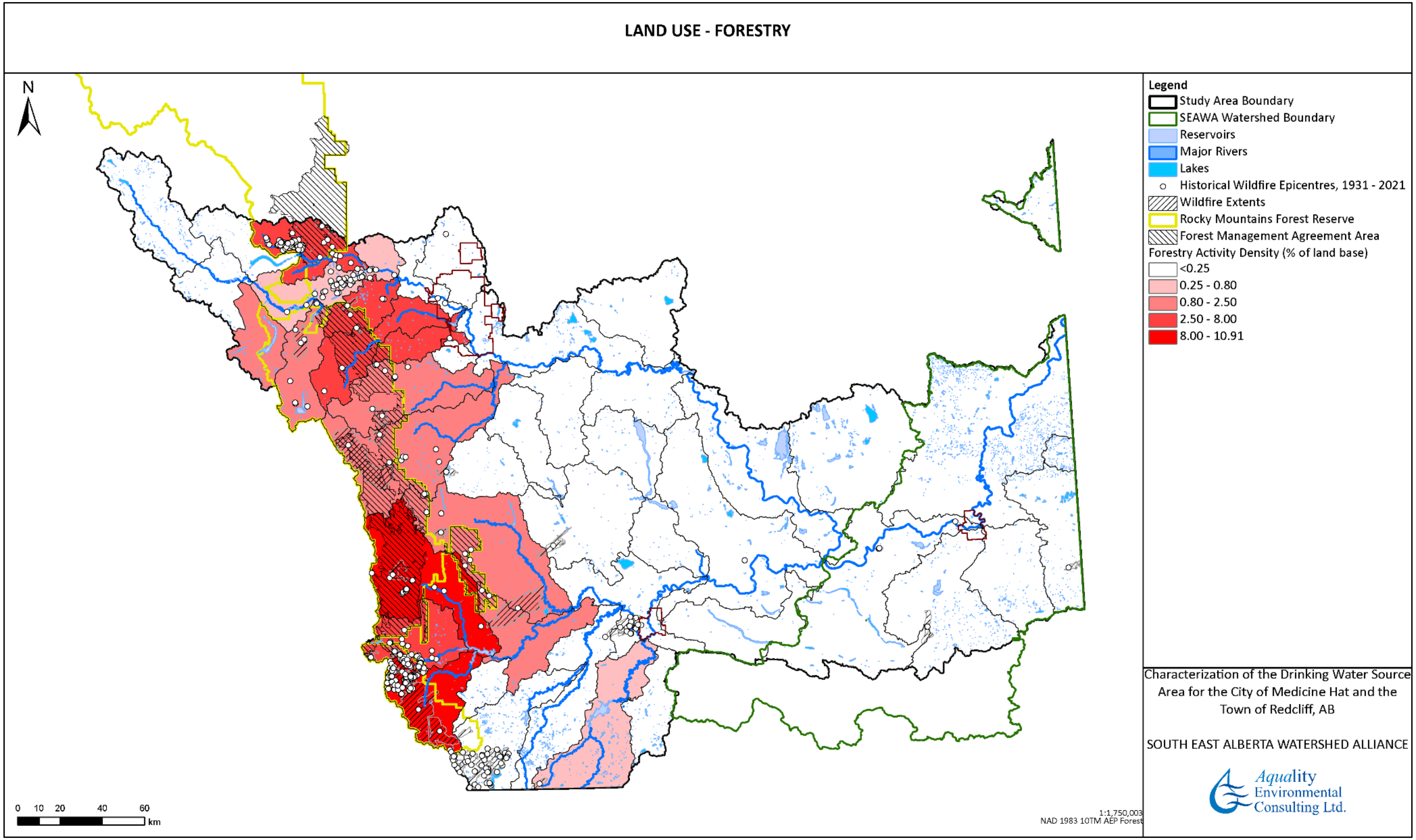

Figure 25. Forestry activity density and historical wildfire distributions.

3.2.3 Mining

Mining includes resource extraction activities requiring stripping of the land and excavation of a mineral resource. Extraction of mineral resources removes vegetation cover, exposing bare substrate and increasing the potential for erosion and sedimentation, with the concomitant increase in potential releases of associated pollutants (see section 3.3.3 below). Mining activities may also impact surface and ground water supplies when extraction occurs either adjacent to surface water bodies, or excavations impinge upon the groundwater table. Such activities can alter natural flows by diverting water into excavations, thereby reducing surface flows, or through requiring pumping to keep excavations dry, artificially inflating the rate of shallow groundwater movement into surface water bodies.

Mining activity generally does not make up a large proportion of the land base within the study area (Figure 6). However, on an areal basis these activities are concentrated along the Bow River and Oldman River mainstems, presenting a potentially outsized threat due to the proximity of the threat to major rivers (Figure 26). The predominant resource is aggregate resources (sand and gravel) for the transportation and construction sectors, with the density of extraction activities corresponding to the distribution of these resources along both present-day and prehistoric valleys and floodplains.

Coal extraction also contributes significantly to mining areas, with extraction areas tending to be fewer in number and less distributed across the landscape, but with larger mine sizes where they occur. Coal extraction carries additional potential threats to water quality, primarily due to the threat of contamination of surface and groundwater supplies with runoff contaminated by hydrocarbons, heavy metals, and metalloids such as selenium. Coal mines are more concentrated in the Oldman River basin than in the Bow River basin. However, the nature and magnitude of these risks cannot be readily addressed by a broad landscape-level analysis; these sources more closely behave as point sources for potential pollutants, and generally have a greater level of impact analysis and mitigation required from regulatory bodies. Risks from future mining activities in particular should be considered on an individual rather than watershed-level basis.

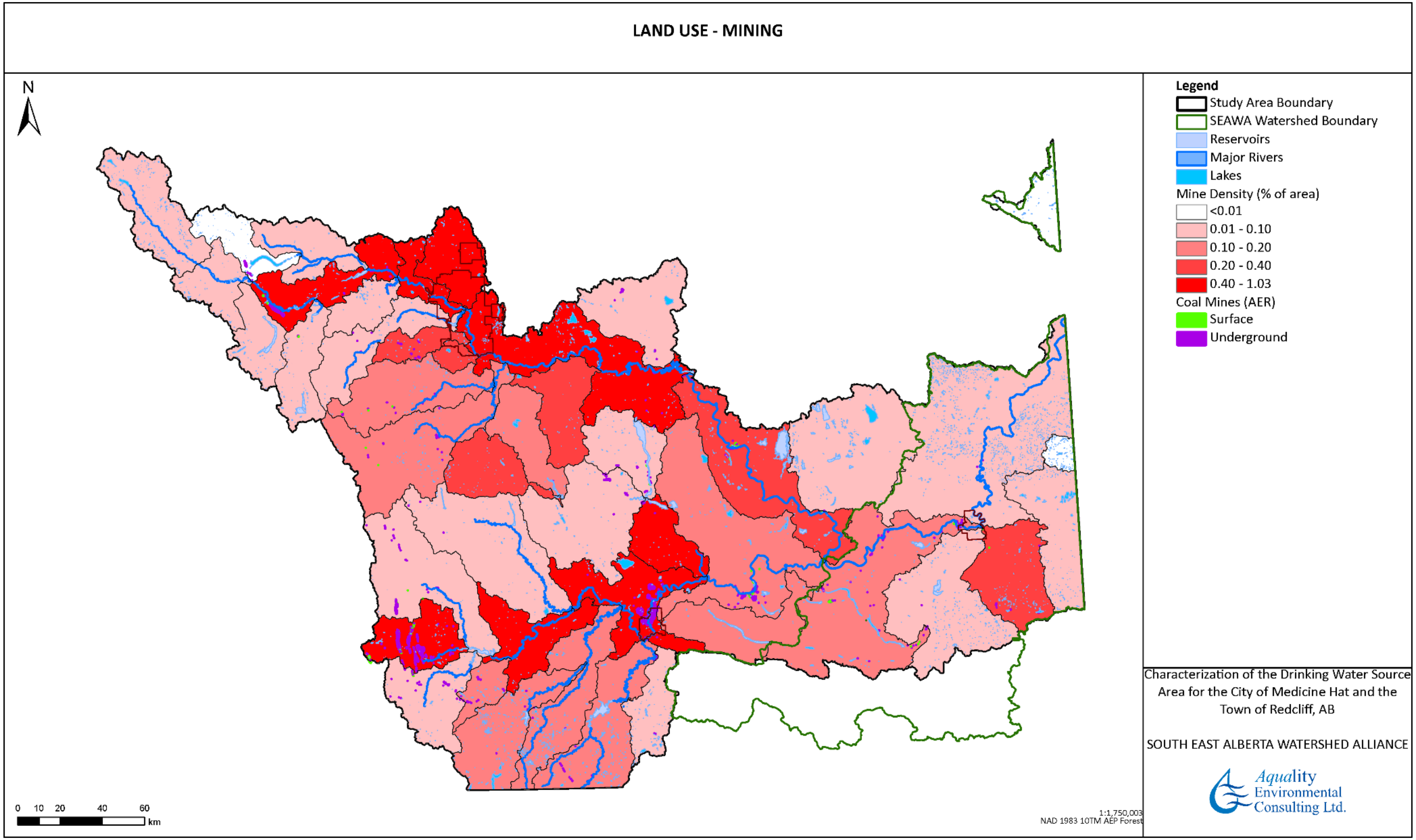

Figure 26. Mining density within the study area.

3.3 Water Quantity

As a result of a combination of high population size and high levels of agricultural production, the South Saskatchewan River Basin has and continues to experience pressure on available water resources. In addition to the needs of various sectors, Alberta also has an obligation to ensure that sufficient flows within the South Saskatchewan River are passed through to our downstream neighbours in Saskatchewan, under the 1969 Master Agreement on Apportionment (MAA) (Prairie Provinces Water Board, 1969). The primary purpose of this agreement was to allow the sharing of water in eastward flowing streams that cross interprovincial boundaries. Under this agreement, one-half the natural flow within the South Saskatchewan River must be permitted to flow into Saskatchewan.

Because of these pressures and requirements, and in response to increasing water allocations, the Oldman, Bow and South Saskatchewan Sub-basins were closed to any surface water withdrawals in 2006. Under this closure, no new surface water allocations are permitted within the basin, as one mechanism to prevent future shortages. As a part of the closure, the Province established Water Conservation Objectives (WCO) for the basin, requiring that diversions be reduced or halted whenever flows fall below the WCO. The WCO was established at 45% of naturalized flows or 10% greater than current instream objective, whichever is greater (Alberta Environment, 2007). Junior water licenses issued since the establishment are subject to temporary suspension of diversions when flows in the river fall below the WCO value.

3.3.1 Allocations, Use, and Water Conservation Objectives

Within the SSRB (excluding the Red Deer River), the current annual surface water allocation is 5,067,500 dam^3. The overwhelming majority of this water is allocated to the irrigation sector with 79 % of allocations (Table 5). The next highest allocation is to the municipal sector, receiving 14 % of allocations. Livestock watering, commercial and industrial use, petroleum, and other sectors receive 7 % of the total allocation. Allocations are relatively evenly split between the Bow and Oldman River Basins, with a relatively minor allocation from the South Saskatchewan mainstem downstream of the Bow and Oldman confluence.

As a percentage of allocation, water use by the livestock, industrial, and petroleum sectors is highest, with 89 to 111 % of allocated water used annually, though these sectors represent a minor fraction of total allocations. In contrast, the irrigation and municipal sectors, which combined represent more than 90 % of total allocations, use just 40 % and 8 % of their respective allocations (excluding return flows). Across all sectors, actual use of water is substantially below allocation, with 1,813,500 dam^3 used annually, or approximately 36 % of total allocations from the basin (Table 6).

The average annualized natural flow within the SSRB, against which requirements under the MAA and WCOs are determined, was calculated to be 7,002,000 dam^3/year on the South Saskatchewan River at Medicine Hat (AMEC Earth & Environmental, 2009). Based on this figure, the water available for use within the basin is approximately 3,501,000 dam^3/year for requirements under MAA, and

3,851,100 dam^3/year for requirements under the WCO averaged across the entire year, although comparisons of diversions to naturalized flow for the purposes of the WCO should be conducted on an instantaneous basis. Based on the more conservative pass-through requirement, allocations within the SSRB are equivalent to 145 % of currently available allocatable water, while actual use is equivalent to 52 % of allocatable water.

Table 5. Surface water allocations (dam^3/year) by sector (AMEC Earth & Environmental, 2009).

Sector	Bow River	Oldman River	South Saskatchewan River	Total Allocation	Sector Allocation %
Municipal	486,647	66,939	164,940	718,526	14%
Irrigation	1,997,814	1,963,544	63,227	4,024,585	79%
Livestock	0	22,313	13,745	36,058	1%
Commercial	25,613	22,313	2,749	50,675	1%
Petroleum	0	0	5,498	5,498	0%
Industrial	25,613	0	16,494	42,107	1%
Other	25,613	156,191	8,247	190,051	4%
Total (dam^3)	2,561,300	2,231,300	274,900	5,067,500	100%

Table 6. Surface water use (dam^3/year) by sector (AMEC Earth & Environmental, 2009).

Sector	Bow	Oldman	South Saskatchewan	Total Use	Sector Use %	Sector Use as % of Allocation
Municipal	43,700	8,800	3,500	56,000	3%	8%
Irrigation	748,200	826,200	42,600	1,617,000	89%	40%
Livestock	8,000	16,000	8,000	32,000	2%	89%
Commercial	7,300	5,000	700	13,000	1%	26%
Petroleum	1,200	800	4,100	6,100	0%	111%
Industrial	20,100	0	17,200	37,300	2%	89%
Other	8,500	43,600	0	52,100	3%	27%
Total	837,000	900,400	76,100	1,813,500	100%	36%

3.3.2 Historical Flows

As the focus of this study is on potential impacts to the drinking water source for Medicine Hat and Redcliff, flows in the South Saskatchewan River at Medicine Hat were analyzed in the context of water allocations, use, and water conservation objectives. Flows are available for this gauging station from 1911 to 2020 and show a high degree (nearly an order of magnitude) of inter-annual variability over the historical record (Figure 27). There is also evidence of a declining trend in average annual discharge, and an increase in the frequency with which actual discharge falls below naturalized discharge, at least in part to due to increased diversions.

Over the last ten years for which data were available, flows have frequently fallen below the estimated WCO value (calculated as 45 % of the average value for that day of the year), with failure to meet the WCO occurring during some period in 8 out of ten years (Figure 28). These failures appear to have occurred more frequently and for more extended periods of time since 2013; it is expected that altered hydrological management strategies in response to the 2013 flood event are at least partially the cause of this pattern. Flows generally meet WCOs during the low-flow months, with the majority of failures occurring during the summer in the times of highest flows.

Overall, pressures on water supply are expected to grow over time, both due to increased sector use and potentially due to impacts from climate change (see section 3.5 below). The basin is closed but already over-allocated based on available naturalized flow volumes, and there have been increasingly frequent failures to meet WCOs over the past decade. On an annualized basis the total volume of water remaining in the river is meeting requirements under the MAA, but increasing pressure may lead to requirements for closures in the future to allow sufficient pass-through of flows. Under these pressures, it is expected that there will be increasing deficits to junior water license holders, resulting in increasing frequency of diversion suspensions to maintain available water both for in-stream requirements under WCOs and the MAA, and for senior license holders.

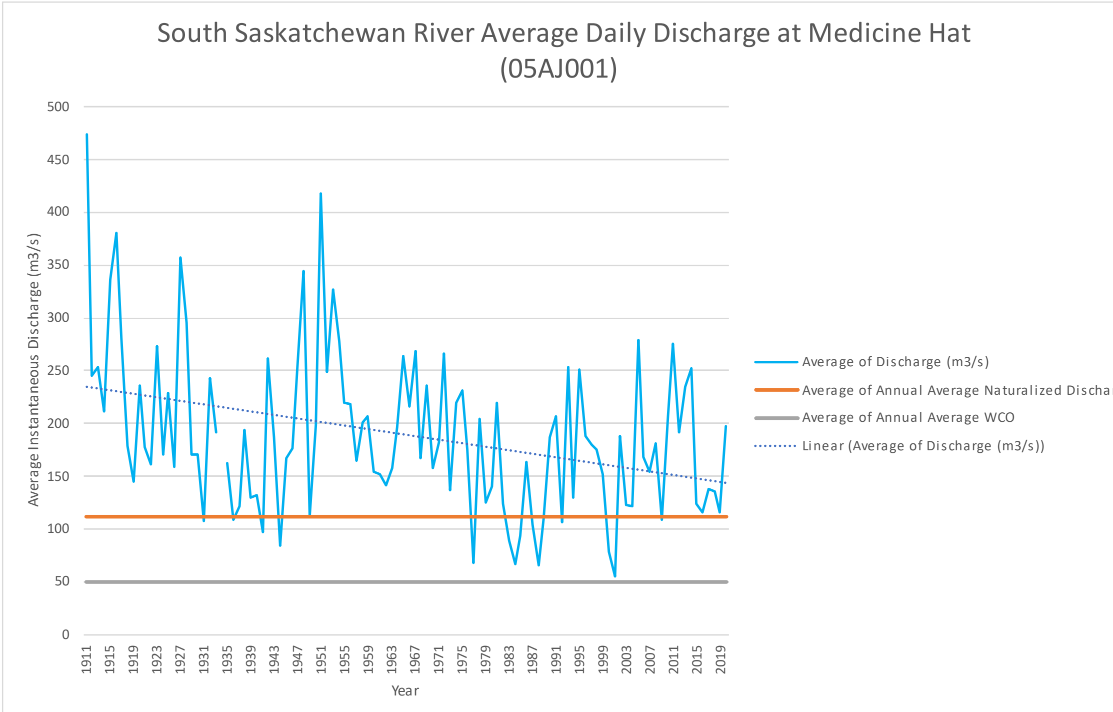

Figure 27. Annual average instantaneous discharge in the South Saskatchewan River at Medicine Hat (05AJ001).

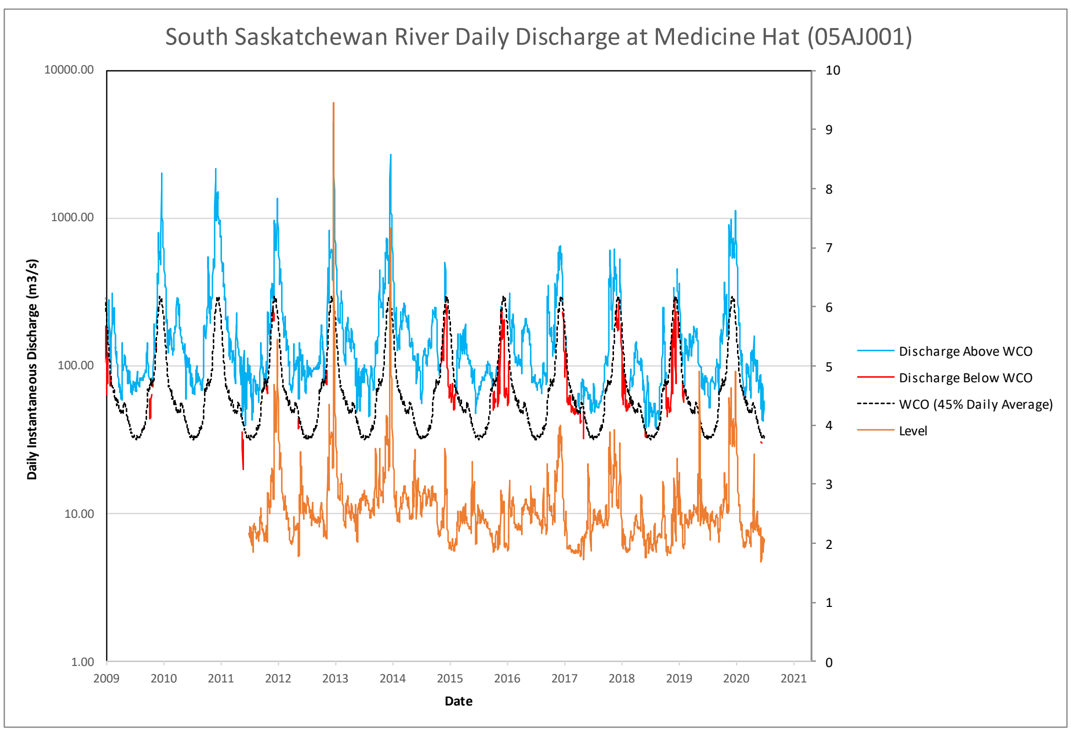

Figure 28. Instantaneous discharge in the South Saskatchewan River at Medicine Hat (05AJ001), in comparison to approximate WCO values calculated on a daily basis (as 45% of the daily average flow). Blue values indicate flows exceeding the WCO value, while red values indicate flows falling below the WCO value.

3.3.3 Water Infrastructure

Water infrastructure includes dams and water control structures, canals, reservoirs, water wells, and wastewater treatment facilities. This type of infrastructure relates to both the quantity and quality of water available on the landscape, through interactions between withdrawals, return flows, and the interaction of water supplies with activities on the landscape. There is considerable water infrastructure in the thirteen Irrigation Districts in southern Alberta. Water has been moved around to allow for settlement and agricultural expansion since the 1880s.

Water well densities are highest in the area to the south of Calgary, with densities of up to 10 wells/km^2 in some subwatersheds (Figure 29). Water wells are a potential threat to water quantity within the study area due to withdrawals and depletion of groundwater at various depths. This could result in reduced groundwater contributions to surface flows, an important contributor to the maintenance of base flows, especially in times of low precipitation.

The high density of water control structures on the landscape includes major reservoirs, but also represent smaller scale weirs, dikes, and dams. The larger reservoirs increase water storage and can assist in the maintenance of flows to improve compliance with WCO and MAA requirements through coordinated operation. The Bow River alone has seven dams and weirs on its main stem and ten other dams on its tributaries. Smaller control structures also increase landscape storage of surface water and can contribute to sustained flows throughout the year; this may help to ameliorate some of the impacts expected due to wetland loss from the landscape (see section 2.5 above). However, they may result in reductions of flows from natural values, potentially exacerbating deficits based on WCOs and the MAA. They are also generally privately owned, resulting in a lack of ability to coordinate management of storage and flows, and potential issues with maintenance from both a water quality and water quantity perspective.

The impact of canals on the landscape is broader, as they support irrigation and consequently large diversion volumes (see section 3.3.1 above). The impacts and potential risks that they have on the landscape are not generally due to the infrastructure per se, but rather due to the wide areas of application of irrigation waters (presently at approximately 6880 km^2 within southern Alberta as a whole) and the contribution to land use change (see section 3.1 above). Current plans for expansion and modernization of the irrigation system are expected to increase the irrigated lands within southern Alberta by approximately 12 %, with nearly all of the expansion occurring within the study area (Government of Alberta, 2021).

Wastewater treatment facilities are distributed widely across the study area, associated with human population centres (Government of Alberta, 2010). Their potential impacts are largely related to water quality (see section 3.4 below), due to the release of treated wastewater that may contain elevated nutrients, metals, hormones, pharmaceuticals, parasites, and other pollutants. They present a threat for drinking water supplies as population growth and aging infrastructure both result in increased release volumes. The potential risk may be reduced over time as older, less efficient treatment facilities are decommissioned and smaller population centres move to centralized regional treatment facilities with increased treatment efficacy.

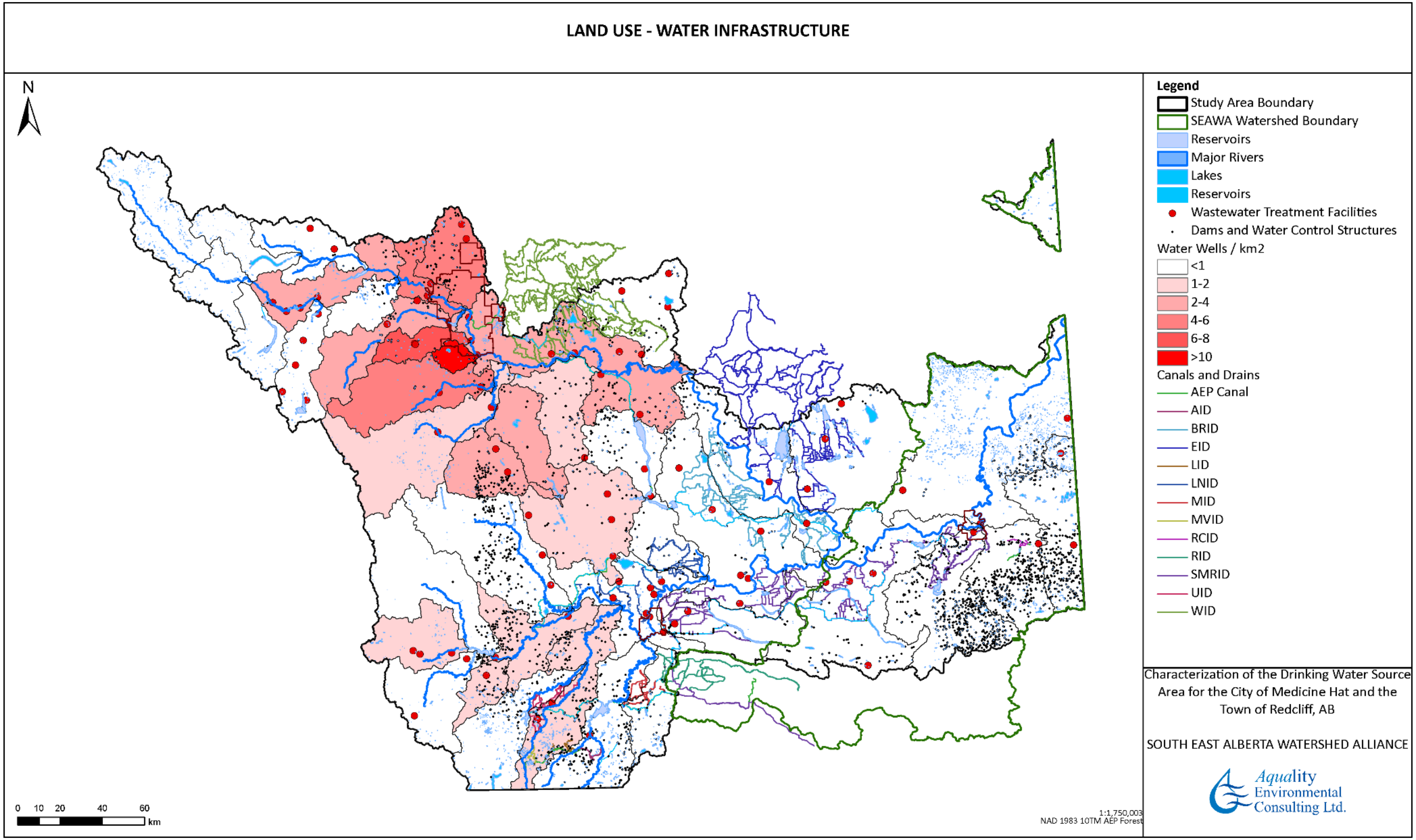

Figure 29. Water infrastructure within the study area.

3.4 Water Quality

Water quality is critical in the protection of drinking water sources. Treatment options are available for the removal of a wide range of potential pollutants, but drinking water processing generally requires relatively pristine sources in order for treatment to be technically effective and economically feasible.

Water quality data from the past 5 years available from the Province of Alberta (Government of Alberta, 2023) was analyzed for suites of indicator parameters. These parameters were selected primarily on the basis of known or suspected threats to water quality based on the findings outlined in the preceding sections, as well as for their importance in treating drinking water. Samples were analyzed for sites from the Long-Term River Network sites (LTRN, primarily on the mainstems of larger rivers) as well as the Tributary Monitoring Network sites (TMN, primarily on smaller tributaries).

3.4.1 Nutrients

The two indicators selected for examination for nutrients were total nitrogen (TN) and total phosphorus (TP). Nutrients are an important class of pollutants as they form the basis for the growth of primary producers such as aquatic plants, algae, and cyanobacteria. Increasing levels of nutrients can lead to eutrophication, resulting in elevated algae growth. In some systems, depending upon the relative concentrations of nitrogen and phosphorus, increased nutrient levels can result in cyanobacterial blooms.

Nitrogen concentrations were generally highest along the Bow River mainstem, for the majority of sample locations downstream from the City of Calgary (Figure 30). Within the tributaries to the Bow River and within the entire Oldman River system, concentrations were lower. Phosphorus concentrations displayed a different pattern from nitrogen, with elevated concentrations seen at some of the sites downstream from the City of Calgary, but throughout the much of the Oldman River system as well (Figure 31).

The difference observed in the spatial patterns followed by these two nutrients likely reflects differences in both their sources and in the manner in which they cycle and are managed within the environment. It is likely that some of the elevated nitrogen concentrations observed downstream from Calgary are the result of wastewater discharge, as nitrogen-containing compounds in wastewater are generally highly soluble and complicated to treat and remove from discharges. Nitrogen-containing compounds in fertilizers are similarly highly soluble, so runoff or return flow from agricultural applications is expected to contribute as well; the pattern of high nitrogen concentrations also matches the areas where fertilizer usage is highest (Figure 21).

Phosphorus, while present in wastewater, is less soluble and is more easily removed from wastewater streams through relatively straightforward treatments such as flocculation. Phosphorus is also a naturally occurring element in many geological formations, and through weathering and erosion can be mobilized into aquatic systems either bound to or forming a constituent of soil particles. This more broadly distributed source of phosphorus explains the wider occurrence of high phosphorus concentrations across the two major tributaries to the South Saskatchewan River.

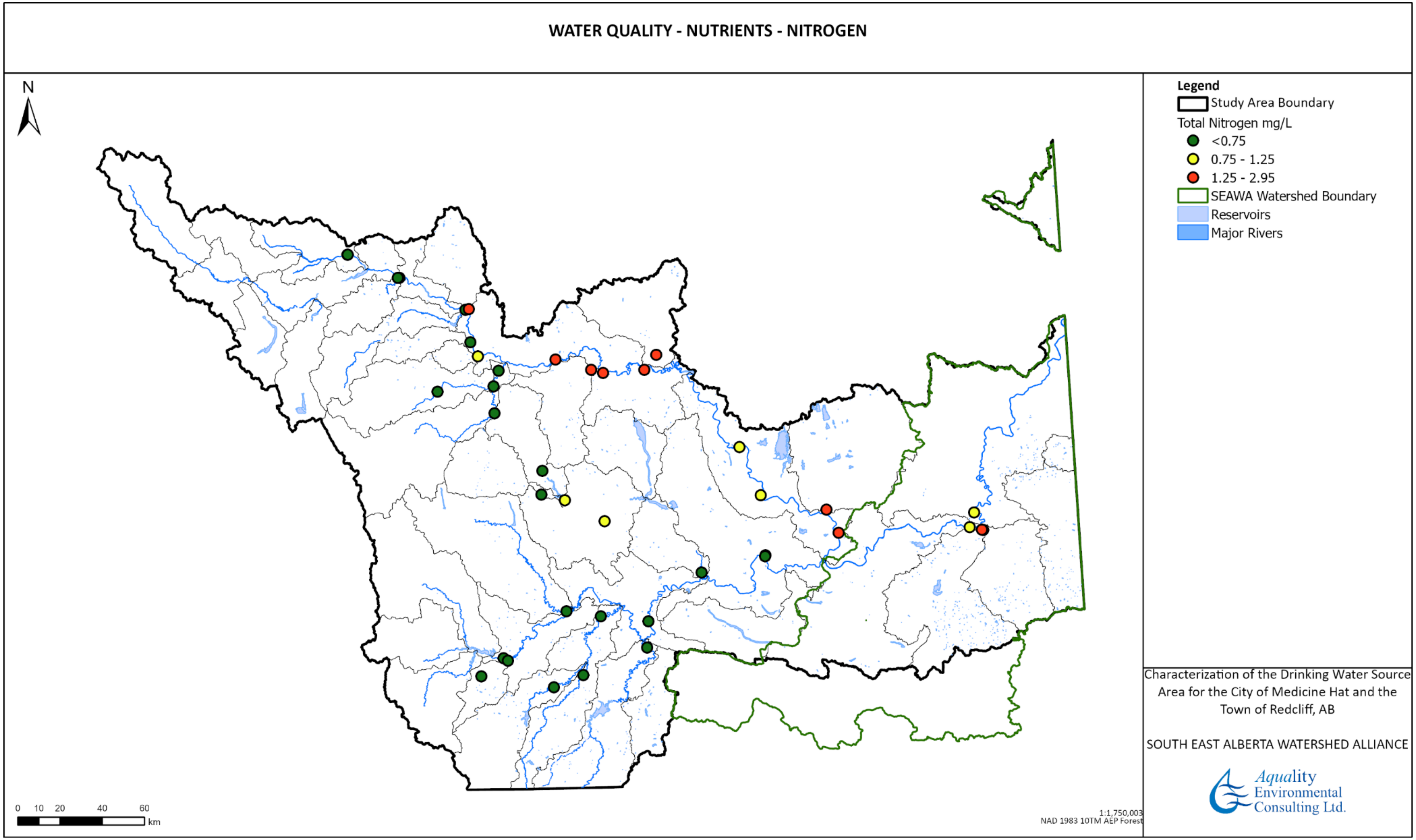

Figure 30. Average total nitrogen concentrations over the period from 2018-2022.

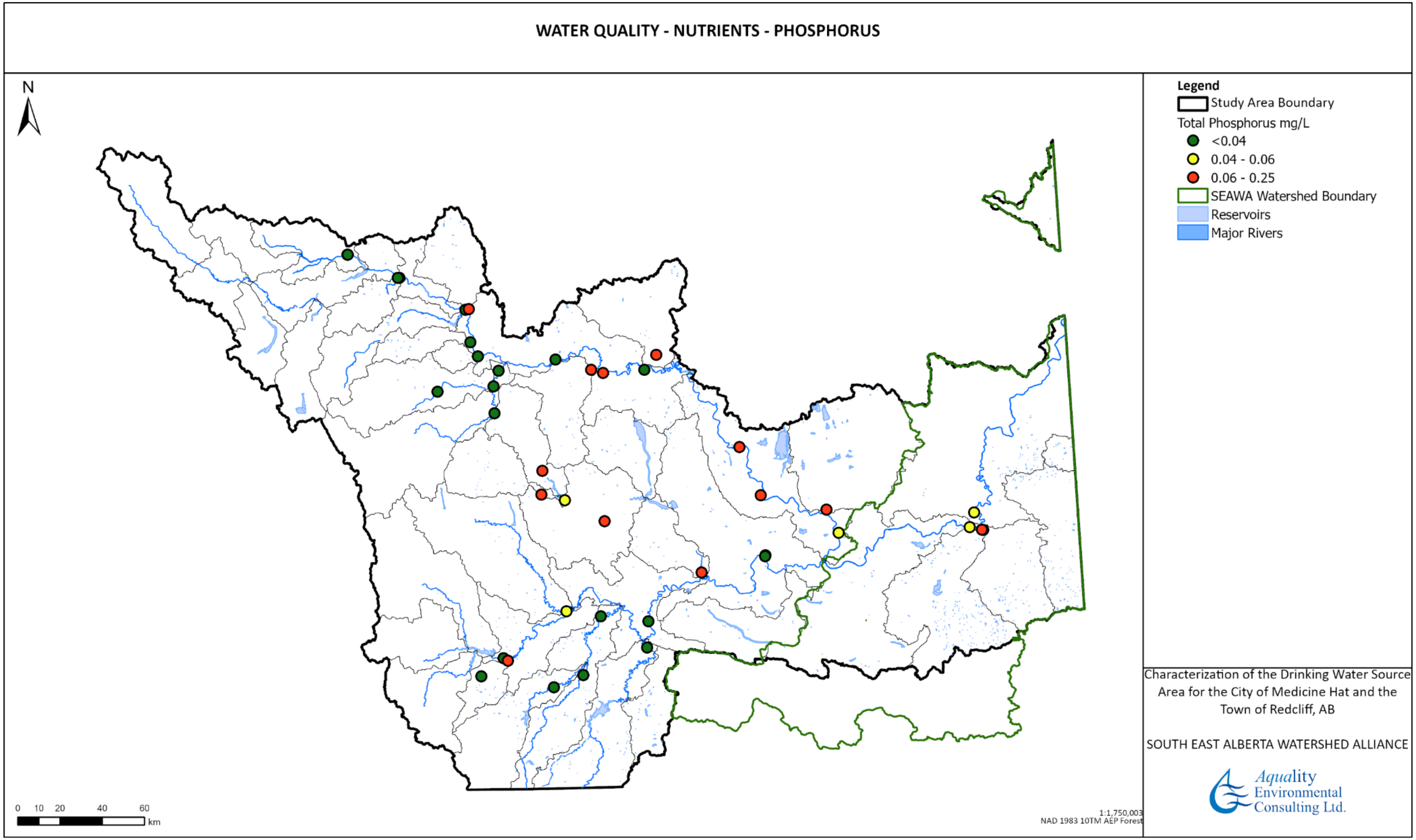

Figure 31. Average total phosphorus concentrations over the period from 2018-2022.

3.4.2 Bacteria

Bacteria are ubiquitous in the natural environment and have commonly been used as an indicator of water quality. Total coliforms, which was formerly used commonly as a metric of water quality, are not necessarily harmful, but are often indicative of contaminated or stagnant waters. *E. coli* have a much greater likelihood of adverse health effects on humans or animals, and their presence in high concentrations in water bodies often indicates contamination from sewage systems or agricultural runoff. Therefore *E. coli* was the only bacteriological parameter analyzed.

E. coli concentrations follow a broadly similar spatial pattern to Total Nitrogen, with the majority of high concentrations found on the Bow River downstream of the City of Calgary (Figure 32). However, concentrations are not consistently high, indicating that there are likely contributions from other sources along the mainstem, including agricultural lands and smaller wastewater treatment facilities.

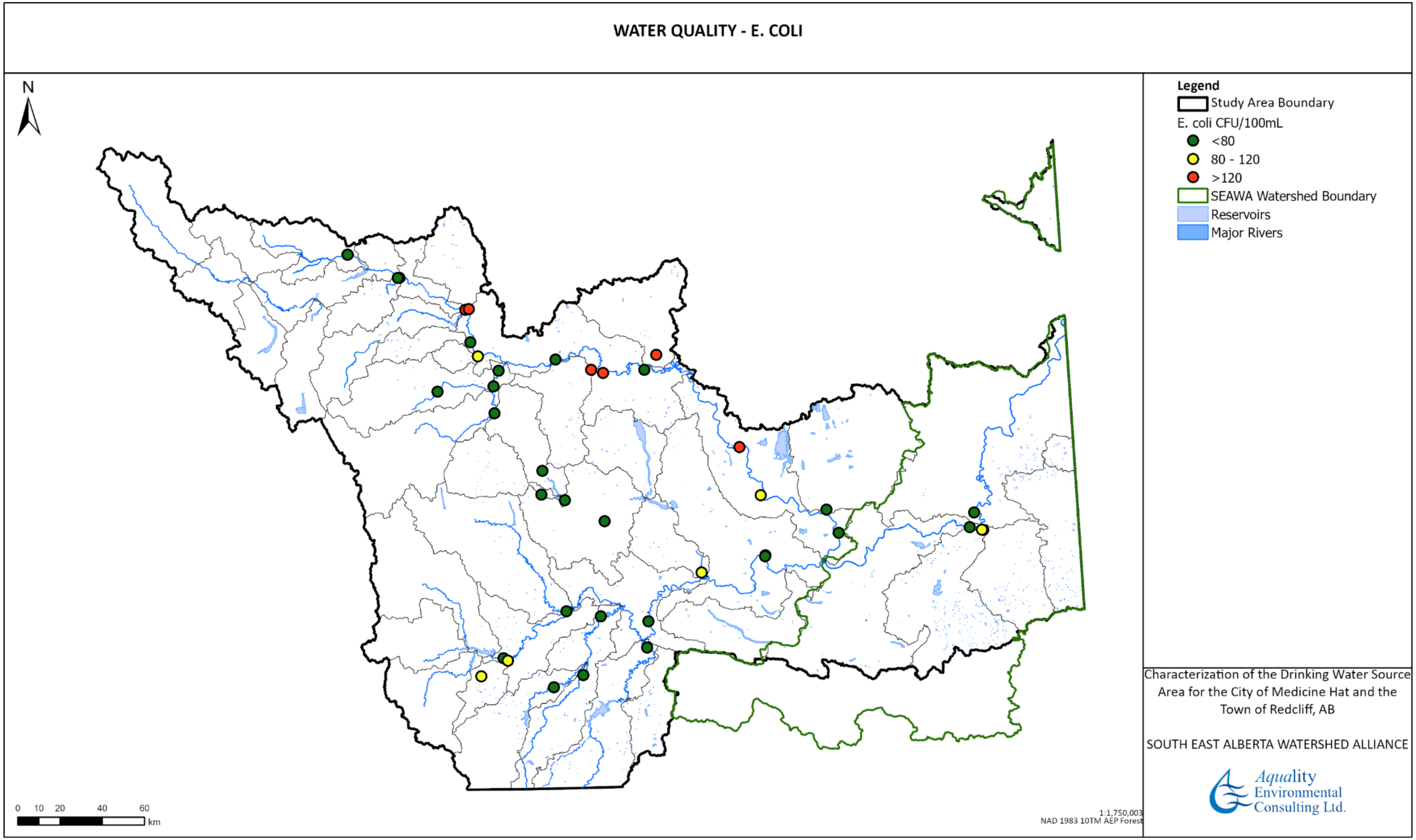

Figure 32. Average *E. coli* concentrations over the period from 2018-2022.

3.4.3 Metals

Metals are considered to be pollutants when they pose a threat to aquatic life, human health, or the environment. Metals can be a significant source of pollutants in surface waters when they are present in concentrations higher than natural levels, though in some circumstances naturally occurring concentrations can be harmful as well. Common sources of metal pollutants include industrial processes (such as mining and manufacturing) and stormwater runoff from anthropogenically altered landscapes. Additionally, erosion and sedimentation can result in increased metals pollution, as metals frequently bind to or are components of soil particles. Removal from drinking water sources can be technically complex and prohibitively expensive.

A select group of metals of known concern within the basin were analyzed for concentrations within the study area, including aluminum, cadmium, iron, lead, mercury, selenium, and zinc. These were selected based on the potential toxicity, the occurrence of frequent elevated values in other studies, varied anthropogenic and environmental sources, and parameters of concern from known or proposed activities within the watershed. Where possible, concentrations were compared to guideline values from the Environmental Quality Guidelines for Alberta Surface Waters (Government of Alberta, 2018).

Aluminum concentrations were high throughout the vast majority of the study area, especially in the Oldman Basin (Figure 33). Aluminum is naturally present in soils, and is expected to occur at higher concentrations when erosion and sedimentation carry soil particles into aquatic systems. The high concentrations found may not be indicative of a potential problem with aluminum toxicity, however, as the form measured (total recoverable) only poses a threat when dissolved, and is otherwise not in a bioavailable form. The dissolution and toxicity of aluminum are pH-dependent, so guideline values have a decreasing relationship with pH for values below 6.5; the vast majority of samples (>99.9 % of samples) have pH values greater than 6.5, indicating limited concerns with aluminum toxicity in these systems.

Cadmium concentrations were generally moderate throughout study area but were more frequently elevated in Oldman Basin (Figure 34). Concentrations throughout much of the study area were comparable to or in exceedance of the minimum guideline value (0.04 ug/L); however, the guideline increases with water hardness, and no station averages exceeded the guideline calculated based on the average hardness of all samples (0.33 ug/L based on an average hardness of 242 mg/L). Cadmium is common in industrial discharge and runoff from mining and smelting operations, but can also occur naturally through soil erosion and rock weathering.

Iron was variable across the study area, but was consistently elevated in lower reaches of the Bow and Oldman and within the South Saskatchewan mainstem (Figure 35). As with aluminum, iron is naturally present in soils, and is expected to occur at higher concentrations when erosion and sedimentation carry soil particles into aquatic systems. It is similarly only considered a concern from a toxicity perspective when dissolved.

Lead was generally low, but increased slightly downstream towards the lower Bow and in the South Saskatchewan mainstem (Figure 36). The vast majority of station averages were below the minimum guideline value (1 ug/L); however, as with cadmium, the guideline increases with water hardness, and no station averages exceeded the guideline calculated based on the average hardness of all samples (7 ug/L based on an average hardness of 242 mg/L).

Mercury, selenium, and zinc generally followed a similar spatial trend, with variable concentrations across the study area but were highest in the Bow River downstream of Calgary and in the South Saskatchewan mainstem (Figure 37, Figure 38, and Figure 39). Mercury concentrations overall were low, with all averages at each monitoring station falling below the guideline value (5 ng/L). Selenium concentrations were higher relative to guidelines, with some station averages exceeding the guideline value of 2 ug/L, and several more exceeding the "Alert Concentration" of 1 ug/L, indicating a need for additional monitoring to detect potential bioaccumulation and allow proactive management (Government of Alberta, 2018). Zinc concentrations overall were low, with all averages at each monitoring station falling below the guideline value (30 ug/L).

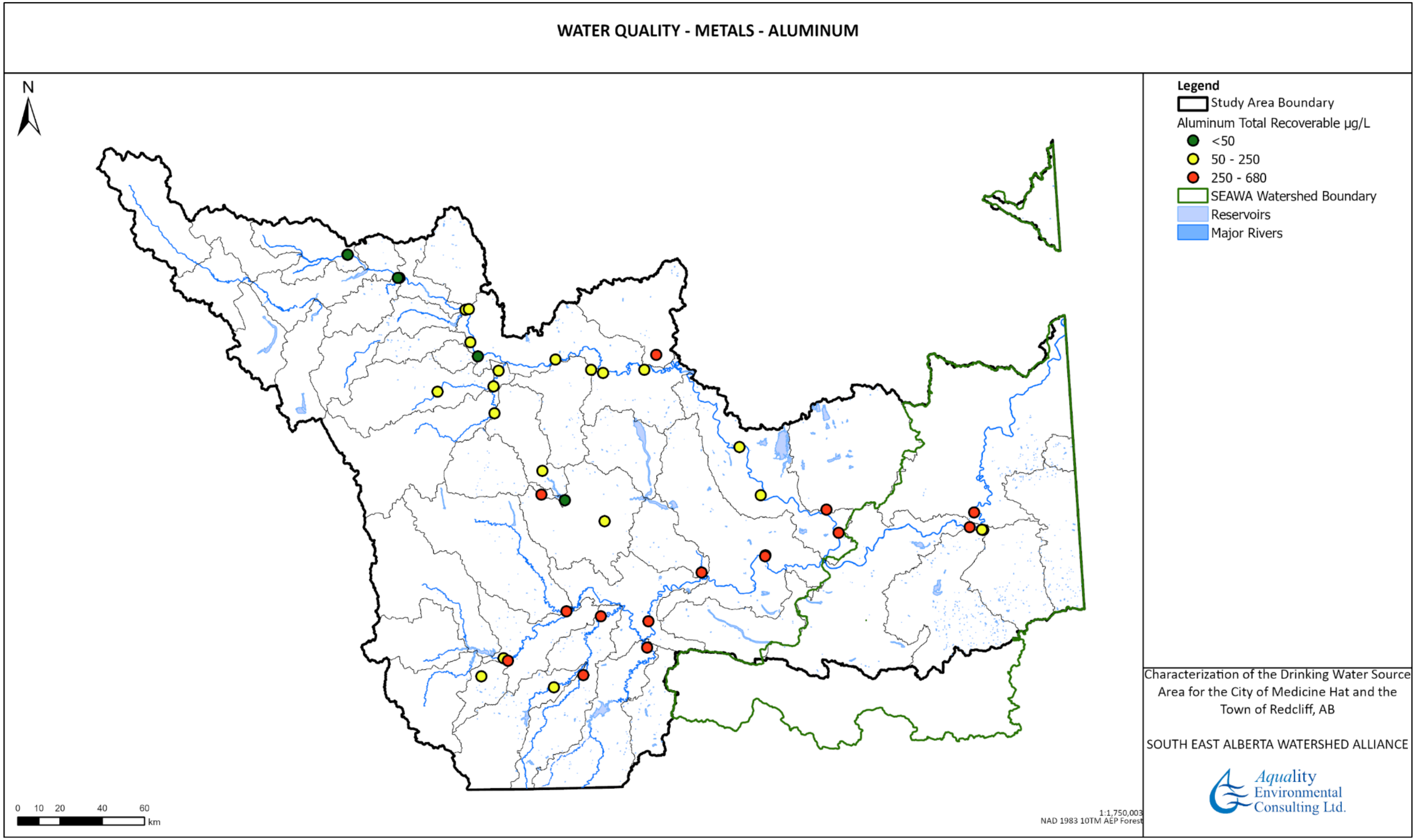

Figure 33. Average aluminum concentrations over the period from 2018-2022.

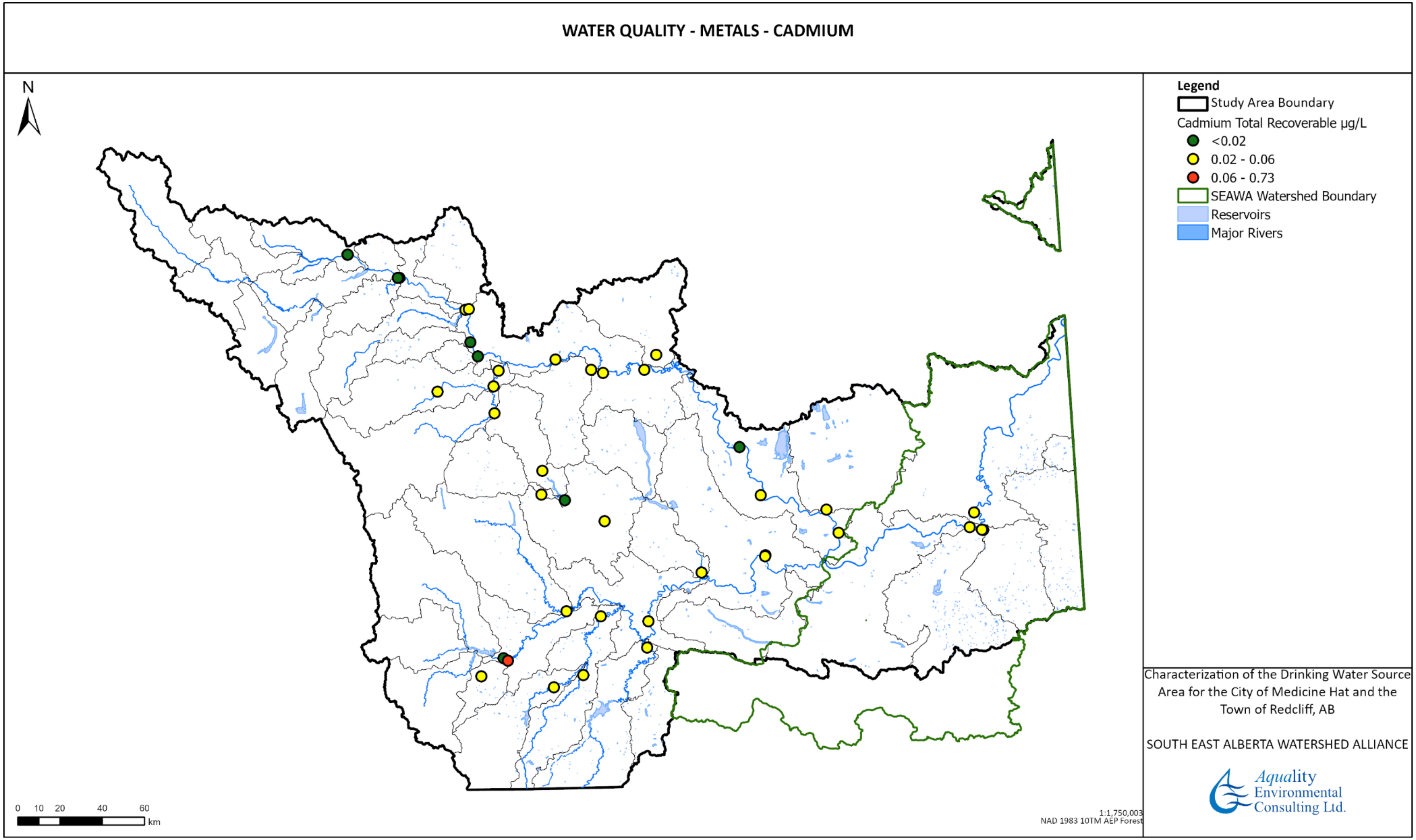

Figure 34. Average cadmium concentrations over the period from 2018-2022.

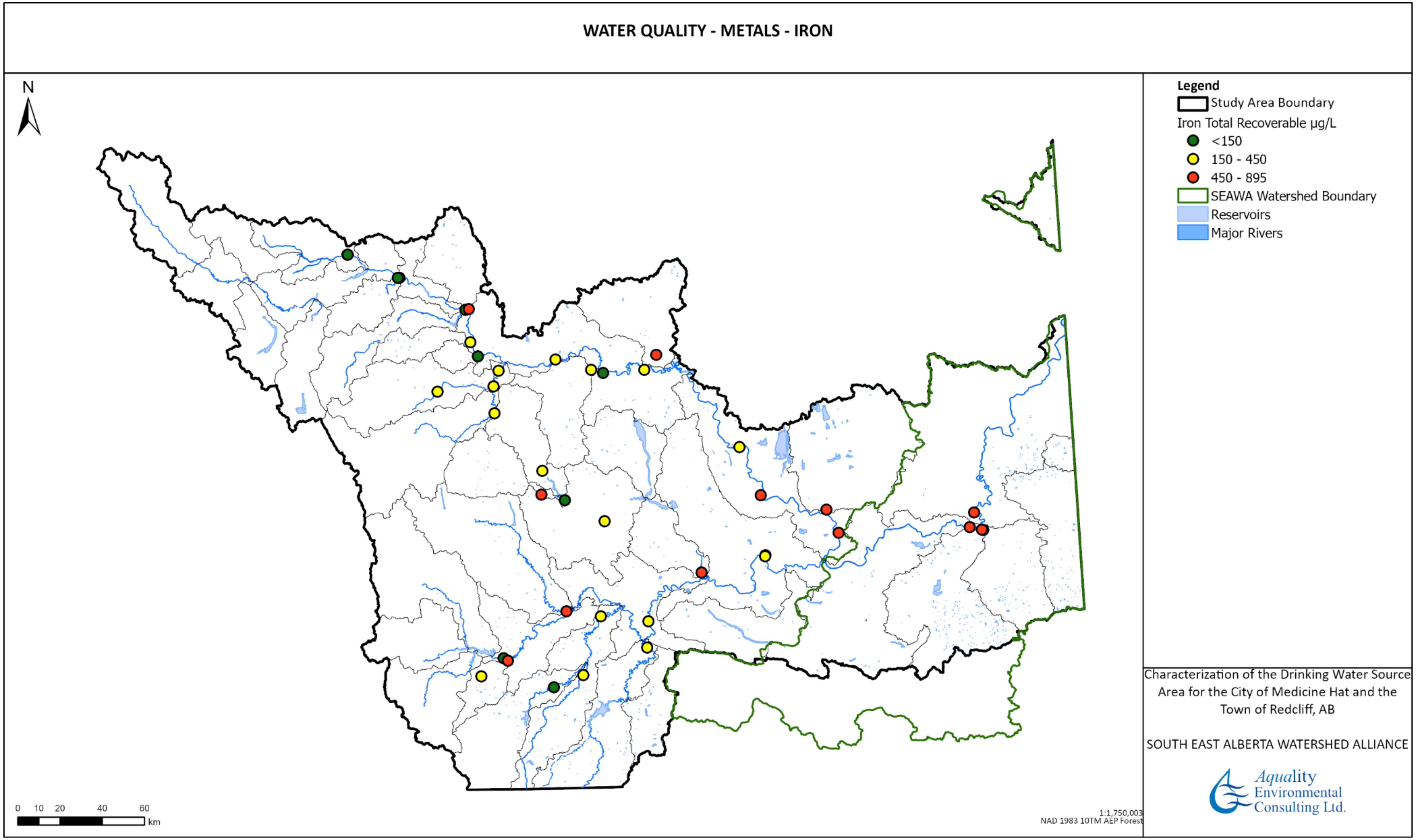

Figure 35. Average iron concentrations over the period from 2018-2022.

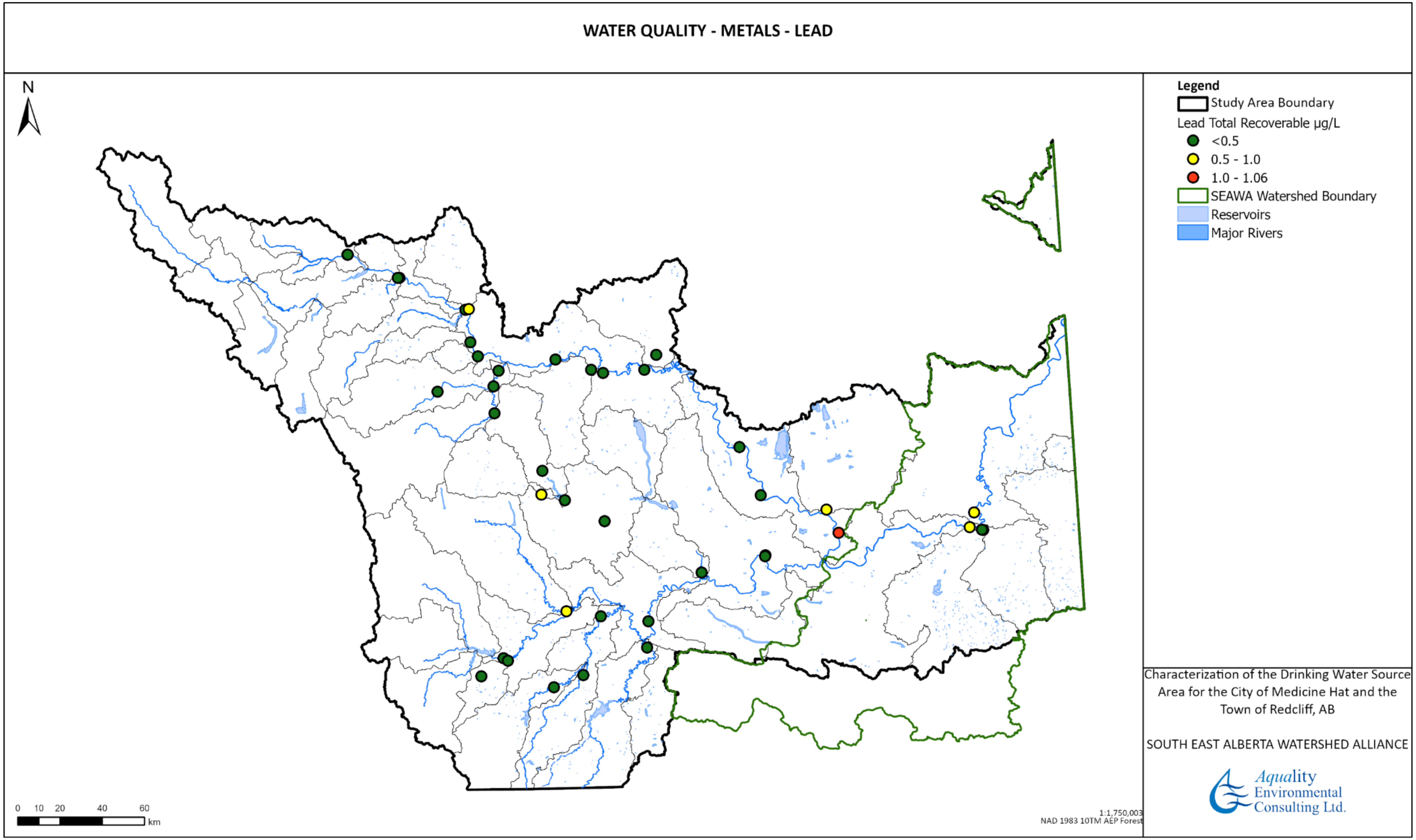

Figure 36. Average lead concentrations over the period from 2018-2022.

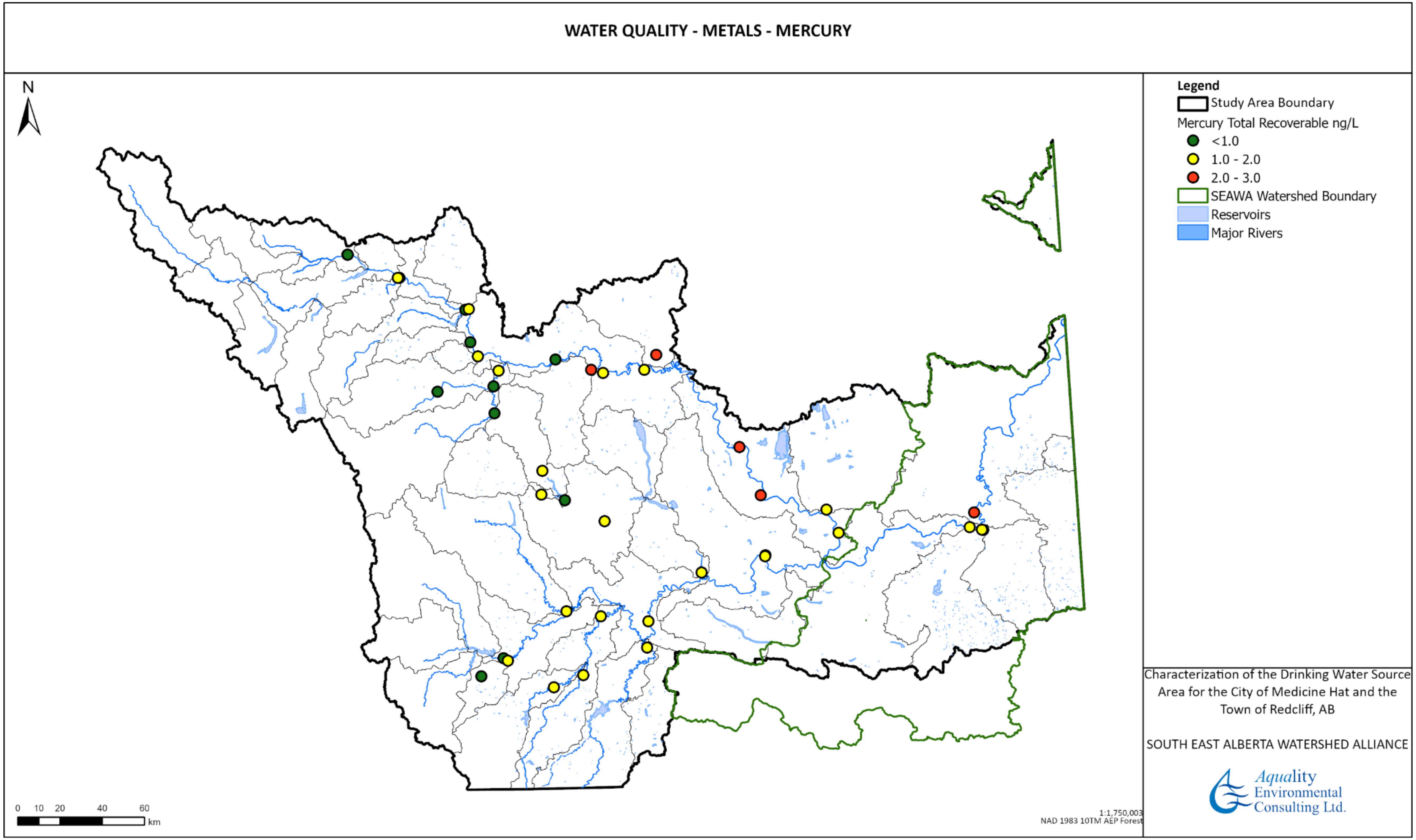

Figure 37. Average mercury concentrations over the period from 2018-2022.

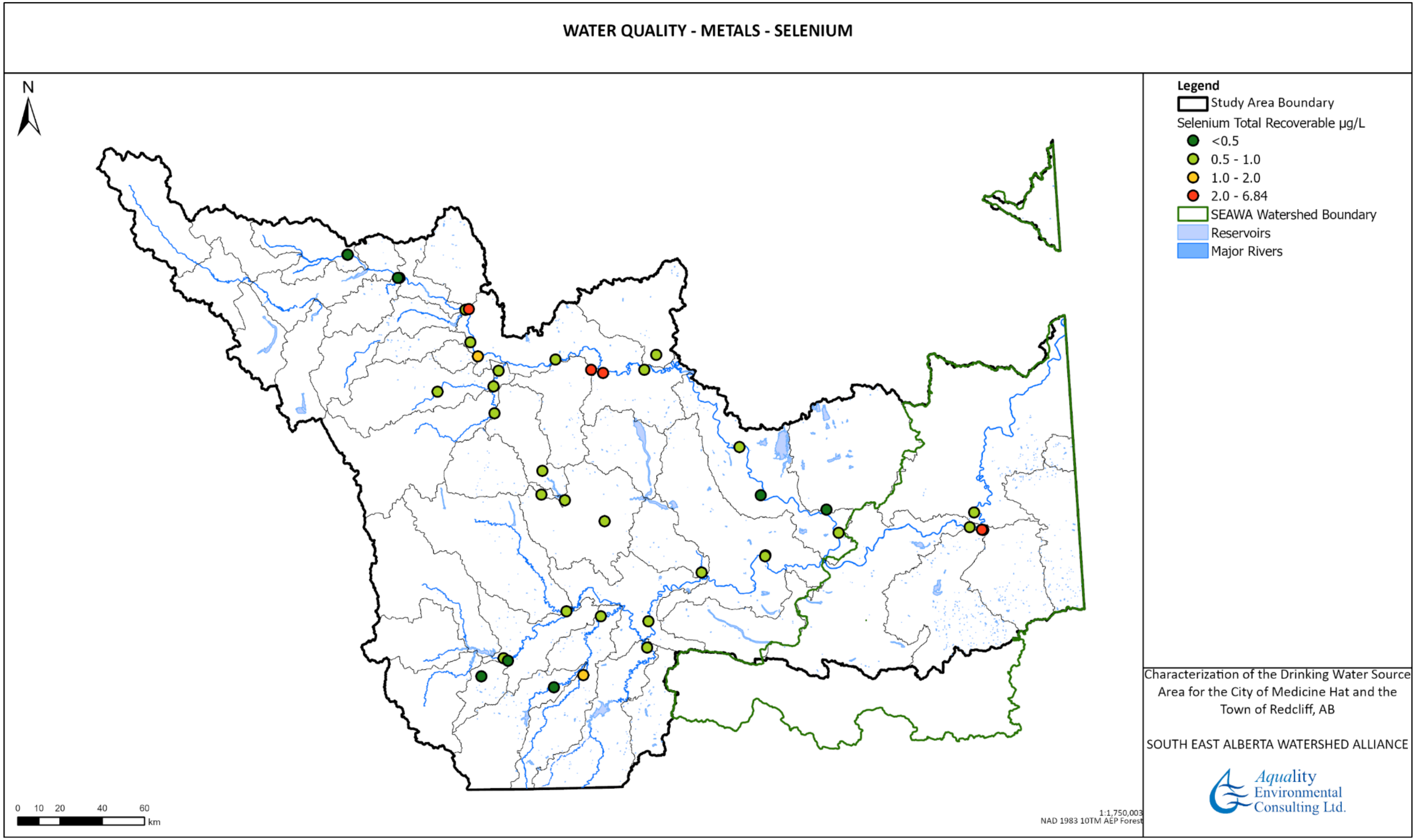

Figure 38. Average selenium concentrations over the period from 2018-2022.

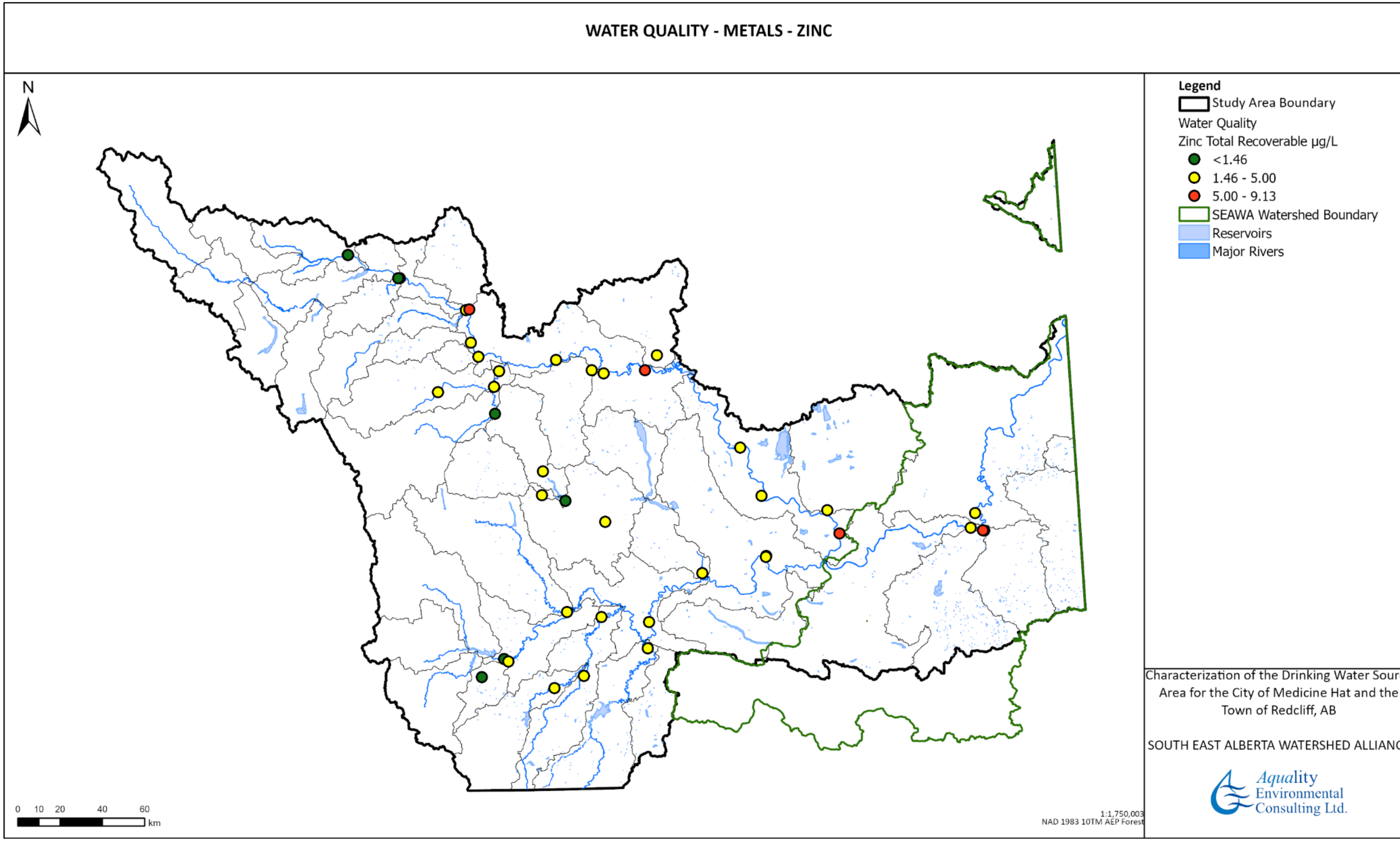

Figure 39. Average zinc concentrations over the period from 2018-2022.

3.4.4 Pesticides

Pesticide use in Alberta is widespread and they are frequently encountered in surface waters, due to the high intensity of agricultural activities. Pesticides are frequently of concern in water quality monitoring studies because of the high density of water bodies in the province, their method of application, and the ease with which they may enter surface water bodies. They also have effects on biological systems at low concentrations and their removal from water during drinking water treatment is both technically difficult and costly. There are also very few guidelines for safe concentrations within aquatic systems, in part because of the large number of different pesticides in use.

Rather than an analysis of each individual pesticide, the entire suite of pesticides was analyzed as a whole, to determine whether or not they were detected in each sample. The metric used was the number of pesticide detections per pesticide analyzed within each sample, in order to remove some bias due to variable numbers of pesticides analyzed at each period. Pesticides have only been regularly sampled at the LTRN sites.

Rates of detection were lowest in the upper reaches of the Bow and Oldman Rivers, and uniformly higher throughout the downstream reaches (Figure 40). The highest rates of detection identified were found on the South Saskatchewan River at Medicine Hat, where an average of approximately 3.8 pesticides were detected at each sampling event. The distribution of high detection rates corresponds closely to the areas found to have the highest proportion of agricultural lands with insecticide, fungicide, and herbicide use (see Figure 19, Figure 20, and Figure 22 in section 3.1 above).

Of the 31 detected pesticides, 19 were herbicides (including precursors and breakdown products, and one compound with dual herbicidal-fungicidal bioactivity), 8 were fungicides, and 5 were insecticides (Table 7). The most commonly detected pesticide was 2,4-D, which was detected in approximately 60 % of samples tested. It is a systemic broadleaf-specific herbicide commonly used in cereal crops and as a pre-seeding herbicide for broadleaf weeds. 2,4-D breaks down in soils within 2 weeks, but in aquatic sediments has a half-life of 186 days (Jervais, Luukinen, Buhl, & Stone, 2008). Six other pesticides had detection rates over 10 %, of which all but one (Benomyl, a fungicide) were herbicides.

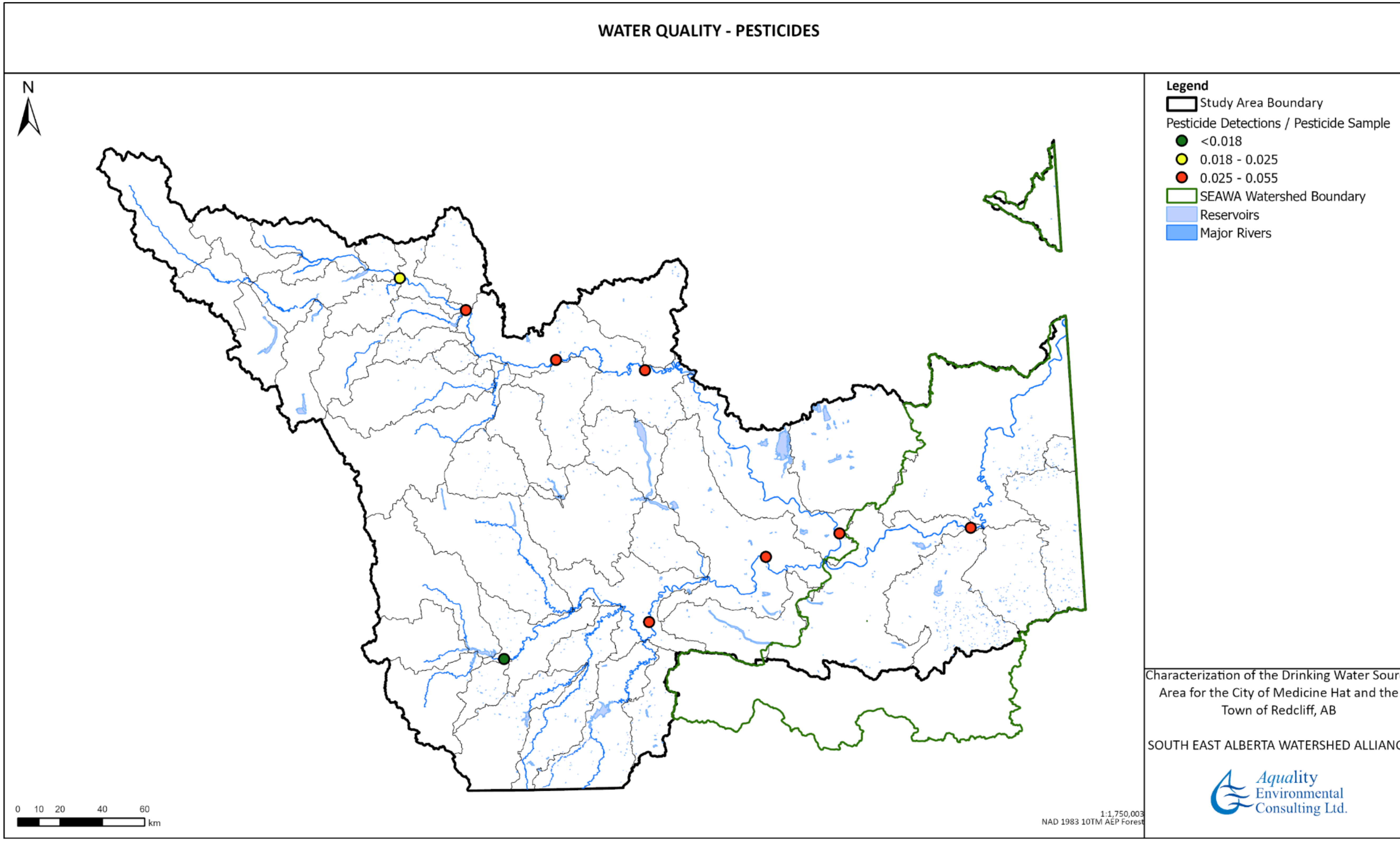

Figure 40. Average pesticide detection rates for all samples collected from 2018 to 2022. Values are the number of positive detections per pesticide analyzed.

Table 7. Pesticides detected in samples analyzed from 2018 to 2022 from all LTRN sites in the study area.

Pesticide	Pesticide Class	Number of Detections	Number of Samples	Detection Rate
2,4-D (Dichlorophenoxyacetic acid)	H	1008	1762	57.2%
MCPP (Mecoprop)	H	493	1573	31.3%
MCPA	H	438	1746	25.1%
Benomyl	F	30	134	22.4%
Dicamba (Banvel)	H	308	1637	18.8%
Glyphosate (Roundup)	H	17	141	12.1%
Fluroxypyr	H	101	981	10.3%
Propiconazole	F	8	98	8.2%
Bromoxynil	H	101	1610	6.3%
Temephos	I	1	16	6.3%
Pyridaben	I	6	98	6.1%
Permethrin	I	6	98	6.1%
Azoxystrobin	F	8	134	6.0%
2,4-Dichlorophenol	H*	48	1134	4.2%
Carbamate (EPTC)	H	4	98	4.1%
Picloram (Tordon)	H	60	1640	3.7%
Atrazine	H	55	1640	3.4%
Clopyralid (Lontrel)	H	51	1555	3.3%
Triallate (Avadex BW)	H	41	1457	2.8%
Dichlorprop(2,4-DP)	H	47	1736	2.7%
Tebuconazole	F	3	134	2.2%
Difenoconazole	F	3	134	2.2%
Diazinon	I	37	1732	2.1%
Aminomethyl phosphonic acid	H**	3	141	2.1%
Quinclorac	H	2	98	2.0%
Deltamethrin	I	2	98	2.0%
Triclopyr	H/F	19	1140	1.7%
Triticonazole	F	2	134	1.5%
Imazamethabenz-methyl	H	20	1477	1.4%
Napropamide	H	1	98	1.0%
Iprodione	F	10	981	1.0%

* - precursor
** - breakdown product

3.4.5 Wastewater and Stormwater Pollutants

There are a range of current and emerging pollutants of concern that are present in wastewater and stormwater, but which are not regularly sampled as part of the LTRN and TMN programs. The majority of these are anthropogenic in nature, and include pharmaceuticals and personal care products (PPCP), microplastics, and the emerging class of so-called "forever chemicals" perfluoroalkyl and polyfluoroalkyl substances (PFAS). These generally enter aquatic ecosystems through treated wastewater, as most current systems do not specifically treat for their removal (Wang & Wang, 2016; Sol, et. al., 2021; Thompson, et al., 2022). Hydrocarbons are generally more of a concern in stormwater than in wastewater, but consistently-collected data are similarly unavailable.

PPCPs encompass a wide range of chemical compounds, and may have similarly wide impacts on human health; the majority of research into human health impacts has focused on endocrine-disrupting effects of hormone or hormone-analogues, and the potential impacts of antibiotics such as the development of antibiotic resistant bacterial strains (Yang, Toor, & Reisinger, 2021). Preliminary evidence suggest that microplastics may have impacts on human health through the inducement of inflammatory responses, as well as toxicity at sufficiently high concentration (XiaoZhi, 2021). PFAS compounds have a wide range of effects which include impacts to reproductive systems, thyroid function, immune response, and liver function (Agency for Toxic Substances and Disease Registry, 2021). These three groups of compounds are not generally analyzed in surface waters, but pose a potential risk to human health and where possible should be considered for future monitoring programs.

3.5 Climate Change

An ensemble of climate data models was analyzed for the SSRB to determine both historical norms for the region, and to determine potential future trends under an area of climate change scenarios (Ouranos, 2023). The two primary variables of focus were total annual precipitation and mean annual temperature. The data used in these models were calculated from historical weather station data, which was then de-trended to remove noise and anomalies and modeled for the entire observation and prediction period from 1951 to 2100. Norms were analyzed for data from the 30-year period extending from 1982 to 2022, and were previously discussed in section 2.1 above in the context of the distribution of natural subregions within the study area. Future climate change trends were analyzed from 2022 until 2100.

Under the forecasted climate change scenario, changes to mean annual temperatures were relatively homogenous across the study area, increasing by between approximately 3.5 and 4.0°C by 2100. The most extreme increases in temperature were seen in the northwest and northeast portions of the study area, while the central-south areas did not experience as high an increase (Figure 41). Changes to precipitation were more variable, with increases between approximately 15 and 80 mm/y by 2100. The largest increases in precipitation fell at the highest elevations within the Rocky Mountain natural region, declining in a generally east-to-west trend across the Grassland natural region (Figure 42). There was also a slight latitudinal trend, with northern areas generally having lower increases in precipitation. This increase in available water contrasts with the historical decline flows in the mainstem; however, the flows observed at Medicine Hat (see section 3.3.2 above) are the realized flows that include withdrawals. Under the forecasted climate change scenario, naturalized flows are expected to increase, but increases in withdrawals may result in a net decline in flows at Medicine Hat.

Additional analyses indicate that the changes in precipitation are generally expected to result from an increase in the frequency of higher-intensity, short-duration precipitation events, rather than as a broad increase in rates of precipitation (Intergovernmental Panel on Climate Change, 2018). This suggests that while overall precipitation and potential annual average flows within the river will increase, it may not result in an increase in the amount of water available for use without additional on- or off-channel storage capacity. Consequently, climate change may result in an increase the frequency of both flood and drought conditions without alterations to hydrological management within the study area. Increases in precipitation intensity are also expected to have negative impacts on water quality, ranging from minor impacts due to increased surface runoff and erosion, up to catastrophic impacts due to the failure of water management structures and wastewater treatment facilities.

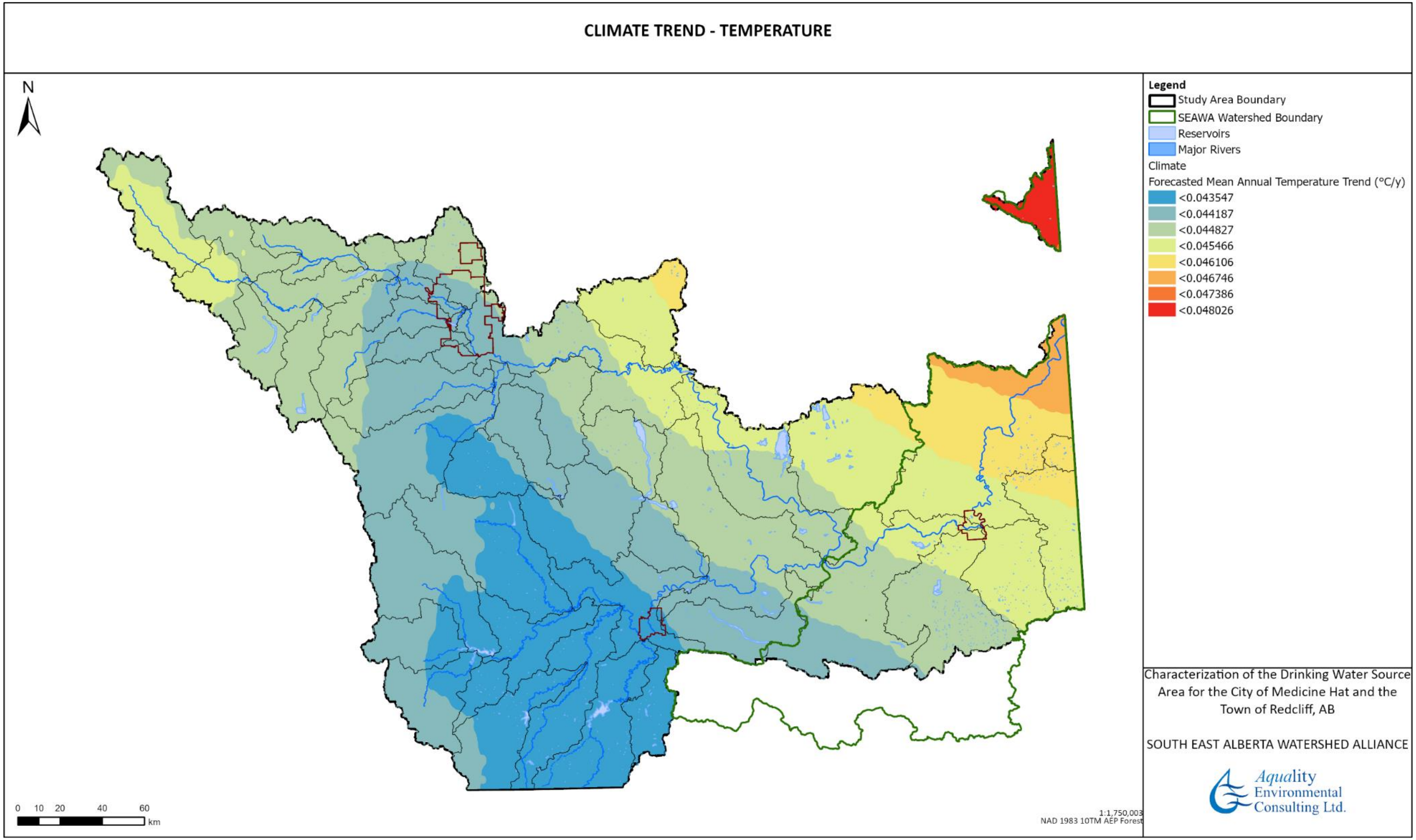

Figure 41. Forecasted climate change scenario for the SSRB, change in mean annual temperature per year.

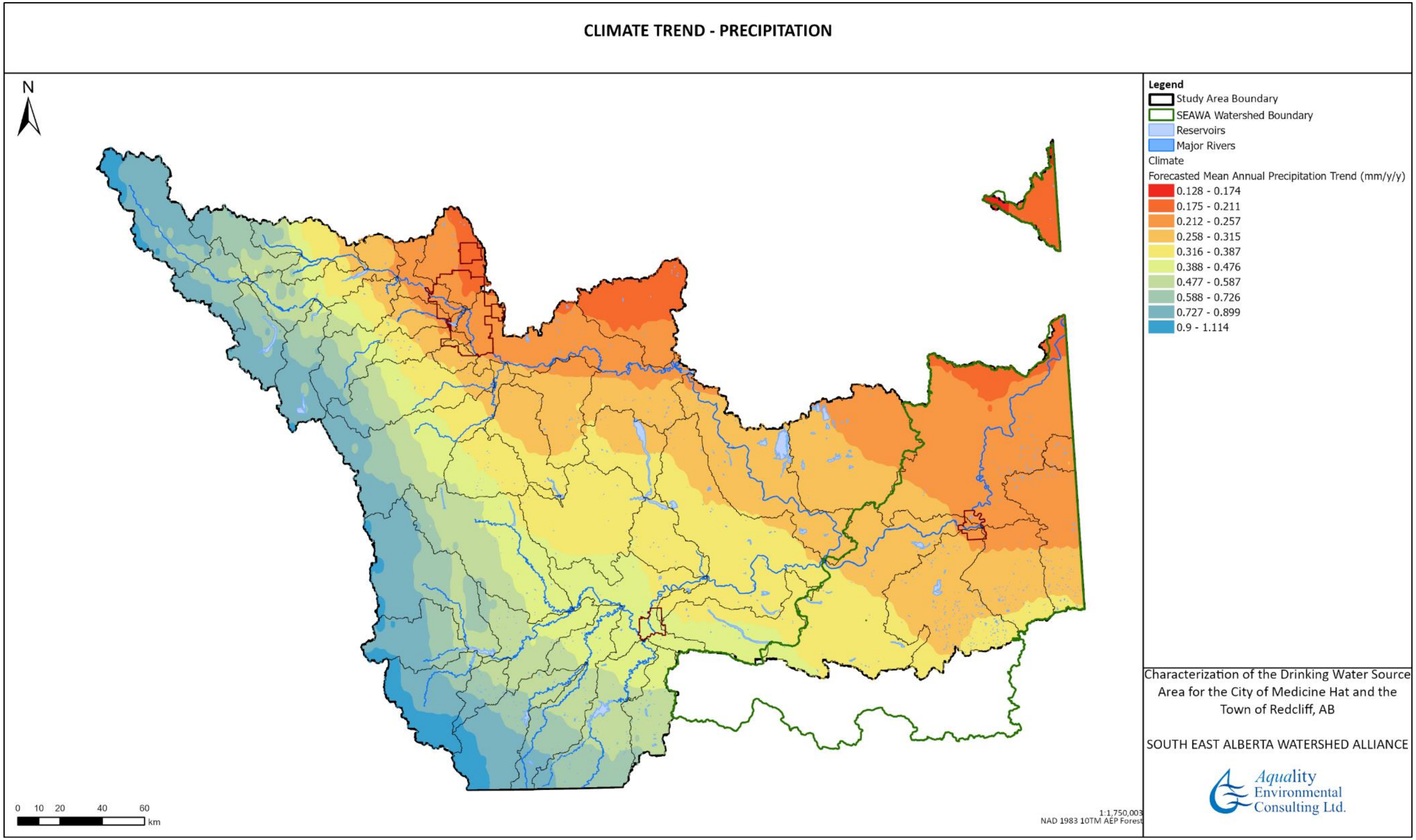

Figure 42. Forecasted climate change scenario for the SSRB, change in mean annual precipitation per year.

4 Conclusions

Threats to the drinking water source in the SEAWA watershed are broadly broken down into issues impacting water quantity and factors impacting water quality. Water quantity issues relate to the conflicting demands for water by various sectors active within the study area, and the factors that will alter the availability of water in the future. Water quality issues relate to the pressures on the health of the aquatic environment that will alter the usability of that water. Activities within the study area frequently have impacts on both quantity and quality of drinking water sources through complex interactions between local and landscape-level effects.

At the largest scales, the primary threats to water quality are landscape-level changes, especially the continued alteration of natural landscapes through the conversion to alternative land uses. The primary driver of land use change varies across the study area, with forestry activities dominating in the higher elevation Rocky Mountain natural region and agriculture dominating in the Grassland natural region. Conversion to residential use or urban sprawl is most important in the region surrounding the City of Calgary, while oil and gas operations have a greater effect on land use change to the north of Medicine Hat. Across the entire study area, the greatest land use changes in terms of overall area are a result of agricultural activities.

Agriculture can pose significant threats to drinking water source quality in a number of ways, through excess erosion and increases in the concentration of pollutants (primarily nutrients, pesticides, and bacteria) entering systems through runoff. Agricultural intensity has been shown to be the best predictor of decreased water quality within the settled regions of Alberta (Lorenz, 2008). Threats from forestry activities are somewhat similar, with increased risk from excess soil erosion and the application of pesticides. Oil and gas activities at a landscape level are primarily a threat to surface waters through alteration of vegetation for pad and access construction, though additional threats from accidental product releases and contamination of groundwater are an additional consideration. Mining activities, while making up a smaller proportion of land use within the basin, generally occur in close proximity water supplies, increasing the risk due to erosion and sedimentation generally, and increases in the quantities of specific pollutants such as hydrocarbons and heavy metals in the case of coal mining.

Threats to the quality of drinking water due to land use change are primarily the result of an increase in activities contributing pollutants that end up in surface water supplies through surface runoff. The nature of these pollutants varies with end land use. However, for nearly all such landscape-level threats, a reduction in the associated risks can be obtained through protection and restoration of degraded or drained riparian areas and wetlands. These areas act as buffers, absorbing pollutants as surface runoff is slowed by existing vegetation, allowing uptake or infiltration to reduce the pollutant concentration entering watercourses.

Additional threats to drinking water supplies can be attributed to population growth and the accompanying potential urban sprawl. Increases in the areas given over to human habitat result in elevated stormwater runoff due to increased impermeable surfaces and increased wastewater production due to higher use. Mitigations for issues with the quality and quantity of stormwater include a wide range of urban planning approaches falling under the general category of low-impact development (LID), such as increasing the use of permeable surfaces, construction of rain gardens, and stormwater capture for reuse. These can all aid in reducing the volume of stormwater as well as the concentrations of pollutants, and can complement upgrades to stormwater infrastructure to capture a greater proportion of pollutants before they reach aquatic ecosystems.

Future threats to overall quantities available as a drinking water source stem from the fact that water is a finite resource that varies in availability over both space and time. Allocations of water diversions at the current time are broadly being met, though deficits appear to be occurring with greater frequency over the past decade. The largest allocations of water diversions are to irrigation and the municipal sector, which both have excess available allocations compared to current needs overall, though limitations for specific municipal areas are occurring due to an imbalance between allocations and local population growth, representing a significant immediate risk to available water supplies in some areas. However, allocations within the basin far outstrip the volume of water actually available for diversion, and it is expected that increased population and intensity of agricultural activity will result in conflict as elevated demand and temporary suspension of diversions by junior license holders as the intensity of these pressures grows. There is evidence of unutilized excess flow volumes during some portions of the year, suggesting that some of these threats to water quantity could be reduced with changes in hydrological management and the development of increased storage capacity within the basin.

As a backdrop to issues of both water quality and quantity issues, the current state of the landscape and future pressures on available water supplies are generally based on the current state of the environment. However, many of the issues with water quantity (and to a lesser extent quality) are expected to be exacerbated by current climate change scenarios and status quo management. The study area is expected to experience increased temperatures, as well as increased precipitation on a declining west-to-east gradient. Current forecasts suggest an increasing likelihood of more sporadic intense precipitation events, which may result in increased flooding and contamination of surface water supplies. Conversely, because the increased precipitation from high-intensity events cannot be used in place immediately when it falls, there is also expected to be an increase in the frequency of precipitation and soil moisture deficits during the growing season due to increased evapotranspiration. Some of these impacts may be mitigable through changes in hydrological management indicated above for water quantity issues in general.

The initial focal area for this study was limited to the SEAWA watershed at the downstream end of the South Saskatchewan River basin within Alberta. The study area was expanded to include the upstream reaches as well, due to the dependance of water quality and quantity on upstream activities and management practices. For the majority of threats examined, many of the realized or potential impacts have already occurred by the time water flows have arrived at the downstream end of the basin;

therefore, management of these risks is not something that can be accomplished solely within the geographic boundaries of the area in which the impacts will occur. There will need to be a concerted, interjurisdictional management of threats and risks and cooperation with upstream partners using a multi-barrier approach to ensure the protection of drinking water supplies in the SEAWA watershed.

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