CHAPTER 11

A PROPOSED GROUNDWATER MONITORING NETWORK FOR THE UPPER NOTTAWASAGA RIVER DRAINAGE BASIN

By

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11.1 LOCATION

The Upper Nottawasaga River drainage basin is located in south-central Ontario between the longitudes 79^{0}35' and 80^{0}16' W and the latitudes of 43^{0}56' and 44^{0}18' N. The basin is approximately 53 km long in an east-west direction and 22 km wide in a north-south direction. It is bounded on the east by the Holland River basin, on the south by the Humber River basin, on the west by the Grand River basin, and on the north by the lower Nottawasaga basin.

The Upper Nottawasaga River and some of its tributaries rise in a plain west of the Niagara Escarpment and flow down the Escarpment through deeply cut rock valleys towards Baxter. From Baxter, the Nottawasaga River flows northward until it discharges into Nottawasaga Bay at Wasaga Beach. The total drainage area of the basin is approximately 1217 km^2. The main sub-basins of the Upper Nottawasaga River are Boyne River (220 km^2), the Sheldon Creek (85 km^2), and the Innisfil Creek (474 km^2). The basin contains portions of the Counties of Dufferin, Peel, Simcoe, and York. There are five main population centres in the basin, Alliston, Beeton, Cookstown, Shelburne, and Tottenham.

NOTE: A Key Map was included as part of the figures for this chapter. Those who wish to make a hard copy of the chapter can also make a transparency of the Key Map and use it for orientation purposes with the other figures.

11.2 LAND USE

Most of the population within the basin is rural and the basin economy is primarily agricultural with emphasis on livestock-raising and mixed farming. The primary uses of land in the basin are for crop production on the sand plain adjacent to the Nottawasaga River, and for improved and unimproved pasture throughout much of the remainder of the basin. A number of special cash crops are cultivated, the most notable being tobacco, potatoes, and sod. Woodland areas occur west of the Niagara Escarpment and within the river valleys.

Alliston is the largest urban center within the basin and has experienced a large rate of population growth since the building of an automobile production facility in the town. Alliston also has a potato processing plant. It also has a plant which produces hospital supplies. Canada Packers Ltd. operates a poultry eviscerating plant in the Village of Shelburne. Honey, tire pumps, and lumber products are also produced in the village.

11.3 GROUNDWATER USE

Groundwater in the Upper Nottawasaga River basin is used for rural domestic water supply, municipal water supply, and livestock watering. Rural water needs are met by groundwater from dug, bored, and drilled wells. Livestock watering, on the other hand, is met from groundwater sources as well as from ponds and streams.

The total number of water wells within the basin that have geographic coordinates on file with the Ministry of the Environment is 4,221. Of these wells, 683 (16.1%) are bedrock wells, 3,338 (79.0%) are bedrock wells, and the rest are of unknown type. The majority of the bedrock wells are located in the western part of the basin.

Municipal water-supply systems exist at Alliston, Beeton, Cookstown, Shelburne, and Tottenham. All of these systems utilize groundwater. Alliston and Beeton obtain their water supplies from wells developed in the Alliston Sand Aquifer, the two municipal wells serving Shelburne are constructed in the Amabel Aquifer, and Cookstown and Tottenham obtain their water supplies from deep overburden wells.

Flowing wells especially those that penetrate the Alliston Sand Aquifer within the Lake Algonquin sand plain are too often left to flow without any particular use being made of the water. This is often a needless waste of the resource and the control of these flowing wells would be an important conservation measure. In addition, groundwater contamination by nutrients and road salts within the extensive areas of sand and gravel east of the Niagara Escarpment and on the Lake Algonquin sand plain is a potential problem that requires continuous attention.

11.4 PHYSIOGRAPHY

According to Chapman and Putnam (1984), the Upper Nottawasaga River basin contains parts of five physiographic regions, the Dundalk Till Plain, the Niagara Escarpment, the Horseshoe Moraines, the Peterborough Drumlin Field, and the Simcoe Lowlands.

A small area in the extreme western part of the basin is part of the Dundalk Till Plain physiographic region which represents the "roof" of peninsular Ontario in the Counties of Dufferin, Grey, and Wellington. The region, which is covered by a fluted till plain, is bounded on the east by moraines. Also, some morainic ridges lie inside the boundary near

Shelburne. The headwaters of the Saugeen, Maitland, Grand Rivers, and the Nottawasaga are located within the Dundalk Till Plain. The plain is characterized by swamps or bogs and by poorly drained depressions.The chief urban center on the plain within the basin is Shelburne.

The Niagara Escarpment is a prominent physiographic feature within the western part of the basin. The Escarpment, which has an elevation of about 485 m (a.s.l.), is exposed locally as vertical cliffs, 35 to 40 m high, for short distances north and south of Mono Center. The cliffs mark the edge of the Silurian dolomite formations. At other localities, the Escarpment is difficult to define and most of the rock slopes are obscured by hummocky, bouldery ridges and deposits of sand and gravel.

The Horseshoe Moraines physiographic region within the basin is a part of a large morainic system that forms a horseshoe shaped region lying around the upland between Lake Huron, Lake Ontario, and Georgian Bay. The region includes several tracts of stony shallow drift on the Niagara cuesta. It also includes an assortment of kame sand and gravel and other ice-contact and meltwater deposits. In the southern portion of this region, the surface material consists mainly of outwash sands and gravels, deposited by glacial meltwater. Generally, the land surface is rugged, in places deeply dissected, and slopes toward the east. Surface elevations range from 240 m in the river valleys to 460 m (a.s.l.) in the area of kame deposits adjacent to the Escarpment.

The Peterborough Drumlin Field physiographic region within the basin is a part of a belt of a rolling till plain with thousands of drumlins that extends from Hastings County in the east to Simcoe County in the west. The physiographic region within the basin covers large areas and contains approximately 100 drumlins which have a northeast-southwest orientation. Land surface elevations range from about 220 m to approximately 420 m (a.s.l.). The main surface deposit in the region is a sand to silt till, but local deposits of clay, sand, and gravel exist in the eastern and southeastern portions of the region.

The Simcoe Lowlands physiographic region includes the plains bordering Georgian Bay and Lake Simcoe. These plains are being drained into Nottawasaga Bay, mostly by way of the Nottawasaga River, and into Lake Simcoe mostly through the Holland River system. The Simcoe Lowlands region consists of flat-lying areas that occur adjacent to the Nottawasaga River. In addition, large portions of the drainage areas of the Boyne River and Sheldon and Innisfil Creeks are part of the region.

Most of the surface elevations within the Simcoe Lowlands region are below 230 m (a.s.l.). The surface deposits consist mainly of fine- to medium-grained sands which were deposited in glacial Lake Algonquin. At lower elevations, very fine sand, silt, and thin clay deposits are present. Above the shoreline of Lake Algonquin, most of the surface deposits are sand and gravel of glaciofluvial origin.

The southernmost portion of the Lowlands, where the Upper Nottawasaga and its tributaries deposited deep beds of sand and silt, is called the Tecumseth Flats. Through these level plains the watercourses have cut only shallow channels and drainage is generally poor. At the head of the Innisfil Creek there is a bog of some 2000 acres, while another of about 1,200 acres is found farther down the creek near Randall Station. A third large bog of about 9,000 acres lies along the Bailey Creek in Tecumseth and Adjala Townships.

11.5 BEDROCK TOPOGRAPHY AND GEOLOGY

The Palaeozoic rocks underlying the Upper Nottawasaga drainage basin consist of shale, dolomite, and limestone of Ordovician and Silurian age. Sibul and Choo-Ying (1971) prepared a map of the bedrock elevation within the basin and described the bedrock topography. A modified bedrock topography map is shown on Figure Up-1.

The elevation of the bedrock within the basin ranges from over 500 m (a.s.l.) above the Niagara Escarpment to about 130 m (a.s.l.) along the basin’s eastern boundaries. The Escarpment is a prominent topographic feature on the present land surface as well as on the buried bedrock surface. Below the Escarpment, the bedrock slopes eastward toward the Laurentian Valley, a regional bedrock valley that extends from Georgian Bay to Lake Ontario.

According to Sibul and Choo -Ying (1971), incised into the Escarpment is a deep bedrock valley, the trend of which approximates the overlying Hockley Valley. Three other significant bedrock channels occur along the Escarpment. All are thought to have been formed by fluvial or glaciofluvial erosion. The largest channel, of which only a remnant remains, is inferred to have extended between the Escarpment and the bedrock highs beneath Violet Hill and Sheldon Hill at elevations between 335 and 365 m (a.s.l.). The second channel is located near the northern end of the Escarpment where the valley floor is at an approximate elevation of 365 m (a.s.l.). The third channel is located between the exposed face of the Escarpment and the three small bedrock promontories immediately east of the Escarpment. The approximate elevation of the floor of this channel is 426 m (a.s.l.).

The oldest Palaeozoic rocks within the basin are the limestones of the Bobcaygeon Formation of the Simcoe Group (Figure Up-2). The formation which ranges in thickness from 7 to 87 m is of Middle Ordovician age. The Bobcaygeon Formation is overlain by the Verulam Formation which consists of limestones with interbeds of shales, 32 to 65 m thick. The youngest unit in the Simcoe Group sequence is the Lindsay Formation which has a thickness of 67 m and is comprised of two members. The lower member (unnamed) consists of limestones and the upper Collingwood Member consists of limestones and calcareous shales.

Overlying the Simcoe Group are the shales of Blue Mountain, Georgian Bay and

Queenston Formations of Upper Ordovician age. The Blue Mountain Formation consists of shales and has a maximum thickness of 60 m. The Georgian Bay Formation, with an average thickness of 100 m and a maximum thickness of 200 m, is comprised of shales with minor interbeds of siltstones and limestones. The youngest unit in the Upper Ordovician sequence is the Queenston Formation with a thickness ranging from 45 to 335 m. The unit consists of shales with interbeds of limestones and calcareous siltstones.

Overlying the Ordovician rocks are formations comprised mainly of dolostones, shales, limestones and sandstones of Lower Silurian age. These rocks are represented by the Cataract Group which includes the Whirlpool, Manitoulin, and Cabot Head Formations.

The Whirlpool Formation outcrops along the Niagara Escarpment and is comprised of up to 9 m of sandstones. The Manitoulin Formation outcrops along the Niagara Escarpment and occurs extensively in the subsurface of southwestern Ontario. It consists of dolostones with a maximum thickness of 25 m. The Cabot Head Formation occurs throughout southwestern Ontario and the Niagara Peninsula. It consists of 10 to 39 m of non-calcareous shales with minor calcareous sandstones, dolostones and limestones.

The youngest Palaeozoic rocks within the basin are the dolomites of the Amabel Formation of Middle Silurian age which extends from the Escarpment to the western boundaries of the basin. The dolomites are up to 38 m thick.

11.6 OVERBURDEN THICKNESS AND GEOLOGY

The overburden in the Upper Nottawasaga River basin consists of glacial, glaciofluvial, glaciolacustrine deposits of Pleistocene age with minor amounts of alluvial and swamp deposits of Recent age. The thickness of these deposits in the basin varies from 0 to 10 m over the Niagara Escarpment plateau to over 110 m along the eastern boundaries of the basin (Figure Up-3).

The surficial geology of the basin is shown on Figure Up-4 which is based on a map prepared by Sibul and Choo-Ying (1971). Three different tills have been identified within the basin, Tavistock Till, Newmarket Till, and kettleby Till (Thurston et al. 1992). Land forms of glacial deposits in the basin include drumlins, till plains, and end moraines.

The Tavistock Till is found within the basin over the Escarpment plateau. The till, which occurs as gently rolling ground moraine, was deposited by the Huron-Georgian Bay lobes during the Port Bruce Stadial. It is a strongly calcareous, silty clay to silt till between 2 to 12 m in thickness.

The Newmarket Till is found mainly as drumlinized till plains in the eastern part of the basin. The till, which ranges in thickness from 3 to 12 m, was deposited by the Simcoe Lobe during the later part of the Port Bruce Stade. It is a calcareous silt to sandy silt till.

The kettleby Till was deposited by an advance of the Simcoe Lobe during the Port Huron Stade. The till, which is about 2 m thick, occurs within the central parts of the basin to the north and west of Alliston and to the south and southwest of Beeton. The Kettleby Till is a highly calcareous silty clay to clay till.

Numerous drumlins occur exclusively east of the Escarpment and are associated with the Newmarket and Kettleby Tills. The drumlins are elongated hills with crests pointing northeast and tail ends pointing southwest and their cores are composed of silt to sand till.
Proglacial Outwash Deposits

Glaciofluvial ice-contact deposits in the form of kames are found in the basin just east of the Escarpment and in a few localities on top of the Escarpment. According to Sibul and Choo - Ying (1971), kame deposits also occur directly beneath the sand till. An example of such an occurrence is the gravel pit 4 km due south of Beeton where the kame is capped by about five feet of sand till.

Kame deposits consisting of sands and gravels, about 5 to 10 m thick, occur to the at the foot of the Niagara Escarpment at an elevation of about 425 m (a.s.l.) and north of Hockley at elevations between 300 and 325 m (a.s.l.). The deposits were formed by meltwater contained between the Escarpment and the ice.

Glaciofluvial outwash deposits of stratified sands and gravels occur at an elevation of about 305 m north of Thornton, near the southern boundary of the basin southeast of Hockley, and as narrow channels in the vicinity and above the Escarpment.

Glaciolacustrine sediments of clay, silt, and fine sands are found between Cookstown and Beeton. These sediments were deposited in ice-marginal lakes and ponds associated with glacial Lake Schomberg and subsequent phases of Lake Algonquin. Also, thick sequences of clay and silt directly underlie part of the till plains in the basin. Medium- to coarse-grained sands, and occasionally gravels of glaciolacustrine are found near the Innisfil Creek and along the lower part of the Nottawasaga River. Sibul and Choo-Ying (1971) note that as much as15 m of sand, interbedded with minor beds of silt and clay, can be seen in the banks of the Nottawasaga River.

Low, elongated ridges of stratified sand and gravel, formed in shallow-water lacustrine and fluvial environments, occur at an elevation of about 235 m (a.s.l.) on the outwash plain southwest of Alliston, and at an approximate elevation of 220 m (a.s.l.) on the Lake Algonquin sand plain due south of Alliston (Sibul and Choo-Ying 1971).

Recent alluvial deposits of clay, silt, and fine sand occur within the flood plains of various streams. Also, swamp organic deposits up to 1 m thick occur at the head of the Innisfil Creek and along the Bailey Creek in Tecumseth and Adjala Townships.

11.7 OCCURRENCE OF GROUNDWATER IN THE BEDROCK

As indicated earlier, only a small percentage of the wells within the basin are bedrock wells and the majority of these wells are located in the western part of the basin. With the exception of the Amabel Formation, all the other bedrock formations within the basin are of limited value as a source of groundwater supply.

The Simcoe Group is buried under a mantle of overburden deposits that range in thickness from 70 to over 110 m. For this reason, only a few wells have been drilled deep enough to penetrate the limestone formations of the Group which make it difficult to assess its hydrogeologic characteristics within the basin. Singer et al.(1997) calculated the transmissivity values for a sample of 6,414 wells constructed in the rocks of the Simcoe Group in southern Ontario. The geometric mean of the sample's transmissivity values was estimated to be 5.7 m^2/day and the water-yielding capability of the Simcoe Group was assessed to be fair.

According to Sibul and Choo-Ying (1971), the groundwater availability in the Blue Mountain, Georgian Bay and Queenston Formations within the basin is poor. In their study of the hydrogeology of southern Ontario, Singer et al.(1997) treated the Blue Mountain and Georgian Bay Formations as one hydrogeologic unit. About 2,130 wells have been identified within the unit. Of these, a sample of 1,293 wells was selected to determine the transmissivity distributions for the wells within the unit. The minimum and maximum transmissivity values were estimated to range between 0.06 and 1,194 m^2/day, respectively, and the geometric mean of the sample's transmissivity distribution was estimated to be about 3 m^2/day. Given the large number of wells in the sample, Singer et al.(1997) characterized the water-yielding capability of the Blue Mountain-Georgian Bay hydrogeologic unit as poor.

A sample of 2,505 wells was selected by Singer et al.(1997) to estimate the transmissivity distribution for wells completed in the Queenston Formation. The minimum and maximum transmissivity values were found to range from 0.08 to 4,357m^2/day, respectively. The geometric mean of the sample's transmissivity distribution was estimated to be about 3 m^2/day. Given the large number of wells in the sample, Singer et al.(1997) characterized the water-yielding capability of the Queenston hydrogeologic unit as poor.

Singer et al.(1997), noted that all the formations of the Cataract Group are buried under thick sequences of younger rocks. Therefore, from a hydrogeologic point of view, the Cataract Group hydrogeologic unit was characterized as being of limited significance as a source of groundwater.

According to Turner (1976), the Amabel, Lockport and Guelph Formations constitute a high-capacity aquifer in the Niagara Peninsula and in the area between Hamilton and Owen Sound. Sibul and Choo-Ying (1971) indicated that the most of the bedrock wells within the basin derive their water from the Amabel Formation. Average yields from this formation are in the order of 50 to 100 litres per minute. Two municipal wells at Shelburne have penetrated 13 and 18 m of dolomite, and each has an estimated theoretical yield of 0ver 3,000 litres per minute. According to Sibul and Choo-Ying (1971), most of the wells ending in the Amabel Formation are between 15 to 30 m deep, and the majority of the domestic wells penetrate 5 to 10 m of bedrock before obtaining adequate water for supplies. Deeper penetrations into the rock normally have the effect of increasing the yields.

Singer et al.(1997) selected a sample of 6,516 wells in southern Ontario to determine the transmissivity distribution for the Amabel Formation. The minimum and maximum transmissivity values were estimated to range between 0.07 and 7,548 m^2/day, respectively, and the geometric mean of the sample's transmissivity distribution was estimated to be about 15 m^2/day. Given the large number of wells in the sample, Singer et al.(1997) characterized the water-yielding capabilities of the Amabel Formation as being good.

Specific capacity data are available for 440 bedrock wells within the Upper Nottawasaga drainage basin. Of these, 189 wells have specific capacities less than 5 l/min/m (Figure Up-5), 163 wells have specific capacities between 5 and 25 l/min/l (Figure Up-6), 45 wells have specific capacities between 25 and 50 l/min/m (Figure Up-7), and 43 wells have specific capacities higher than 50 l/min/m (Figure Up-8). Based on the distribution of wells on Figure Up-8, it is possible to confirm that the majority of the high capacity wells in the basin are located within the Amabel Formation.

11.8 GROUNDWATER OCCURRENCE IN OVERBURDEN

The overburden thickness east of the Niagara Escarpment ranges from 30 m to over 110 m and one well in the eastern portion of the basin has penetrated more than 150 m of overburden before encountering limestone. As Sibul and Choo-Ying (1971) indicate that although the overburden composition is highly variable, the chances of locating water-bearing formations within the overburden are generally good because of its large thickness. Also, geologic data are sufficient to permit the grouping of significant water-bearing materials in the overburden into aquifer units.

Six overburden aquifer units have been identified by Sibul and Choo-Ying (Map 2743B -5, 1971) within the overburden in the basin, the Kame-Outwash Aquifer Complex, the Till Complex, the Lake Algonquin Sand Aquifer, the Thornton Sand Aquifer, the Alliston Sand Aquifer, and the Hockley Valley Aquifer.

The Kame-Outwash Aquifer Complex is located to the east of the Niagara Escarpment. According to Sibul and Choo-Ying (1971), the aquifer consists of surficial sand and gravel deposits. At most localities these deposits are thick, often 30 m or more in the kame areas and generally 9 to 12 m in most outwash areas. Most of the deposits are unconfined, and the depth to the water table varies according to topography. The specific capacities of wells in these surficial deposits are usually less than 5 l/min/m.

Sibul and Choo-Ying (1971) indicate that most tills in the basin are poorly permeable and form semi-confining layers where they overlie more permeable water-bearing deposits. However, some facies of sand till, as in the southern part of Tecumseth Township, are composed of fairly uniform-grained sand with very little fine-grained material. At such locations, groundwater production from the sand till is limited only by insufficient saturated thicknesses. Where this till is sufficiently thick, large-diameter wells can provide adequate quantities of fresh water for domestic uses.

According to Sibul and Choo-Ying (1971), fine- to medium-grained sand deposits of glacial Lake Algonquin occur below a surface elevation of 230 m and form an unconfined aquifer throughout the sand plain in the basin. The thickness of this surface sand is variable but reaches about 25 m in areas north of Alliston. Most wells indicate a thickness in the order of 12 m. The specific yields of most of the wells in the aquifer are about less than 5 l/min/m.

Sibul and Choo-Ying (1971) have delineated the Thornton Sand Aquifer under the till plain north of Cookstown. The aquifer consists of medium- to coarse-grained sands which are part of a thick sequence of confined lacustrine deposit of sand, silt, and clay in the area. The thickness of the sand varies from a few meters to at least 8 m. A similar sand formation, located in a lacustrine sequence near Fennell on Highway 11, may be an eastward extension of this deposit. Most wells have specific capacities of less than 5 l/min/m.

According to Sibul and Choo-Ying (1971), a deep, confined sand aquifer underlies most of the eastern portion of the basin where the bedrock elevation is generally less than 150 m. (a.s.l.). The sand seems to be part of a deep lacustrine formation that extends south towards Lake Ontario and north toward Georgian Bay. It is usually reported as medium- to coarse-grained and is often overlain by a "blue clay" deposit about 12 m thick, or by a thick deposit of silt and clay, some of which may be glacial till. The majority of domestic wells penetrate only a few meters of the sand formation, and hence, most of the well yields are small.

Sibul and Choo-Ying (1971) have delineated the Hockley Valley Aquifer within a bedrock valley underlying the Nottawasaga River in the region of Hockley Valley and its extension to the northeast. The aquifer consists of gravel up to 6 m thick. The extent of the gravel cannot be precisely defined and wells often encounter water-bearing sand before gravel in the valley.

Data related to short-term pumping tests is available for 1,380 overburden wells. The data indicate that 729 wells (52.8%) have specific capacities ranging from 1 to 5 l/min/m (Figure Up-9), 493 wells (35.7%) have specific capacities between 5 and 25 l/min/m

(Figure Up-10), 86 wells (6.2%) have specific capacities between 25 and 50 l/min/m (Figure Up-11), and the remaining 72 wells (5.3%) have specific capacities larger than 50 l/min/m (Figure Up-12).

11.9 SUGGESTED BEDROCK MONITORING AREAS

Figure Up-13 shows the locations of all the bedrock wells within the basin and the boundaries of suggested areas for monitoring of groundwater in the bedrock. The susceptibility of groundwater to contamination in these areas was determined based on information related to the thickness and type of overburden materials above the bedrock (Figure Up-14).

Areas where groundwater in the bedrock is highly susceptible to contamination are defined as those where the bedrock is either near or at the surface or is covered by highly permeable sand and/or gravel deposits. Areas where the bedrock is moderately susceptible to contamination are defined as those where the overburden above the bedrock contains clay or clay till deposits that are less than 3 m in thickness. Areas where the bedrock has low susceptibility to contamination are defined as those where the overburden contains clay or clay till deposits that are more than 3 m in thickness. The term variable susceptibility to contamination is used for areas where the susceptibility of groundwater to contamination ranges from low to high.

Based on the above definitions, Area (A) is proposed for groundwater monitoring within the bedrock and areas (B, C, D, and E) are optional. Groundwater susceptibility to contamination within Area (A) on Figure Up-13 is variable ranging from high to low, whereas it is low within the optional areas.

Area (A) is located in the western one third of the basin and it is underlain by the rocks of the Queenston Formation, Cataract Group, and the Amabel Formation. It should be noted that the majority of the high capacity wells are within the Amabel Formation in Area (A) and only a few high capacity wells are within the other areas.

Areas (B and C) are underlain by the Blue Mountain Formation and have low susceptibility to contamination. Area (B) is located along the southern topographic divide within the headwaters of the Baily and Keenansville Creeks, whereas Area (C) is located north of Highway 89 within the Boyne River watershed.

Areas (D and E) are underlain by the rocks of the Simcoe Group and also have low susceptibility to contamination. Area (D) is located within the Alliston area, whereas Area (E) is located within the Cookstown area.

11.10 SUGGESTED OVERBURDEN MONITORING AREAS

Figure Up-15 shows the location of overburden wells with specific capacities of over 10 l/min/m, and the boundaries of suggested areas for groundwater monitoring. Groundwater within the suggested areas has a high, variable, or low susceptibility to contamination. The susceptibility of groundwater to contamination in these areas was determined based on information related to the thickness and type of overburden materials (Figure Up-16).

Areas where the shallow overburden aquifers are highly susceptible to contamination are defined as those where sand and/or gravel deposits are either near or at the surface. Areas where shallow overburden aquifers are moderately susceptible to contamination are defined as those where the sand and/or gravel deposits are covered by clay or clay till deposits that are less than 3 m in thickness. Areas where the overburden aquifers have low susceptibility to contamination are defined as those where the overburden contains clay or clay till deposits that are more than 3 m in thickness. The term variable susceptibility to contamination is used for areas where the susceptibility of groundwater to contamination ranges from low to high.

Based on the above definitions, four areas (F, G, H, and I) are proposed for monitoring groundwater within the overburden. The susceptibility of groundwater to contamination is high within areas (G and H), low within Area (I), and variable within Area (F).

Areas (F and G) are located between the southern topographic boundaries and the Sheldon Creek. They contain parts of the Kame-Outwash Aquifer Complex and the Hockley Valley Aquifer and are underlain mainly by glaciofluvial deposits.

Area (H) is located within the Alliston area and is underlain by parts of the Alliston Sand Aquifer and the Lake Algonquin Sand Aquifer. Area (I), on the other hand, is located in the northeast of the basin within the Thornton area and is underlain by till deposits. The area also covers parts of the Thornton Sand Aquifer.

11.11 HISTORICAL MONITORING WELLS

No historical monitoring wells were installed within the Nottawasaga drainage basin. According to Sibul and Choo-Ying (1971), however, a number of monitoring wells were used during the study of the groundwater resources of the Upper Nottawasaga basin. Some of these wells were equipped with automatic recorders and others were measured manually. The types and locations of these wells are as follows:

Well No. 260	An overburden well, 38.72 m deep, and ends in silt. The well is located close to the eastern topographic divide close to an unnamed tributary to Innisfil Creek and contains two piezometers. One piezometer within silt at depth of 12.20 m

	and the other within silt till at depth of 21.34 m.
Well No. 261	An overburden well, 10.37 m deep, ends in silt, and located to the northwest of well 260 close to the same unnamed tributary.
Well No. 262	An overburden well, 40.55 m deep, ends in sand, and located west of Cookstown and just north of Highway 89. The well contains two piezometers; one within silt at depth of 12.19 m and the within clay till at depth of 21.65 m.
Well No. 263	An overburden well, 14.02 m deep, ends in sand, and located west of the Nottawasaga River and east of Elmgrove.
Well No. 264	An overburden well, 34.45 m deep, ends in clay, and located close to the topographic divide east of Highway 15. The well contains two piezometers; one is within silt till at depth of 13.41 m and the other is within clay at depth of 22.87 m.
Well No. 265	An overburden well, 12.80 m deep, ends in sand, and located just to the south of the Nottawasaga River on Highway 15.
Well No. 266	An overburden well, 43.29 m deep, ends in silt till, and located at the intersection of Highways 7 and 15. The well contains three piezometers; the first is within clay at depth of 8.54 m, the second is within clay till at depth of 15.85 m, and the third is at depth of 24.69 m.

All the water level measurements in the above wells were done manually. Automatic recorders, however, were installed in the following two wells:

Alliston Observation Well	An overburden well, 5.78 m deep, ends in sand, and located northeast of Alliston on Highway 10.
Cookstown Observation Well	An overburden well, 12.20 m deep, ends in sand till, and located north of Cookstown on highway 27.

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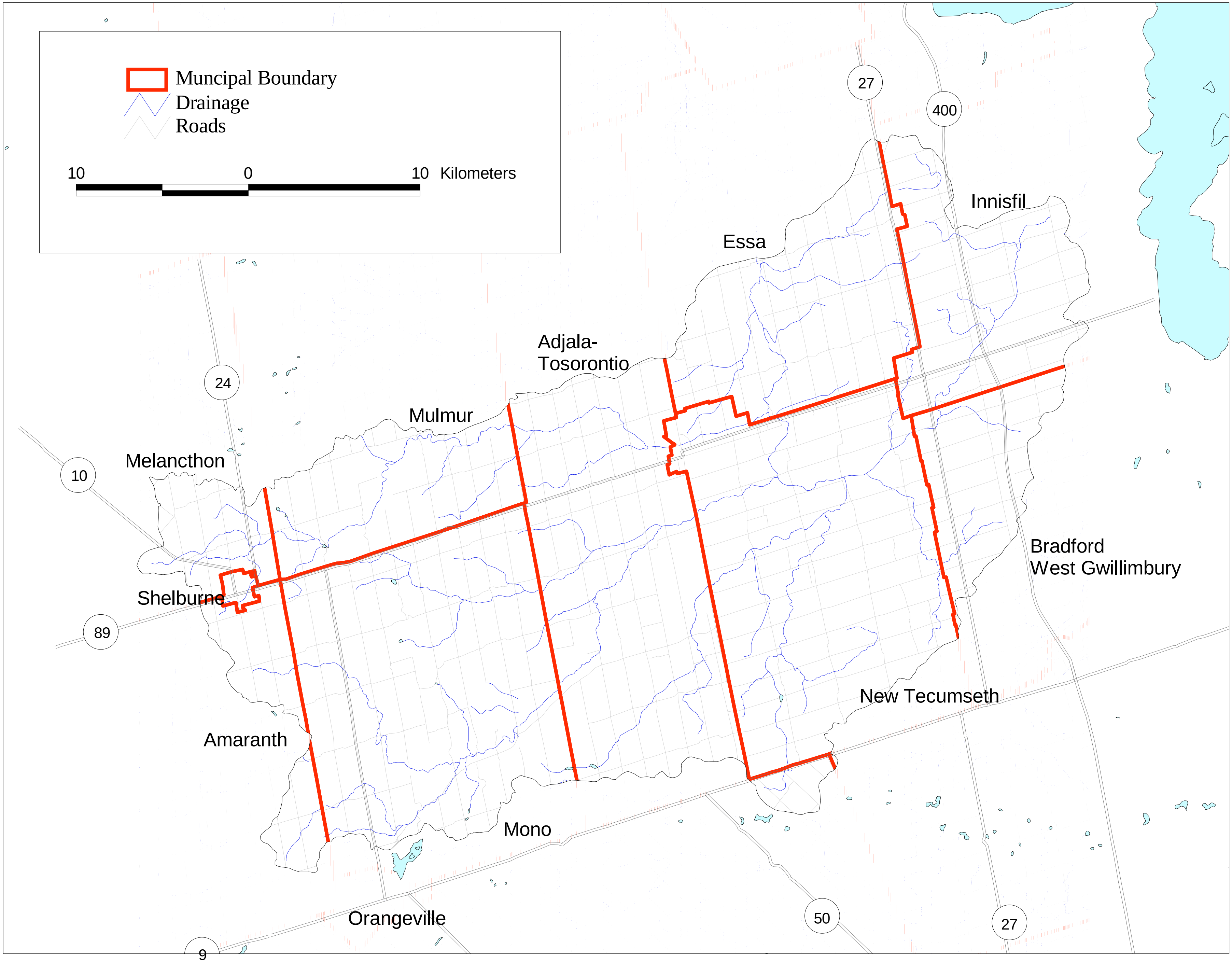
FIGURES

Key Map - Up	A transparency to be used with other figures for orientation purposes.
Figure Up - 1	Bedrock topography in the Upper Nottawasaga drainage basin.
Figure Up - 2	Bedrock geology in the Upper Nottawasaga River drainage basin.
Figure Up - 3	Overburden thickness in the Upper Nottawasaga River drainage basin.
Figure Up - 4	Overburden geology in the Upper Nottawasaga River drainage basin.
Figure Up - 5	Bedrock wells with specific capacities equal to or less than 5 l/min/m.
Figure Up - 6	Bedrock wells with specific capacities between 5 and 25 l/min/m.
Figure Up - 7	Bedrock wells with specific capacities between 25 and 50 l/min/m.
Figure Up - 8	Bedrock wells with specific capacities higher than 50 l/min/m.
Figure Up - 9	Overburden wells with specific capacities equal to or less than 5 l/min/m.
Figure Up -10	Overburden wells with specific capacities between 5 and 25 l/min/m.
Figure Up -11	Overburden wells with specific capacities between 25 and 50 l/min/m.
Figure Up -12	Overburden wells with specific capacities higher than 50 l/min/m.
Figure Up -13	Suggested and optional areas for monitoring groundwater in the bedrock.
Figure Up -14	Panel diagram showing the geologic logs of all bedrock wells.

Figure Up -15 Suggested areas for monitoring groundwater in the overburden.

Figure Up -16 Panel diagram showing the geologic logs of overburden wells with specific capacities higher than 10 l/min/m.



Key Map - Up A transparency to be used with other figures for orientation purposes

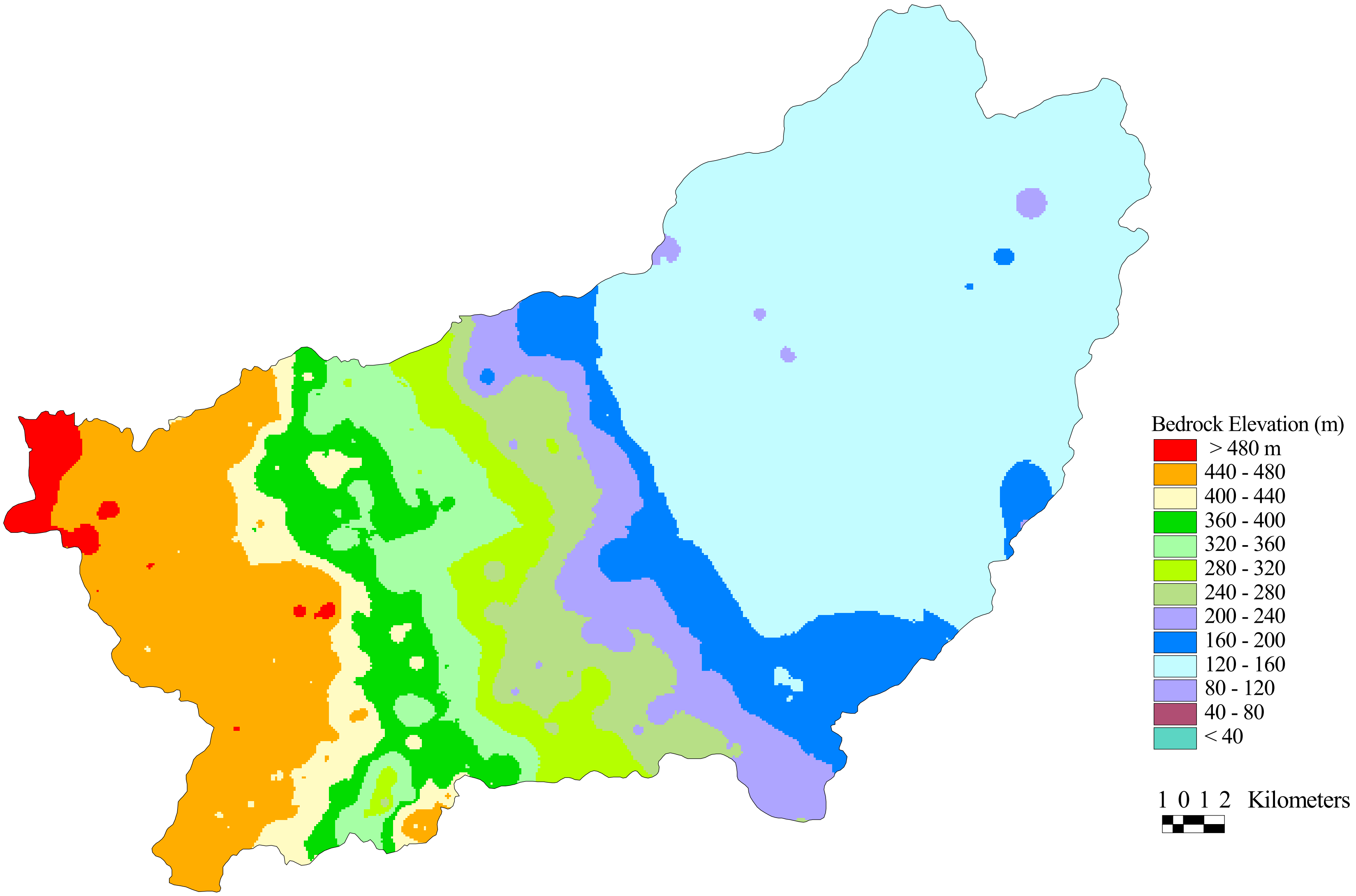


Figure Up-1. Bedrock topography in the Upper Nottawasaga River drainage basin.

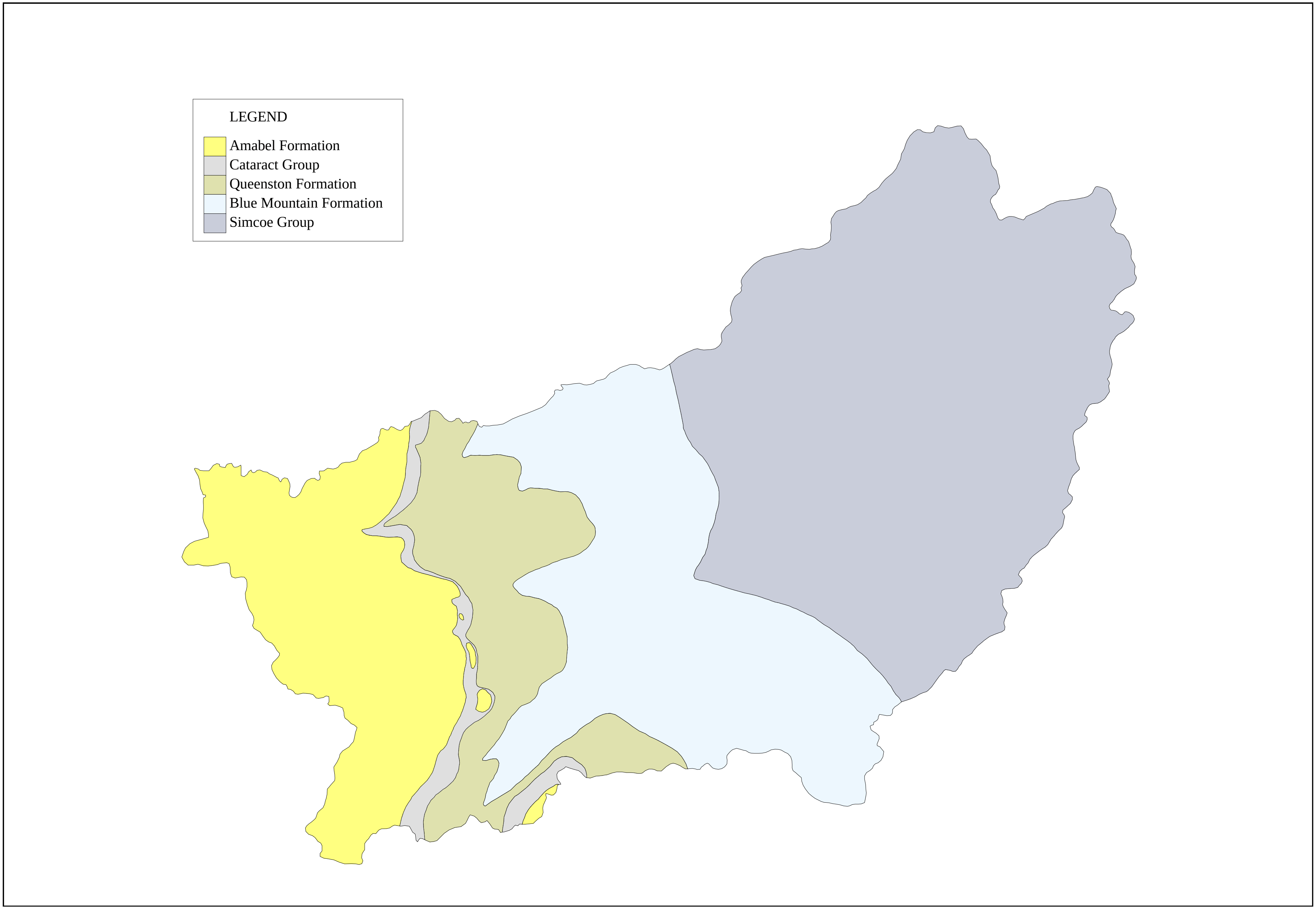


Figure Up-2. Bedrock geology in the Upper Nottawasaga River drainage basin.

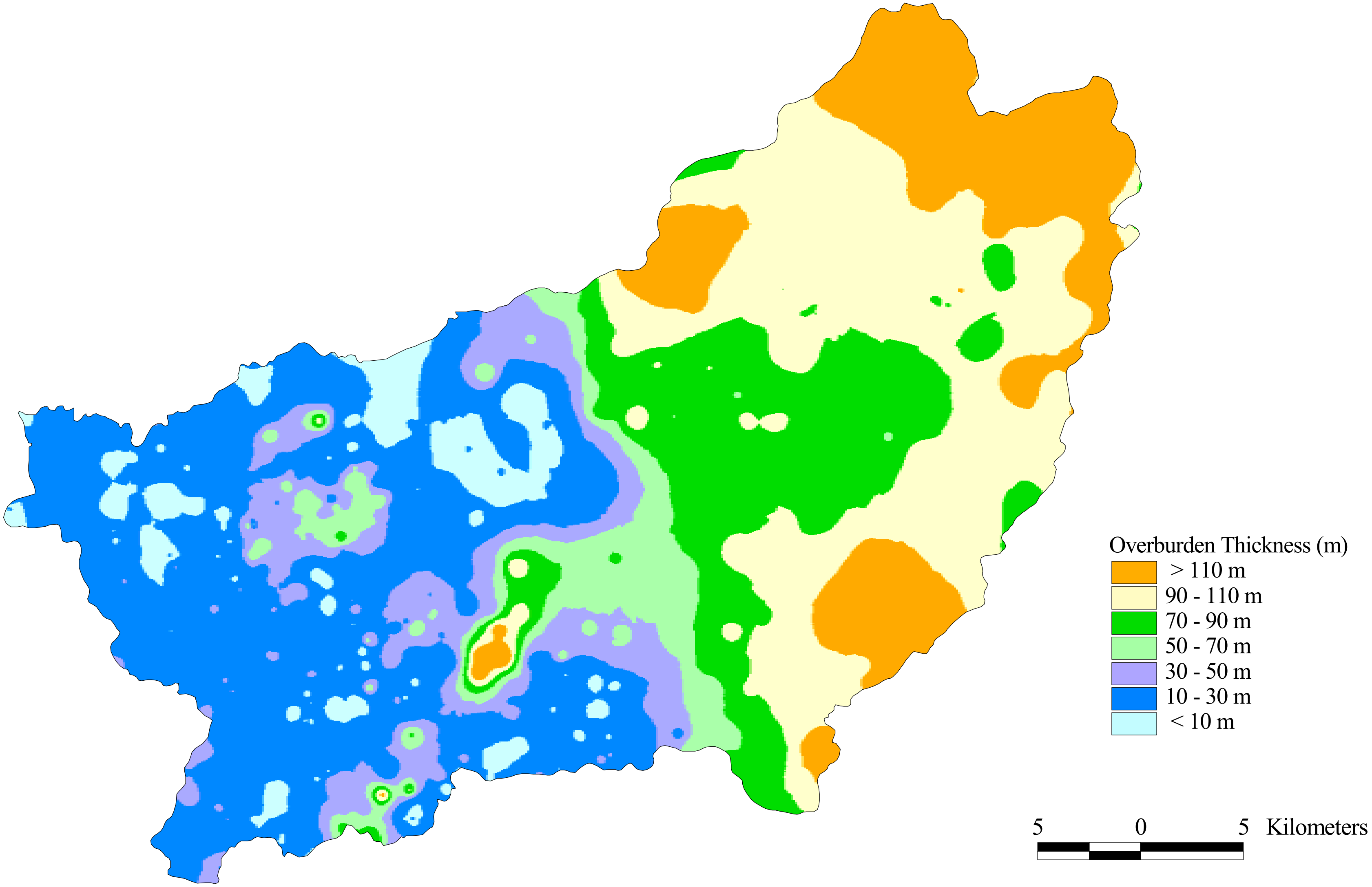


Figure Up-3. Overburden thickness in the Upper Nottawasaga River drainage basin.

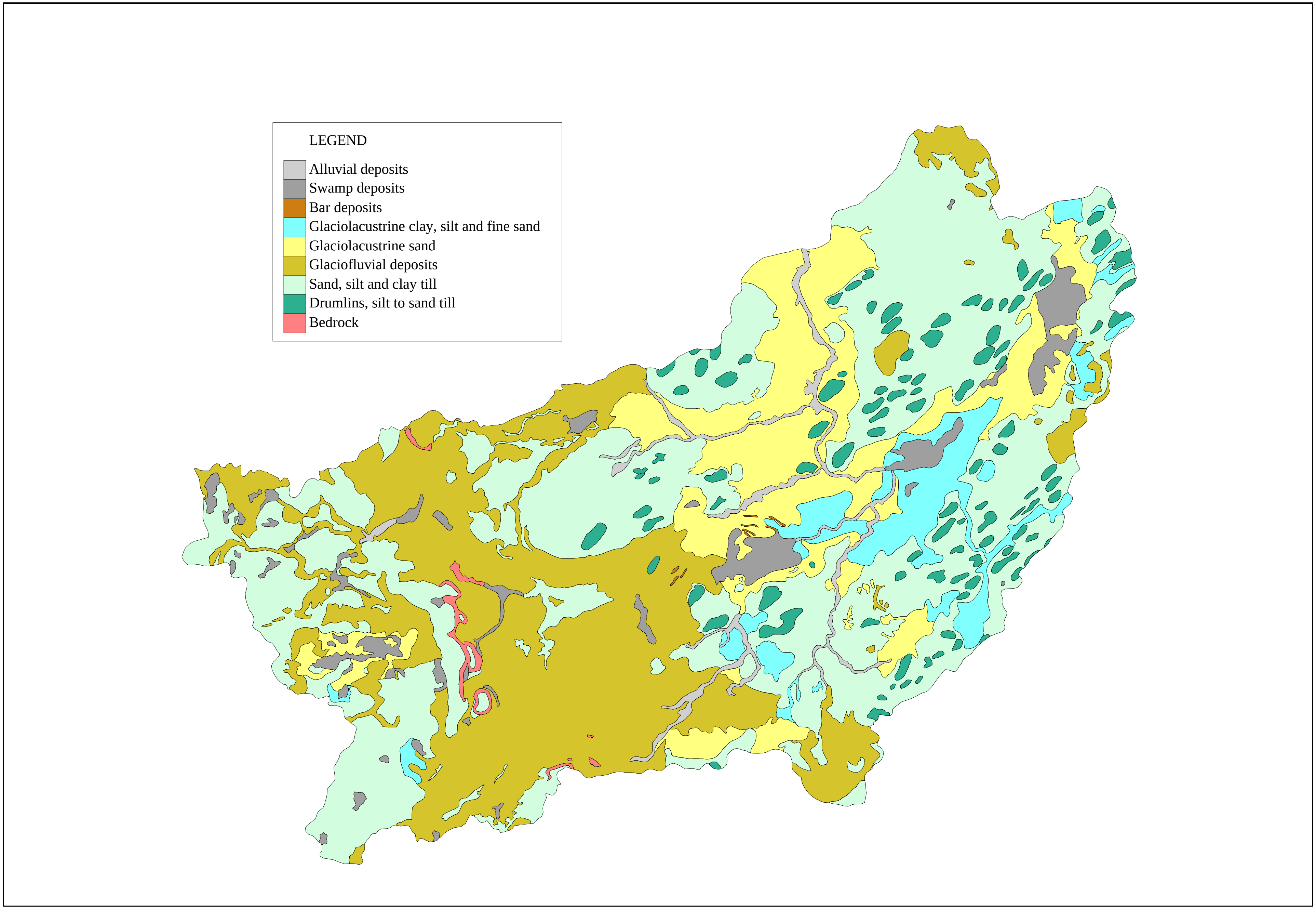


Figure Up-4. Overburden geology in the Upper Nottawasaga River drainage basin.

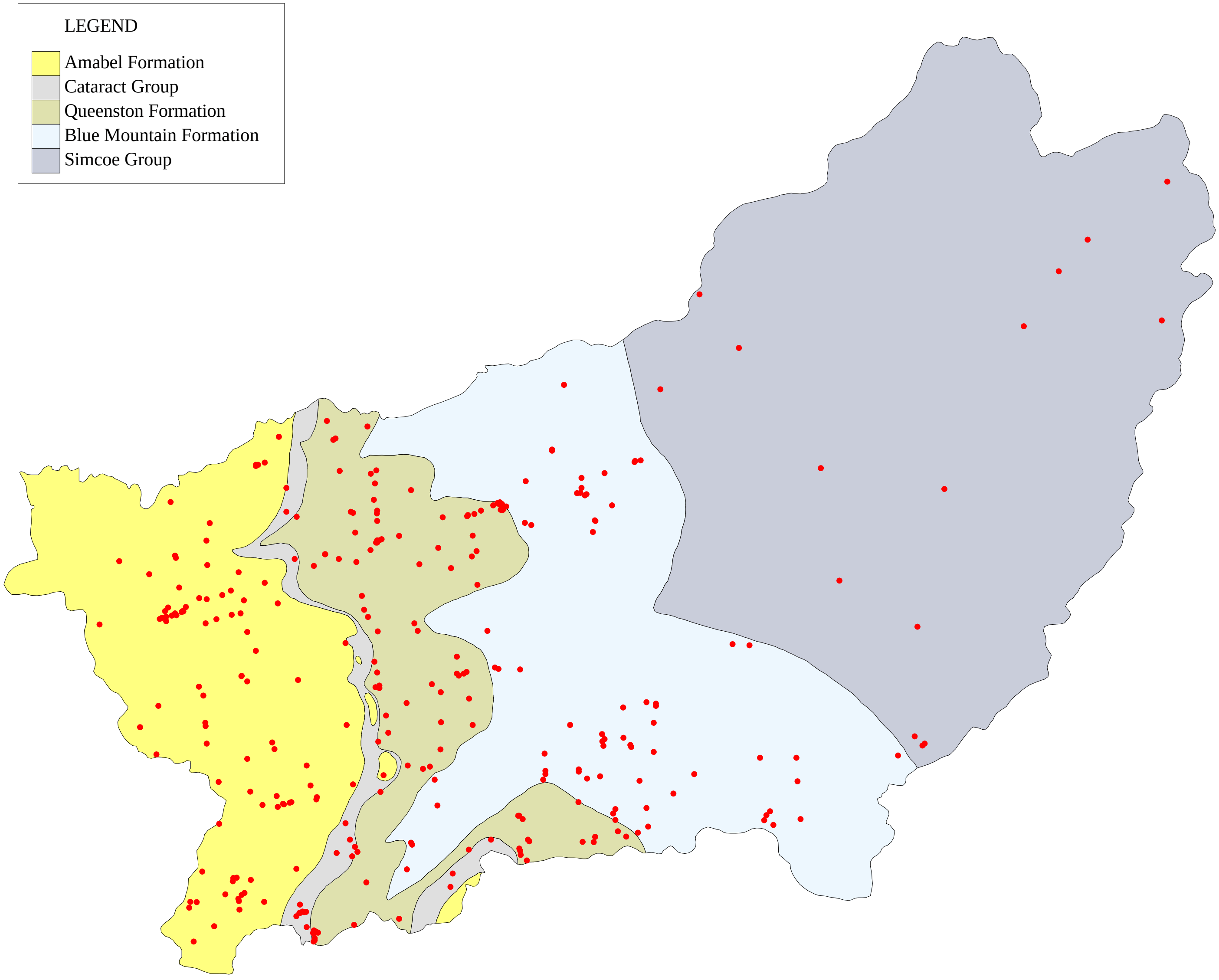


Figure Up-5. Bedrock wells with specific capacities equal to or less than 5 l/min/m.

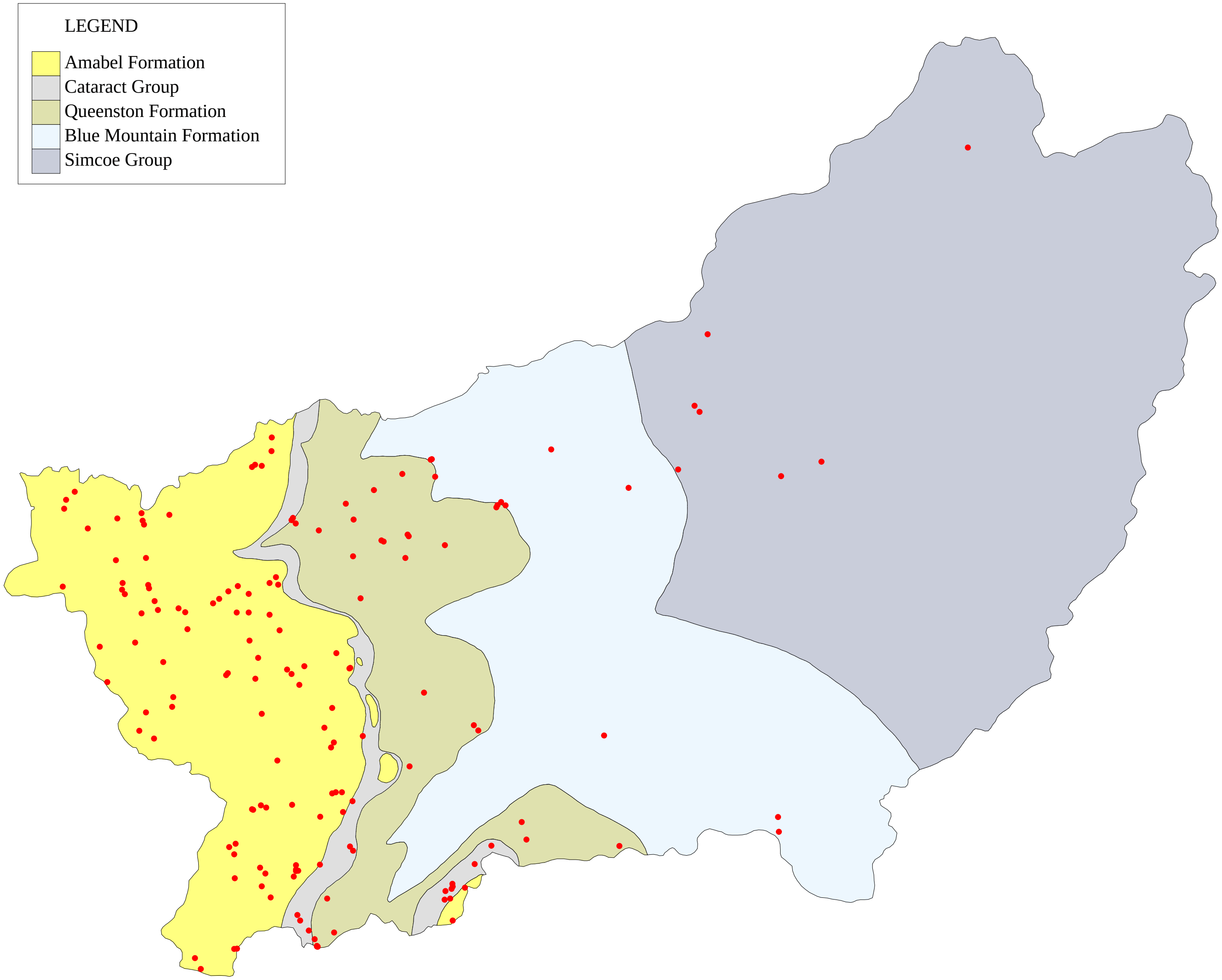


Figure Up-6. Bedrock wells with specific capacities between 5 and 25 l/min/m.

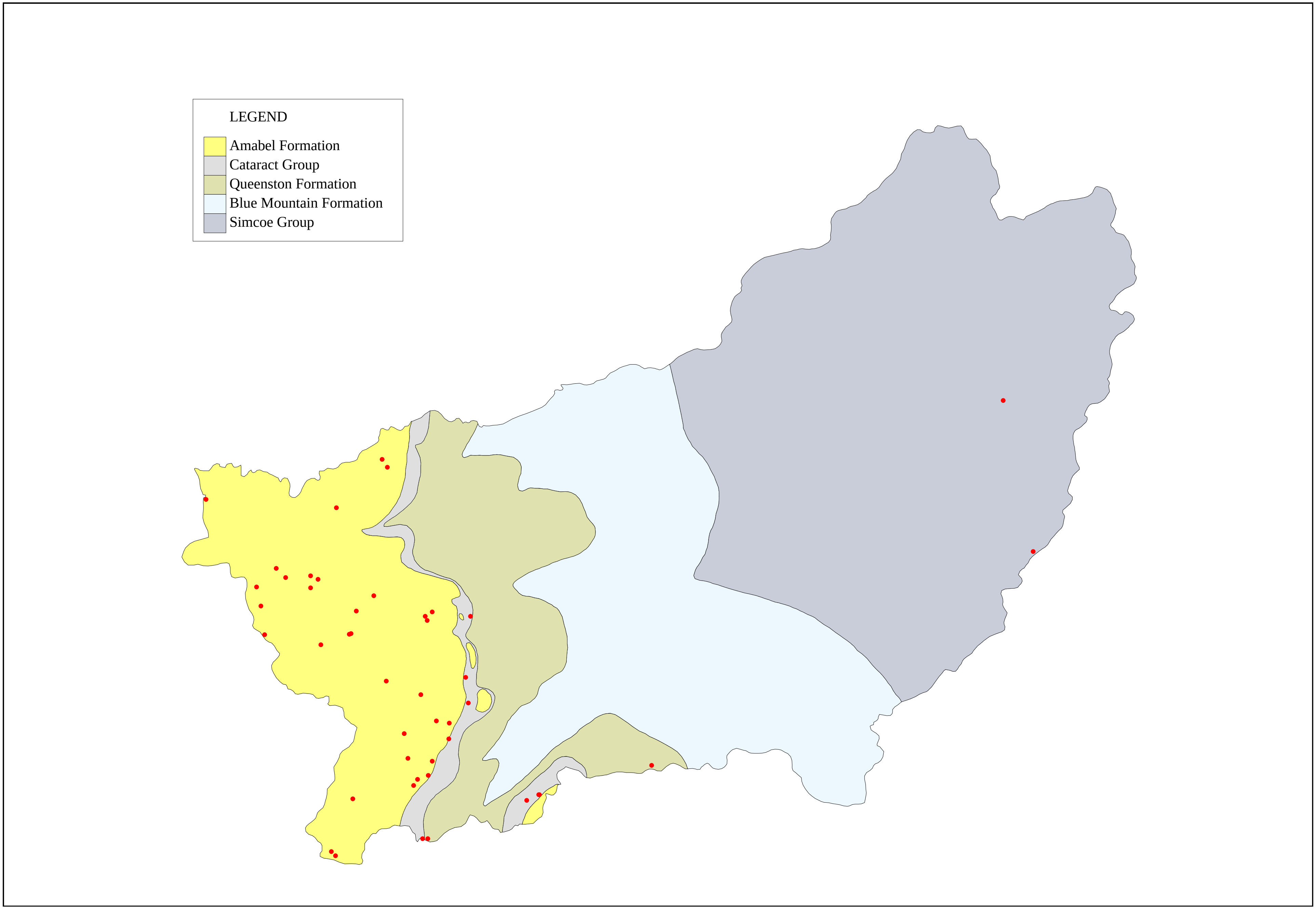


Figure Up-7. Bedrock wells with specific capacities between 25 and 50 l/min/m.

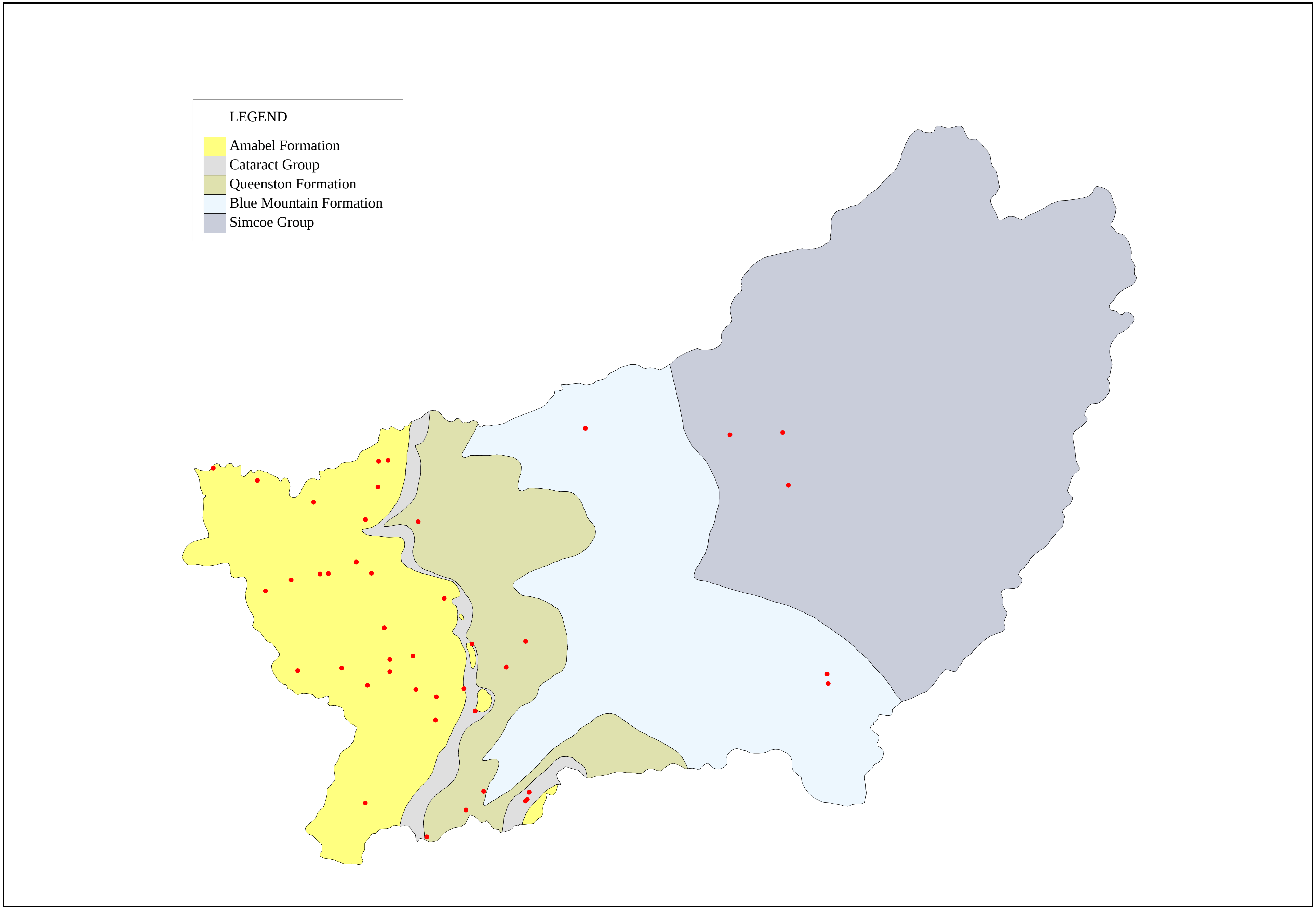


Figure Up-8. Bedrock wells with specific capacities higher than 50 l/min/m.

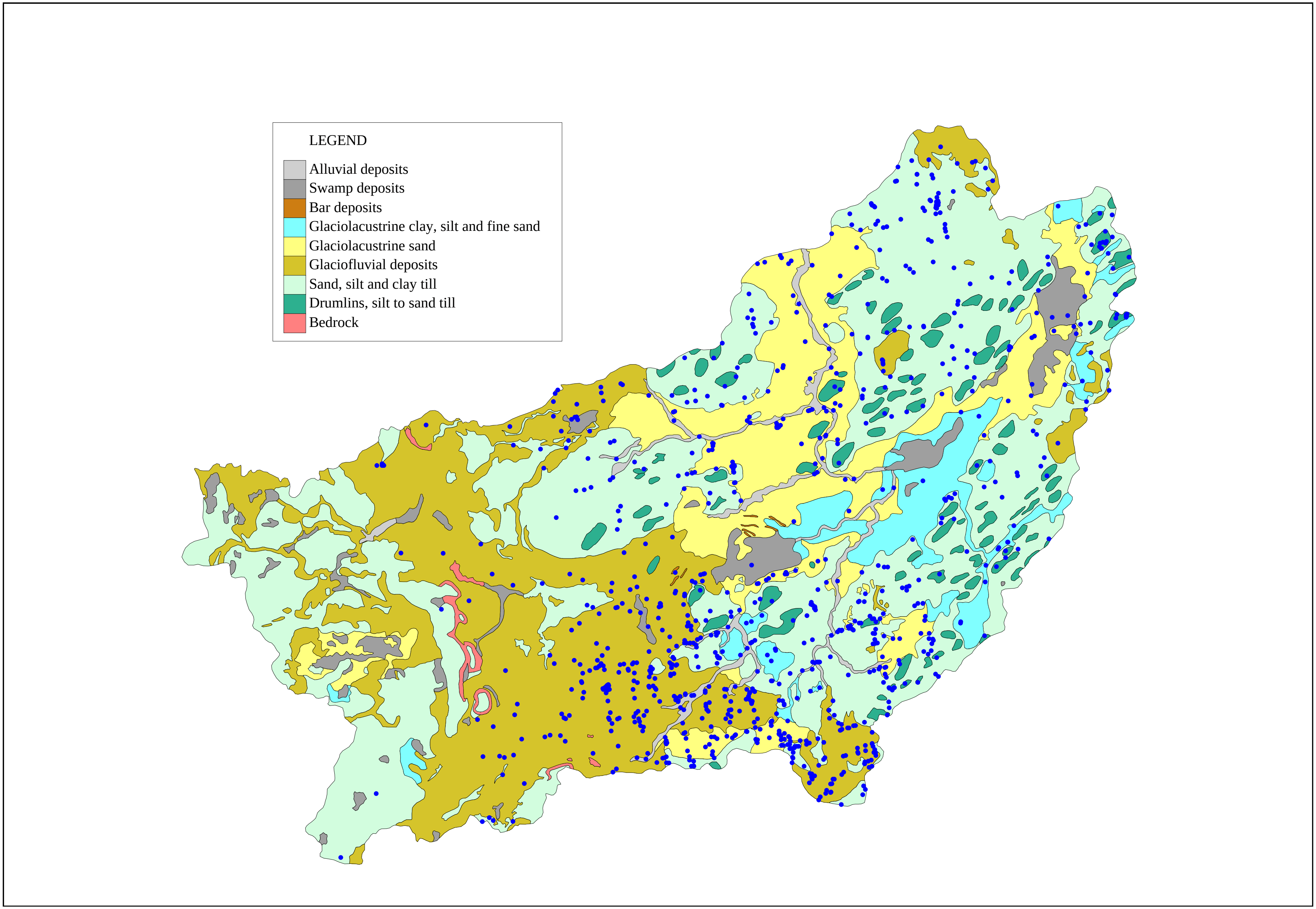


Figure Up-9. Overburden wells with specific capacities equal to or less than 5 l/min/m.

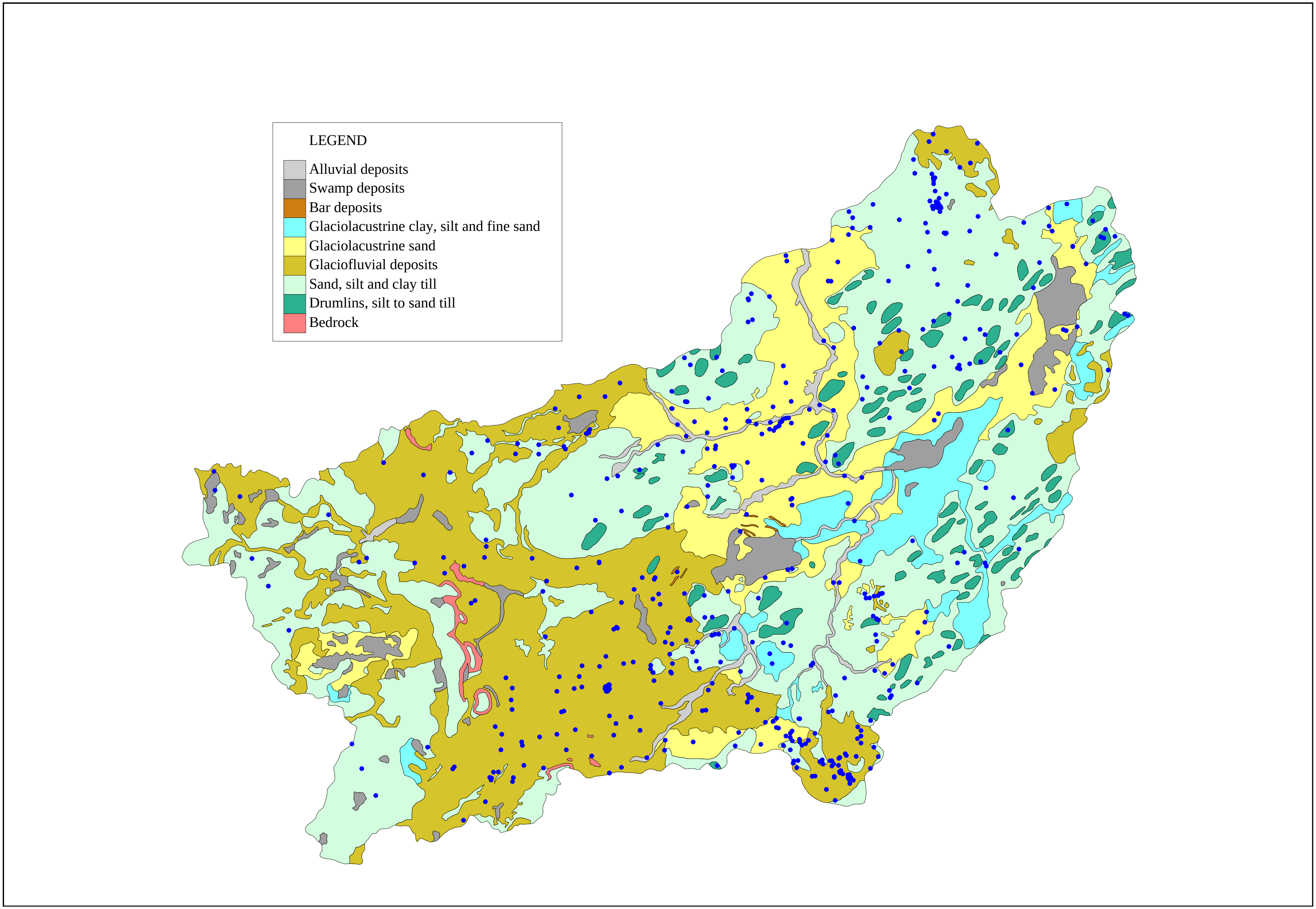


Figure Up-10. Overburden wells with specific capacities between 5 and 25 l/min/m.

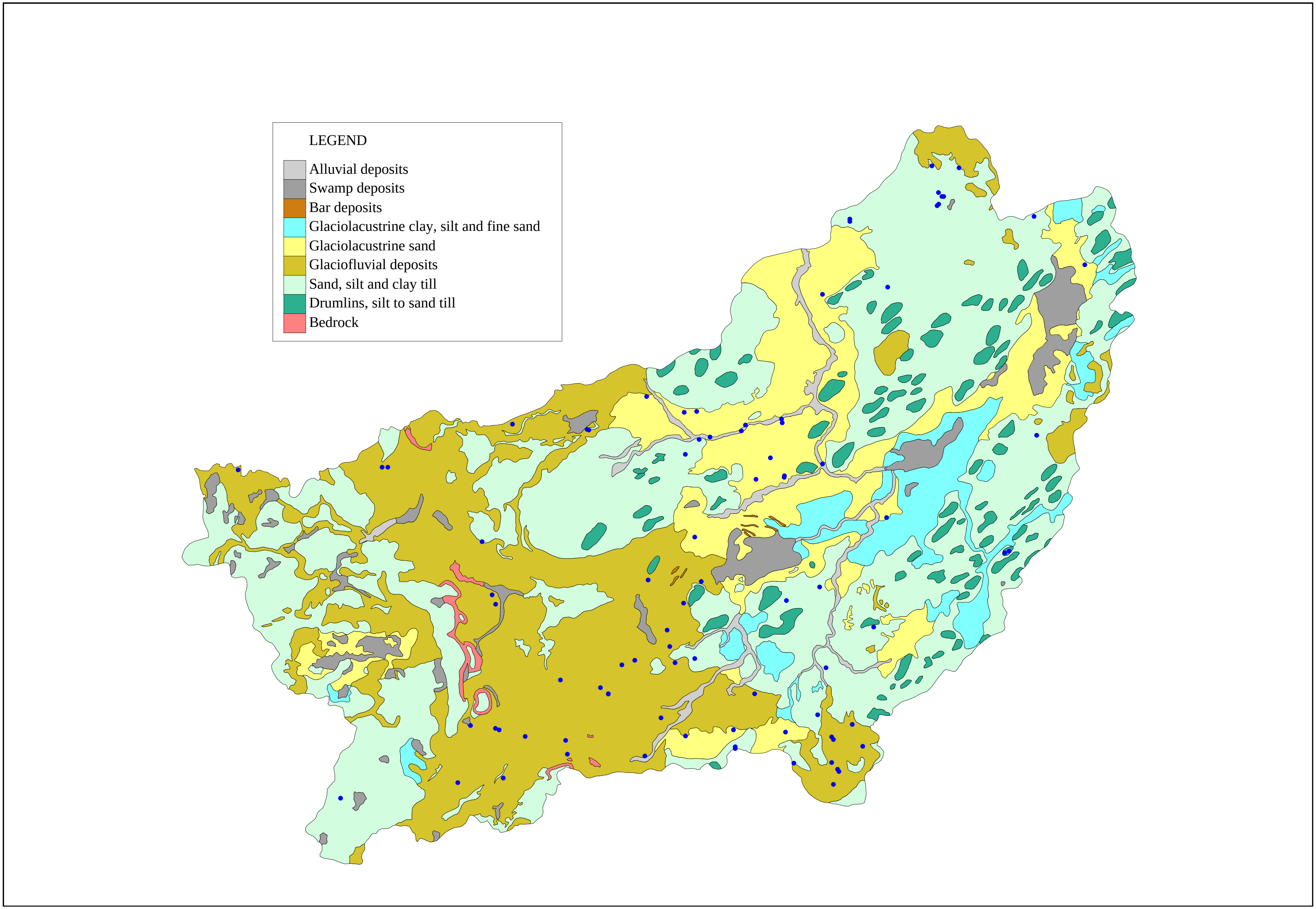


Figure Up-11. Overburden wells with specific capacities between 25 and 50 l/min/m.

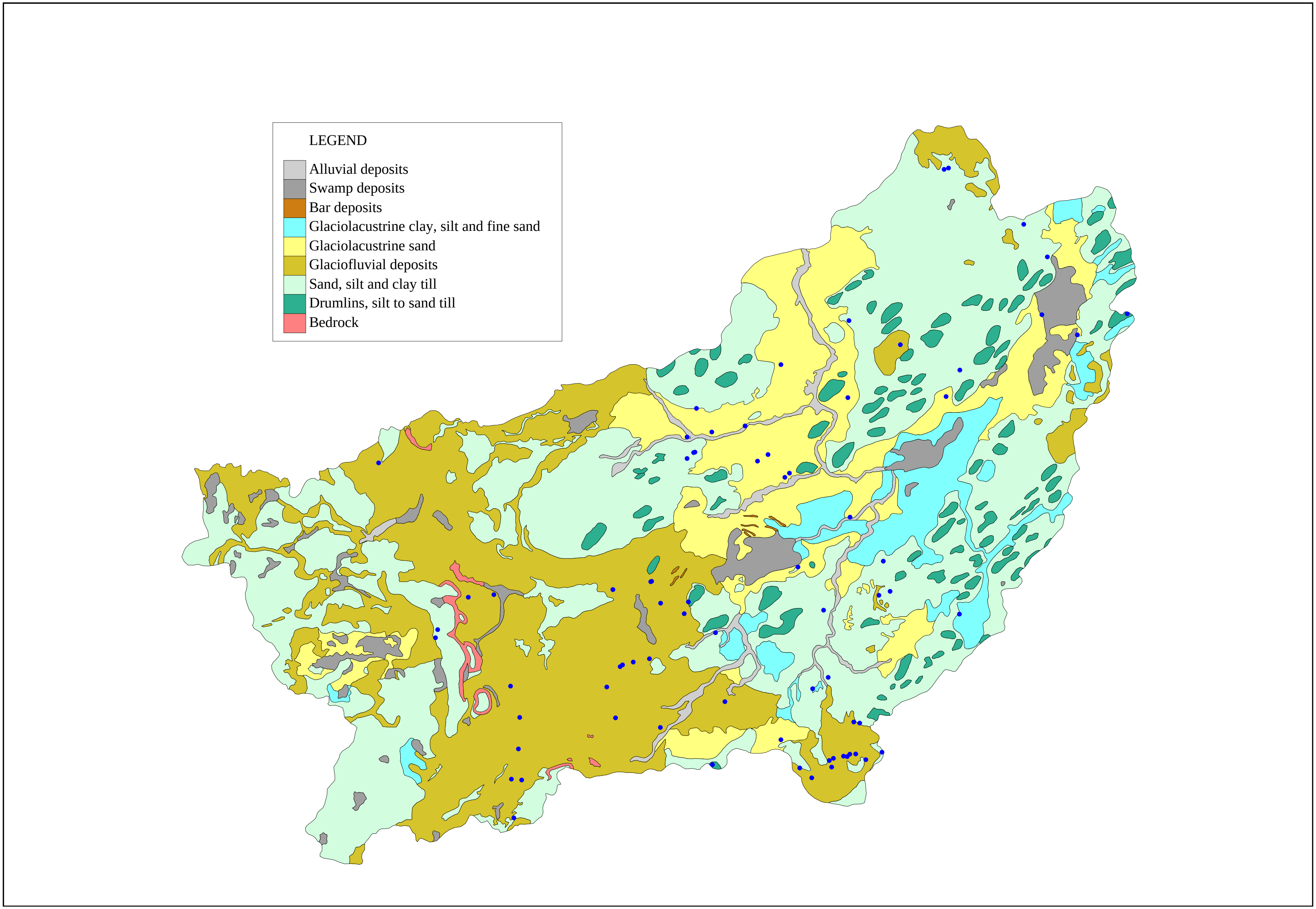


Figure Up-12. Overburden wells with specific capacities higher than 50 l/min/m.

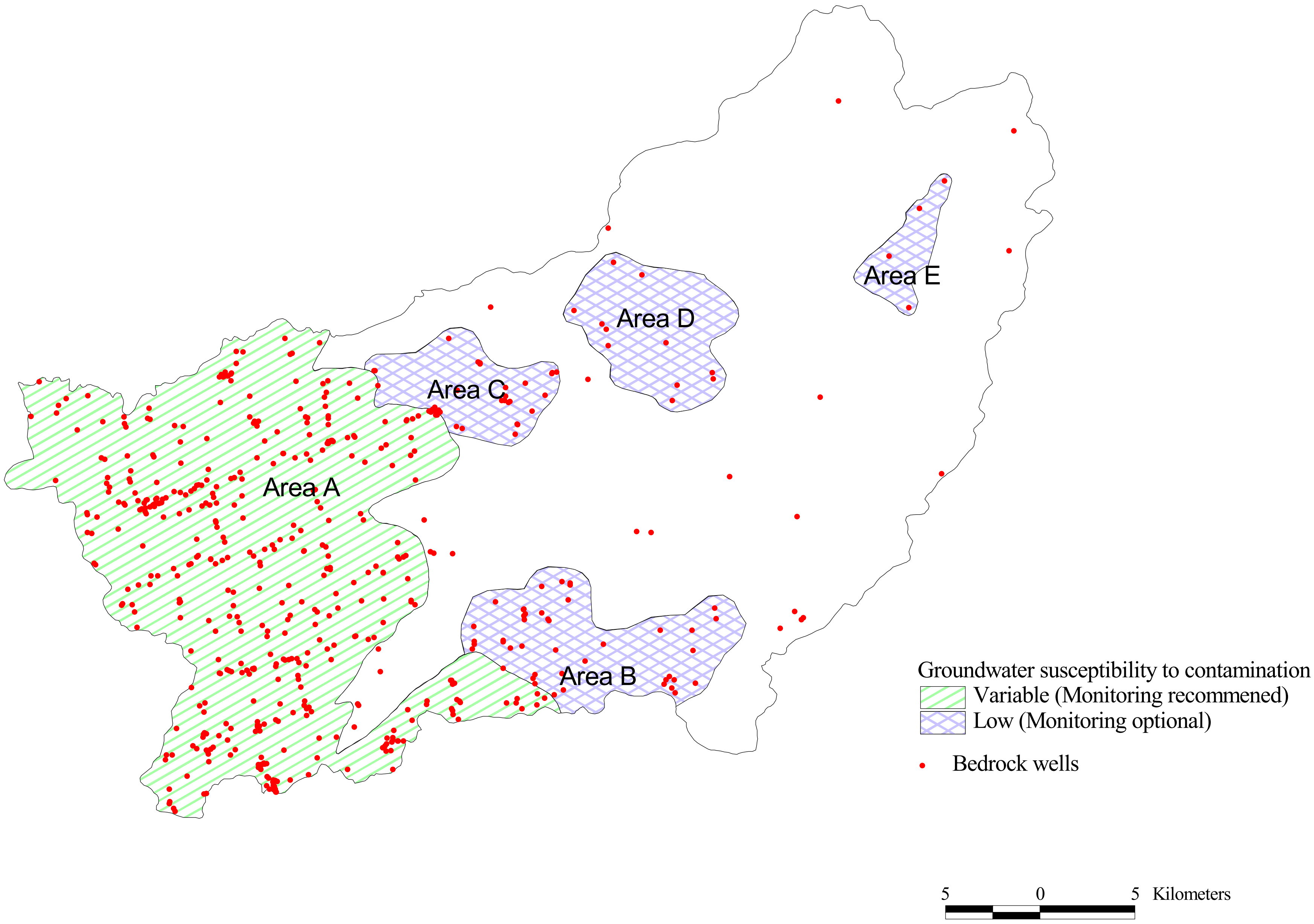


Figure Up-13. Suggested and optional areas for monitoring groundwater in the bedrock.

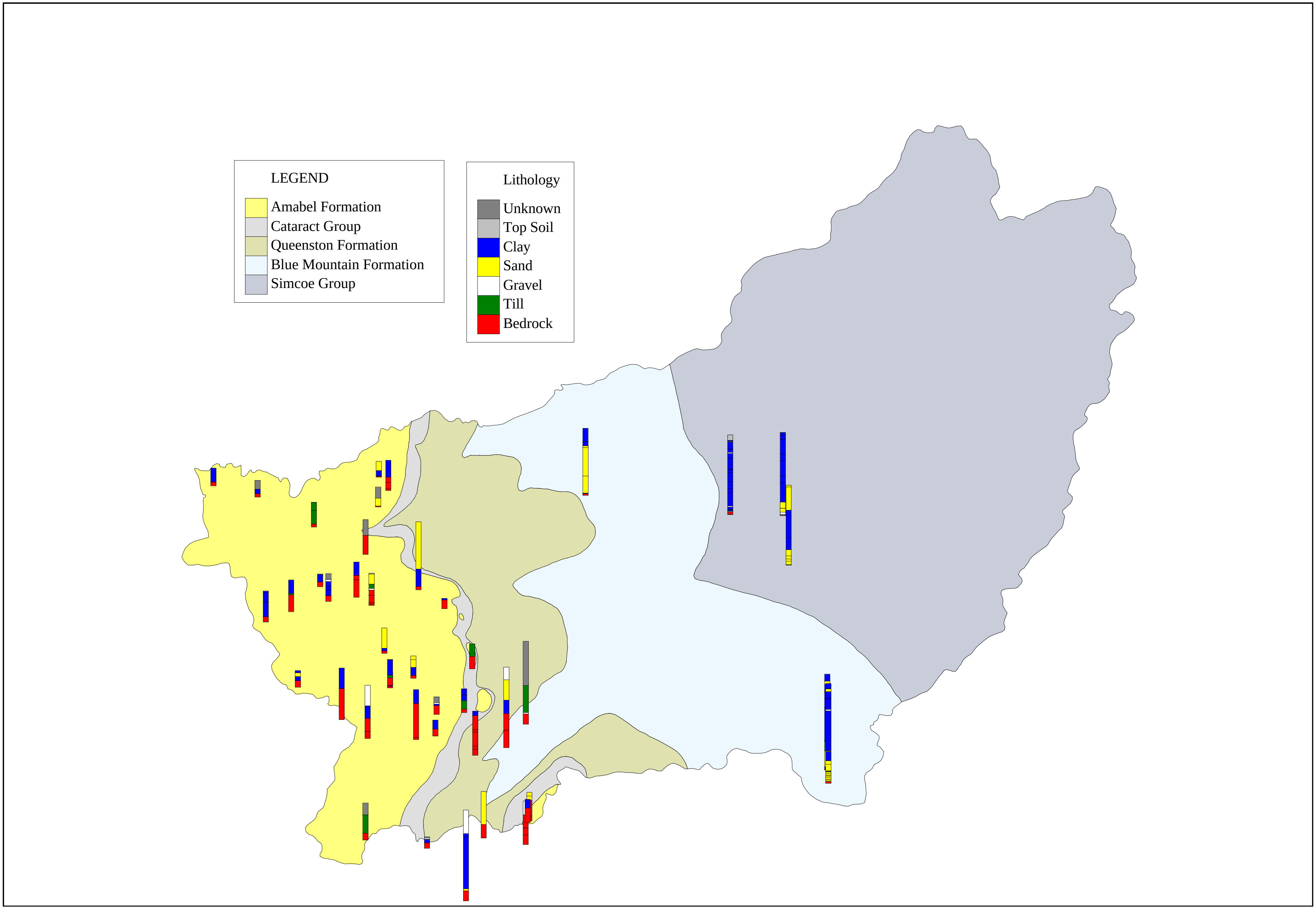


Figure Up-14. Panel diagram showing the geologic logs of bedrock wells with specific capacities higher than 50 l/min/m.

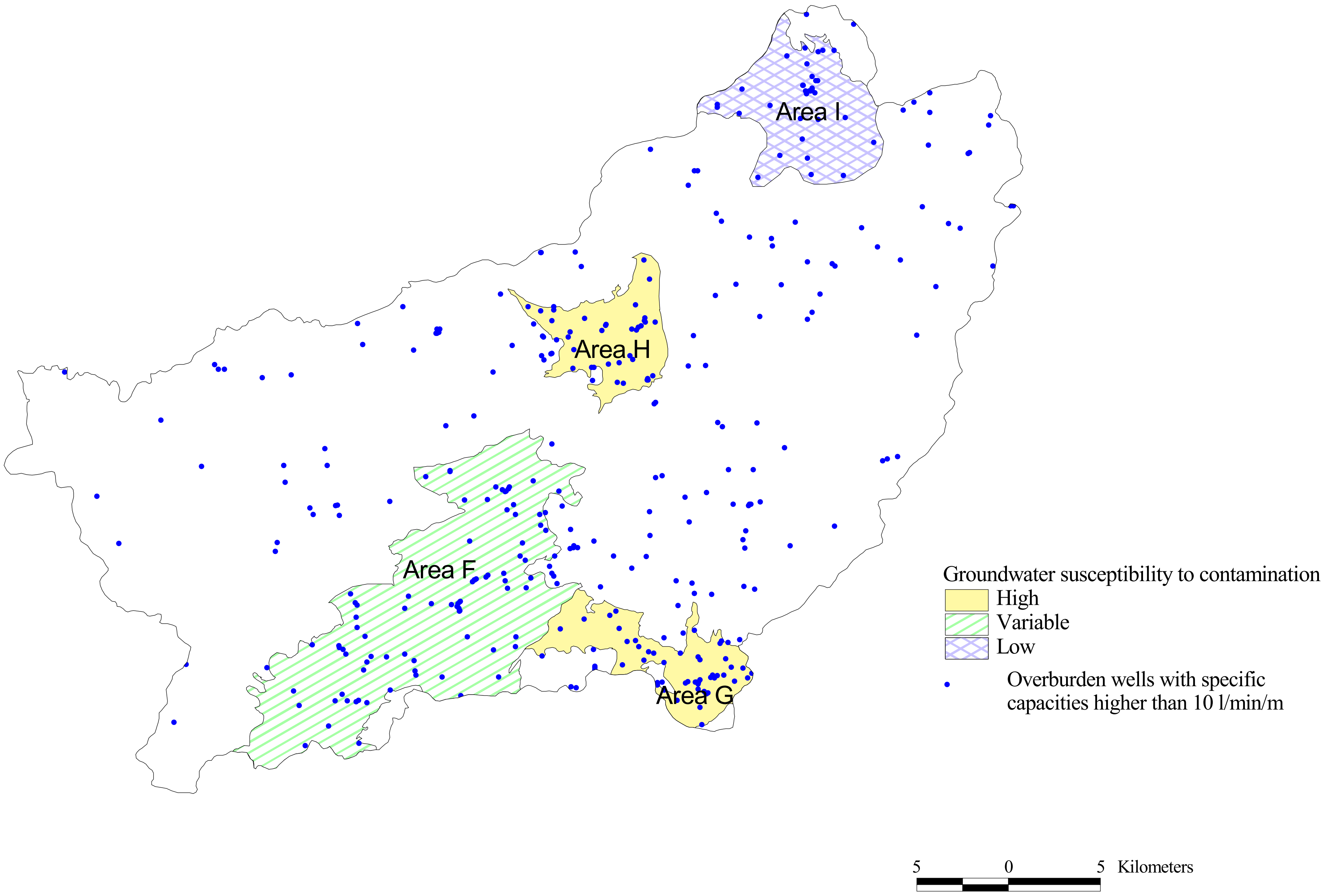


Figure Up-15. Suggested areas for monitoring groundwater in the overburden.

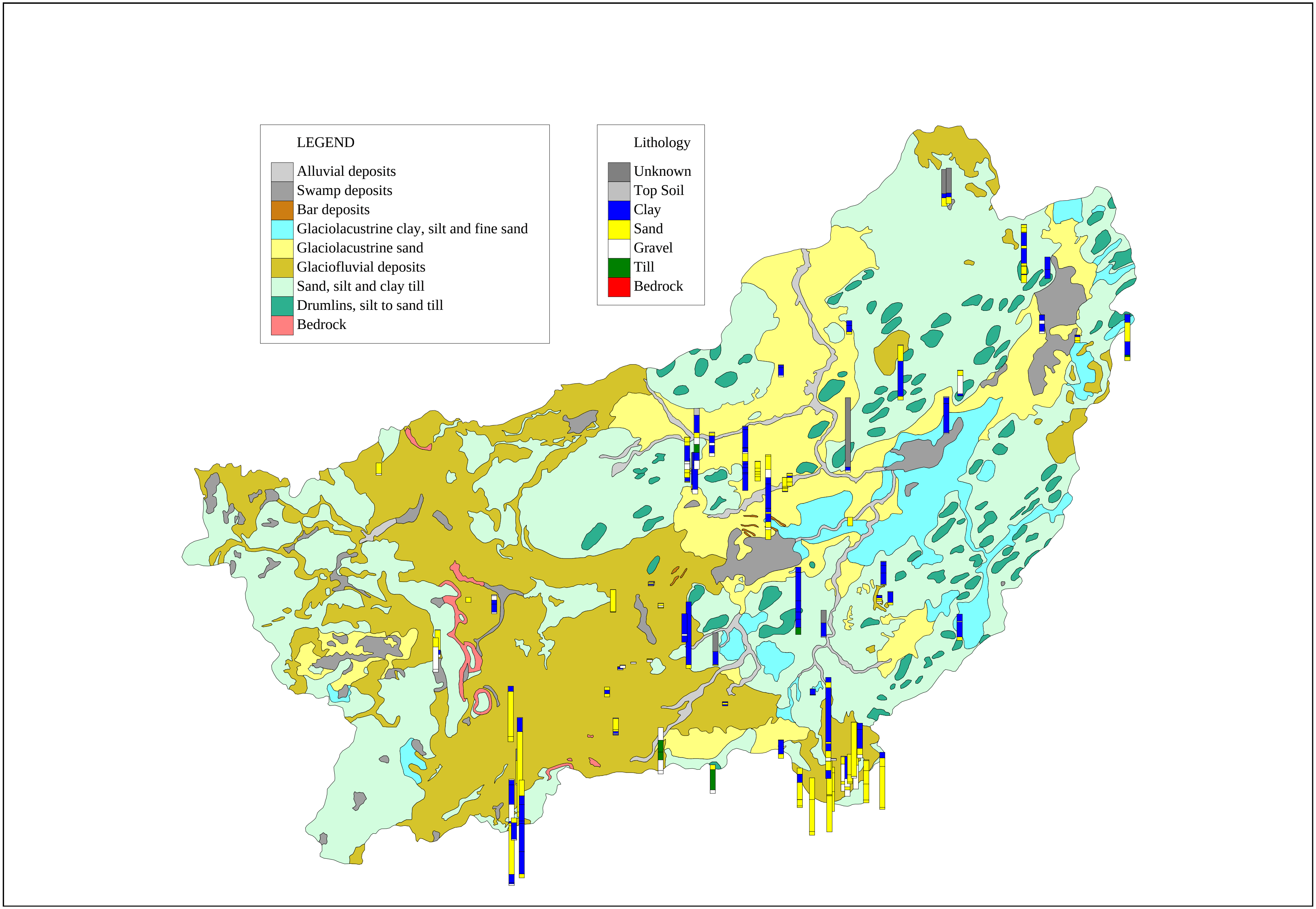


Figure Up-16. Panel diagram showing the geologic logs of overburden wells with specific capacities higher than 50 l/min/m.