CHAPTER FIVE

A PROPOSED GROUNDWATER MONITORING NETWORK FOR THE GRAND RIVER BASIN

By

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5.1 LOCATION

The Grand River drainage basin is located in west central Ontario between latitudes 42^0 50' and $44^0$13' N and longitudes 79^0 29' and 80^0 57' W. The basin has an area of about 6,770 km^2, a length of about190 km, and an average width of about 35 km. Elevations within the basin vary from a high of about 535 m (a.s.l.) near Dundalk to a low of about 174 m (a.s.l.) at Lake Erie.

The Grand River rises northeast of Dundalk at about 526 m (a.s.l.) and drains into Lake Erie at Port Maitland. Chapman and Putnam (1984) noted that the Grand may be divided into an upper part where the river and its branches flow mostly in spillways previously formed in till plains, and a lower part where the river has made its own channel across a lake plain.

The main tributaries to the Grand are the Conestoga, Nith, and Speed Rivers. Other notable but smaller tributaries are Fairchild, Whiteman's, McKenzie, Boston, and Big Creeks. The Conestoga River rises northwest of Arthur, drains an area of about 820 km^2, and has a length of about 82 km. The Nith River rises east of the Milverton Moraine, drains an area of about 1,118 km^2, and has a length of about 158 km. The Speed River rises near Orton, drains an area of about 780 km^2, which constitute the main part of the Guelph Drumlin Field, and has a length of about of 60 km.

The Grand River basin contains the Counties of Wellington and Brand, the Regional Municipality of Waterloo, and parts of the Counties of Grey, Dufferin, Perth and Oxford, and the Regional Municipalities of Hamilton-Wentworth, Halton and Haldimand-Norfolk.

<u>NOTE</u>: 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.

5.2 LAND USE

The Grand River drainage basin contains a variety of physiographic regions, a diversity of soils, and large differences in climatic conditions. The end result is a large variations in land capabilities and land use. Large areas within the basin are used for the production of row crops, cereal wheat, and specialty crops. Other large areas are devoted to fodder corn, mixed grains, hay, and pasture to raise beef animals, hogs, sheep, and poultry. Woodland, forests, idle lands, and wetlands are also found within the basin.

The four cities of Kitchener-Waterloo, Cambridge, Guelph, and Brantford are the largest urban areas within the Grand River basin and contain residential, commercial, and industrial land use types. These cities dominate the commerce of a large part of southwestern Ontario and they are connected with a dense network of roads and highways where large amounts of road salt are being applied during the winter. Other important urban centres include Arthur, Ayr, Caledonia, Drayton, Dundalk, Elmira, Elora, Fergus, Grand Valley, New Hamburg, Paris, and Wellesley.

5.3 GROUNDWATER USE

There are 26,323 records on file with the Ministry of the Environment for wells constructed in the Grand River basin. Of these, 12,666 wells were constructed within the bedrock, 9,796 in the overburden, and the remaining are of unknown type. The majority of the wells are used to meet the needs of rural domestic supplies and livestock watering.

Groundwater is the most important source for municipal water supplies within the Grand River basin. The megalopolis area of Kitchener-Waterloo, Cambridge and Guelph in the central part of the basin is the largest urban area in the province that depends almost exclusively on groundwater for municipal supplies. In addition, there are other small communities in the basin that depend wholly on groundwater for their domestic, commercial and industrial needs. These communities are Arthur, Ayr, Baden-New Hamburg, Caledonia, Dundalk, Elmira-St. Jacobs, Elora, Fergus, Kitchener-Waterloo, Maryhill, Milverton, Paris, Plattsville, Rookwood, and St. George.

5.4 PHYSIOGRAPHY

According to Chapman and Putnam (1984), parts of ten physiographic regions are found within the Grand River basin. These regions include the Dundalk Till Plain, Stratford Till Plain, Hillsburgh Sandhills, Guelph Drumlin Field, Waterloo Hills, Horseshoe Moraines, Oxford Till Plain, Mount Elgin Ridges, Norfolk Sand Plain, and Haldimand Clay Plain.

The Dundalk Till Plain physiographic region is a gently fluted till plain which forms the headwaters of the Grand, Maitland, Nottawasaga, and Saugeen Rivers. The plain is characterized by poor drainage and swamps, bogs, and depressions are common. The chief urban centres on the plain within the Grand River basin are Dundalk, Grand Valley, and Arthur.

The Stratford Till Plain physiographic region extends as a strip south of Grand Valley and Arthur in the Grand River basin to Stratford and London within the Thames River basin. Within the Grand River basin, the plain has a faint knoll and sag relief and is covered by ground moraine which is interrupted by a few terminal moraines. The plain is drained by the Conestoga and Nith Rivers, tributaries of the Grand.

Within the Grand River basin, the Hillsburgh Sandhills physiographic region extends on the south-eastern flank of Dundalk Till Plain from the basin’s topographic divide to an area located to the west of Belwood. The region consists of a moraine which is characterized by a rough topography and sandy materials. The Grand River cuts through this moraine at Belwood where the Shand Dam was constructed. West of Belwood the moraine is smaller and the sand gradually gives way to boulder clay.

The Guelph Drumlin Field physiographic region extends between the Hillsburgh Sandhills in the north and the Paris Moraine to the southeast. The region contains approximately 300 drumlins of all sizes. The drumlins, which are associated with the Lake Ontario Lobe, are characterized by their oval shape and long axes that point due west or northwest. The intervening low ground between the drumlins is largely occupied by gravel terraces and swampy valleys in which the Speed and Eramosa Rivers flow. The main urban centres within this region are Guelph, Fergus, and Elora.

The Waterloo Hills physiographic region is located chiefly within the Regional Municipality of Waterloo but extends into the eastern part of the Township of Blanford-Blenheim, and North Easthope in Perth County. The hills are composed mainly of sand or sandy till while others are kames or kame moraines, with outwash sands occupying the intervening hollows. Adjoining the hilly region is an extensive area of alluvial terraces of the Grand River spillway system. A number of kettle lake and swamps occur in this region. The twin cities of Kitchener-Waterloo and the City of Cambridge are the main urban centres within this physiographic region.

A small area to the southwest of the Waterloo Hill is part of the Oxford Till Plain which extends over most of Oxford County. The plain is composed of calcareous loam till. Also, a small area of the Mount Elgin Ridges physiographic region is within the Grand River basin and is wedged between the Oxford Till Plain to the northwest and the Norfolk Sand Plain to the east and southeast. Two small watersheds within these ridges are drained by the Kenny Creek and the Homer Creek, both tributaries of the Grand.

The Norfolk Sand Plain physiographic region within the Grand River basin is a part of a larger wedge-shaped plain that extends from Lake Erie northward to Brantford on the

Grand River. The plain is composed of sands and silts that were deposited as a delta in glacial Lakes Whittlesey and Warren. Brantford is the main urban center within this region.

The Horseshoe Moraines physiographic region within the Grand River basin is a part of a horseshoe shaped morainic system lying around the upland between Lake Huron, Lake Ontario, and Georgian Bay. Part of the eastern arm of the horseshoe-shaped system is within the basin extending as a strip in a southwesterly direction along the Guelph Drumlin Field and Waterloo Hills and through the Norfolk Sand Plain from the basin’s divide near Acton to the basin’s divide southwest of Paris. The region is hilly and contains numerous gravel terraces.

The lower portions of the Grand River basin are part of the Haldimand Clay Plain physiographic region which extends westward to the Niagara River. The plain is covered mostly by clay and silt which were deposited when the area was submerged in glacial Lake Warren. The Grand River has cut a deep valley in the clay and silt below Brantford. To the east and west of Caledonia and Cayoga, a number of drumlins are scattered over the plain.

5.5 BEDROCK TOPOGRAPHY AND GEOLOGY

Most of the bedrock within the Grand River basin is obscured by the overburden. In the western parts of the basin, the overburden is generally thick whereas in the eastern parts of the basin it is thin and bedrock outcrops are extensive revealing a rough, gently-sloping surface. Outcrops of the Guelph and Lockport-Amabel dolomites can be seen between Hayesland and Sheffield and also occur along Fairchild Creek, Speed River, and Grand River between Galt and Preston. Also, a low-relief bedrock outcrop, known as the Onondaga Escarpment, occurs in the lower parts of the basin to the east of Hagersville.

The bedrock surface has a regional slope from about 500 m (a.s.l.) in the northern parts of the basin to less than140 m (a.s.l.) near Lake Erie (Figure Gr-1). Superimposed on the regional slope are many rises and hollows, the most notable of these are the buried valleys. Many of the buried valleys, particularly the larger ones, appear to be abandoned valleys of earlier water courses. By far the most prominent of these is the Dundas Valley, the lower portion of which extends from southwest of Dundas to south of Burlington. The valley was probably cut by an earlier Grand River and deepened by glacial action. A prominent valley, probably the ancestral Speed River, can be traced from east of Eramosa south to the Reformatory where it jogs southwest and joins the Eramosa River at Victoria Street in Guelph. The valley was probably cut by an earlier Grand River and deepened by glacial action. Also, the Elora-Fergus Valley was identified north of Kitchener-Waterloo.

The Grand River basin is underlain by Paleozoic formations of Ordovician, Silurian, and Devonian age which extend as belts trending almost in north-south direction. The formations consist predominantly of dolomite and limestone with some shale and chert and have a gentle dip westward toward the Michigan Basin. These formations have been classified as Queenston, Whirpool, Manitoulin, Cabot Head, Amabel-Lockport, Guelph, Salina, Bass Island, Oriskany, Bois Blanc, Amherstburg-Onondaga in order of decreasing age from east to west (Sanford 1969; Sibul et al. 1980; Thurston et al.1992).

The rocks of the Queenston Formation of Upper Ordovician age are the oldest rocks in the basin. These rocks consist of red shale and mudstone and are exposed within a small area in the Dundas Valley west of Hamilton. The Whirpool (sandstone), Manitoulin (dolomite), and Cabot Head (shale) Formations of the Cataract Group of Lower Silurian age overlie the Queenston Formation and also outcrop in the Dundas Valley.

The grey to dark brown dolomites of the Amabel-Lockport Formations of Middle Silurian age occurs in the extreme eastern portions of the basin. The Amabel Formation is the northwards equivalent of the Lockport Formation and is distinguished from it by the presence of numerous reef structures. Overlying the Amabel Formation and extending under most of the eastern parts of the basin is the Guelph Formation of Middle Silurian age. The Guelph Formation consists of cream-colored crystalline dolomite. The Salina Formation of upper Silurian age underlies a large portion of the western half of the basin and consists of dolomite, limestone, and shale.

Overlying the Salina Formation, are the dolostones of the Bass Island Formation of Upper Silurian age. The formation subcrops as a narrow band in the extreme western parts of the basin. The Oriskany Formation of Lower Devonian age subcrops within a small area in Oneida and North Cayuga Townships. Overlying the Bass Island Formation with unconformity are the limestones of the Bois Blanc Formation of Middle Devonian age.

The next younger rocks that subcrop in the extreme western portions of the basin are those of the Amherstburg-Onondaga Formations of Middle Devonian age. The Onondaga Formation consists of limestone and the Amherstburg Formation consists of dolomite. The bedrock geology, as mapped by Sandford (1969), is given on Figure Gr-2.

5.6 OVERBURDEN THICKNESS AND GEOLOGY

The Grand River basin has been subjected to glaciation by four different ice lobes which acted independently or in pairs at various times. The lobes involved were the Huron Lobe from the west, the Georgian Bay Lobe from the northwest, the Ontario Lobe from the east, and the Erie Lobe from the southeast. These ice lobes left during their advances and retreats an overburden consisting of glacial, glaciofluvial and glaciolacustrine deposits. The land forms associated with these deposits include ground moraines, end moraines, and drumlins. Parts of a number of end moraines have been identified in the basin. They vary from rough, hummocky accumulations of gravelly till and sand, to gently rolling ridges of silty till. The most important of these are Galt, Waterloo, Breslau, and Paris moraines. Also, numerous drumlins have been identified within the basin and over 300 drumlins have been identified in the Guelph area alone.

5.6.1 Overburden Thickness

The overburden thickness is thin on non-existent in areas where the bedrock outcrops at the surface. Such bedrock outcrops occur along the Fairchild Creek, the Spencer Creek, the Speed and Elora Rivers, the Grand River between Galt and Preston, and at the Elora Gorge in the Elora-Fergus area. In these areas lenses and pockets of drift are seldom more than 5 m thick. In general, the thickness of the overburden increase from east to west. Areas where the overburden thickness is less than 30 m are found in the upper parts of the basin within the Dundalk Till Plain physiographic region, in the east-central parts of the basin within the Guelph Drumlin Field physiographic region, and in the lower parts of the basin mainly within the Haldimand Clay Plain physiographic region. Thick overburden deposits are found within the Waterloo Hills physiographic region. The thickness of these deposits range from 50 to over 110 m (Figure Gr-3).

5.6.2 Glacial Deposits

A number of tills have been identified within the Grand River basin, all are believed to be Wisconsinan, and mostly Late Wisconsinan in age. From oldest to youngest, they are known as the "Lower Beds", Canning Till, Pre-Catfish Creek tills, Catfish Creek Till, Stirton Till, Maryhill Till, Tavistock Till, Port Stanley Drift, Mornington Till, Stratford Till, Wartburg Till, Elma Till, Wentworth Till, and Halton Till. A simplified map of the surficial geology is given on Figure Gr-4.

According to Karrow (1987), the "Lower Beds" unit, which consist mainly of silt till and some sand and gravel, includes all the unclassified sediments below the Canning Till. These beds occur along the Nith River. Also, parts of some of the lower beds of sections near Kitchener probably are of similar age. The beds were tentatively considered to be of early Wisconsinan age.

The Canning till is a nearly pebble-free, silty clay or clayey silt till. It is known to be exposed only in sections along the Nith River and possibly the Grand River (Karrow 1987). The Canning Till was also reported in two boreholes drilled in the Waterloo area (Karrow et al. 1993). Similar fine grained till occurs beneath Catfish Creek Till in the Brantford area (Cowan 1975).

Pre-Catfish Creek tills have been identified in a number of boreholes in the Waterloo area where the Catfish Creek Till lies directly on bedrock. The tills range in texture from silty sand till to clayey silt till. (Karrow et al. 1993). Also, on the east side of Belwood Lake, an exposure of possible Catfish Creek Till was found overlying stratified sand containing clayey silt till. This may represent a till older that the Catfish Creek till or it may be a lens within it (Cowan 1976).

The Catfish Creek Till is usually covered by younger deposits and, therefore, has limited exposure at the surface within the upper parts of the basin. Other outcrops of this till occur in deeply eroded sections along the Conestogo, Nith, and Grand Rivers (Cowan 1976 and1979). The till, which is compact, and has a sandy silt texture, has been also encountered in deep wells in the Waterloo area (Karrow 1987). In the Waterloo area, this till is associated with glaciofluvial silt, sand, and gravel (Karrow et al.1993; Cowan 1976,1979). The geologic logs of the majority of water wells that have been constructed in areas where this till outcrops at the surface do not show any sand or gravel deposits at depth.

The Stirton Till, which is associated with Georgian Bay Lobe, has been observed along the Conestogo Valley between Arthur and Drayton and is thought to be limited to the Conestogo watershed area. The till is usually overlain by Tavistock Till and it is a silt to silty clay till which is dark grey to brown in colour. Based on its stratigraphic position, Karrow (1974) assigned Stirton Till to the Port Bruce Stadial and suggested that it may correlate with the Maryhill Till of the Ontario Lobe to the east.

The Maryhill Till is a silty clay to clayey silt till with a low pebble content and a moderate carbonate content. It occurs along the banks of the Grand River, in the parts of some of its tributary streams such as the Laurel Creek, and in the Guelph area along the Breslau Moraine (Karrow 1987). Drilling in the Waterloo area indicates that Maryhill Till overlies the Catfish Creek Till and is associated with glaciofluvial and glaciolacustrine sediments as well as with local tills (Karrow et al. 1993). The geologic logs of the majority of water wells that have been constructed in areas where this till outcrops at the surface show extensive sand or gravel deposits at depth.

The Tavistock Till is a silt to a clayey silt till containing about two percent pebbles. It frequently overlies the Catfish Creek Till in the Grand River basin. The Tavistock Till is associated with the Huron-Georgian Bay Lobe and was formerly mapped as the "Northern Till" in the Guelph area (Karrow 1968) and as "Till C" in the Conestogo area (Karrow 1971). Drilling in the Waterloo area indicates that the Tavistock Till directly overlies the Catfish Creek Till where the Maryhill Till is not present. Otherwise, it overlies the Maryhill Till (Karrow et al. 1993). With the exception of a small area along the western boundary of the basin to the southwest of New Hamburg, the geologic logs of the majority of water wells that have been constructed in areas where this till outcrops at the surface do not show sand or gravel deposits at depth.

The Port Stanley Till varies in texture from sandy silt to clayey silt till and is associated with the Ontario-Erie Llobe. The till occurs at the surface within the Guelph Drumlin Field physiographic region. It is also exposed along the Nith River (Karrow 1963; Cowan 1976) and between Ayr, Paris, and the basin's western topographic divide.

The Mornington Till occurs as a thin ground moraine and is considered by some to be an upper member of Tavistock Till (Cowan 1979). The till is a dark grey to grey silty clay till with rare pebbles. It is very similar texturally and lithologically to both the Tavistock and Stirton Tills. Mornington Till outcrops over an area extending between New Hamburg and Milverton and the basin's western boundaries. The till represents a readvance during retreat of the Tavistock ice. Due to its stratigraphic position, Mornington Till has been assigned to the Port Bruce Stadial (Karrow 1974). The geologic logs of the majority of water wells that have been constructed in areas where this till outcrops at the surface do not show any sand or gravel deposits at depth.

The Stratford Till is a strongly calcareous, sandy silt to silt till. The till is associated with the Huron-Georgian Bay Lobe, and occurs as a thin ground moraine sheet along the western boundaries of the basin to the west of Wellesley and New Hamburg. The Stratford Till is commonly overlain by thin deposits of glaciolacustrine silt and clay. The geologic logs of the majority of water wells that have been constructed in areas where this till outcrops at the surface do not show any sand or gravel deposits at depth.

The Wartburg Till is calcareous, silty clay till, which is very poorly sorted and non-stratified. The till is associated with the Huron-Georgian Bay Lobe. The stratigraphic relationships of the Wartburg Till are poorly known. It forms the core of the Milverton moraine and occurs as ground moraine that is largely buried by Elma Till. A very small outcrop of this till is located along the basin's western boundary to the south of Milverton.

The Elma Till is a deposit of the Georgian Bay lobe. It is calcareous silt, sandy silt to clayey silty till. The till occurs as ground moraine along the western boundaries of the basin to the southwest of Dundalk and between Milverton and Drayton. In other locations, the till is overlain by glaciofluvial sand and gravel, glaciolacustrine silt and younger tills. The geologic logs of the majority of water wells that have been constructed in areas where this till outcrops at the surface do not show any sand or gravel deposits at depth.

The Wentworth Till is sandy till and is usually separated from the lower beds by sand and gravel deposits of kame and outwash origin. The till was deposited by the Ontario-Erie Lobe and it forms the Paris, Galt, and Moffat Moraines (Karrow 1987). The till also outcrops as small drumlins in the lower parts of the basin. The geologic logs of the majority of water wells that have been constructed in areas where this till outcrops at the surface do not show any sand or gravel deposits at depth.

The Halton Till occurs as low-relief ground moraine along the topographic divide north west of Hamilton and, also, in small areas in the lower parts of the basin. Halton Till is predominantly a silt till.

5.6.3 Sand and Gravel Deposits of Glaciofluvial and Glaciolacustrine Origin

Large areas within the Grand River basin are covered with sand and gravel deposits of glaciofluvial or glaciolacustrine origin. The most extensive sequences of these deposits occur throughout most of the Regional Municipality of Waterloo and in Wellington, Brant and Oxford Counties.

The glaciofluvial deposits are associated either with ice-contact stratified drift or with outwash plains and meltwater channels. The ice-contact stratified drift consists primarily of glaciofluvial sediments but may contain lacustrine sediments and till locally. They are characterized by great variability, collapse features, and hummocky topography. Kames, eskers, and end moraines are considered ice-contact deposits.

Kames are found between Doon and Centreville, northwest of Glen Morris, east of Fergus, and southeast of Guelph. Extensive kame sands with some gravels also occur in the Easthope, Waterloo, and Elmira Moraines. Irregular grain-size, sorting, and bedding, and collapse faults are characteristic features.

According to Sibul et al. (1980), the most extensive surficial deposits of sands and gravels in the basin occur throughout most of the Regional Municipality of Waterloo. The materials, for the most part, compose the Waterloo and Elmira Moraine complexes and consists of poorly to well-sorted kame sands and gravels, with associated outwash channels containing well-sorted, fine to coarse sand and fine to medium gravel. Thicknesses of surficial sands and gravels throughout this area range generally from 5 to 15 m, with deposits of up to 40 m occurring locally in Wilmot, Woolwich and Wellesley Townships.

Three prominent eskers extend obliquely across the Guelph Drumlin Field from the Eramosa Valley to the Grand Valley. Their length varies from 15 to 20 km and their height from zero to nearly 15 m. Several smaller eskers may be seen east of Fergus and within the Paris and Galt moraines (Karrow 1987).

Outwash deposits occur as channel fills, terraces along meltwater channels, sheet sands, and gravelly braided outwash between ridges of ice-contact deposits. The outwash deposits are characterized by level to undulating surfaces marked here and there by stream channels and sometimes by kettles. A large area of outwash deposits within the basin appears to be associated directly or indirectly with the Paris and Galt Moraines. Prominent outwash terraces exist along the Grand and Speed Rivers, and an outwash plain separates the Paris and Galt Moraines between Killean Station and Aberfoyle.

Intimately associated with the outwash deposits are the meltwater channel deposits that are sometimes referred to as spillways. The Grand River channel is the largest present-day stream. The channel originated during the retreat of the Tavistock ice from the Orangeville Moraine. A second channel is about 7 km long and is occupied by a tributary of the Schneider Creek. A third channel came down the Speed River Valley and joined with the Grand River at Preston, as it does today, but then continued southwest to the Nith River valley along a valley now occupied by the Cedar Creek. A fourth channel follows the Conestogo River south of Highway 9. In addition, numerous small channels occur within the Guelph Drumlin Field.

5.6.4 Silts and Clays of Glaciolacustrine Origin

Almost all of the lower parts of the Grand River basin from Brantford to Port Maitland are covered with glaciolacustrine sediments consisting of clay, silt, shallow water sand, beach bars, and near shore deposits. Small areas of stratified silt, with some clay and sand are also found to southeast of Guelph in the Paris-Galt moraine complex. Subsurface occurrences of such sediments are found in three stratigraphic positions along the Conestogo River. The oldest occur between the Catfish Creek and Stirton Tills, the next oldest between The Stirton and Tavistock Tills, and the youngest between the Tavistock and Mornington Tills (Cowan 1979).

5.6.5 Recent Deposits

Alluvial deposits of stratified gravel, sand, and silt, border most of the streams within the basin. In studying the stream valleys, it is difficult to distinguish between those terraces which were formed during glacial time and those which were formed during post-glacial time. Extensive alluvial terraces occur along the portion of the Grand River between Inverhaugh and Bloomingdale.

Swamps and bogs, filled into varying depth by organic soil, peat, and muck and muds are numerous within the basin. The largest swamp is the Beverly Swamp which is found east of the Galt and Moffat Moraines. Smaller swamps are numerous in the basin and are found west of Mill Grove, south of Campbellville, north of Lake Medad, between Ayr and Blair, east of Kitchener, within the belt occupied by the Paris Moraine, and within the outwash in front of the Galt Moraine.

5.7 GROUNDWATER OCCURRENCE IN THE BEDROCK

As indicated earlier, most of the wells in the Grand River basin are bedrock wells. Sibul et al. (1980) indicated that the highest groundwater yields from the bedrock, in excess of 900 l/min, are found in the central, northwestern, and northern parts of the basin, generally corresponding to areas of permeable limestones and dolomites. Guelph, Lockport, and

Amabel Formations of Middle Silurian age and the Salina Formation of Upper Silurian age are the most productive and the most widely used bedrock aquifers within the basin. Due to their limited extent within the basin, the Bass Island and Bois Blanc Formations which are highly productive are not widely used as sources of water supply.

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. The permeability of the Amabel, Lockport and Guelph aquifer is highly variable and it is due primarily to presence of fractures and the chemical dissolution of the upper few metres of dolomites. Most domestic wells obtain adequate water supplies with penetrations of less than 3 m and the potential for developing high-capacity wells in the aquifer is good.

Sibul et al. (1980) indicated that domestic supplies can be obtained readily throughout the Amabel, Lockport and Guelph Formations; and high-capacity, municipal wells that tap the formations provide water supplies for the cities of Cambridge, Guelph and many other smaller towns. Areas containing highest well yields, outside of the major urbanized areas, are located in the vicinity of the Towns of Fergus-Elora, Arthur and Dundalk, and in the Townships of Puslinch, Erin, Amaranth and East Luther.

According to Sibul et al.(1980), the depths of wells in the Amabel, Lockport and Guelph Formations are variable, depending on the overburden thickness. Generally, most of the domestic wells obtain water from the upper 15 m of the aquifer, while municipal and some industrial wells penetrate the bedrock to depths of 30 to 188 m.

Singer et al.(1997) selected a sample of 6,516 wells constructed within the Amabel Formation in southern Ontario to determine the transmissivity distribution for the formation. The minimum and maximum transmissivity values for the sample were estimated to range between 0.1 and 7,550 m^2/day, respectively. The 10 and 90 percentile values were estimated to range between 1.54 and 134.80 m^2/day, respectively, and the geometric mean of the sample's transmissivity distribution was estimated to be about 15.5 m^2/day.

A second sample of 1,662 wells was selected by Singer et al.(1997) to determine the transmissivity distribution for wells completed in the Lockport Formation. The minimum and maximum transmissivity values were estimated to range between 0.1 and 1,880 m^2/day, respectively. The 10 and 90 percentile values were to range between 1.69 and 141.00 m^2/day, respectively, and the geometric mean of the second sample's transmissivity distribution was estimated to be about 21 m^2/day.

A third sample of 6,072 wells was selected by Singer et al.(1997) to determine the transmissivity distribution for wells completed in the Guelph Formation. The minimum and maximum transmissivity values were estimated to range between 0.1 and 5,720 m^2/day, respectively. The 10 and 90 percentile values were estimated to range between 1.4 and 105 m^2/day, respectively, and the geometric mean of the third sample's transmissivity distribution was estimated to be about12 m^2/day.

According to Singer et al.(1997), the transmissivity values determined for the Amabel, Lockport and Guelph Formations indicate that the water-yielding capabilities of the three formations are highly variable, which is most likely a reflection of the variable distribution of the fissure systems within the formations. Nevertheless, the 10 and 90 percentile values for the transmissivity distributions of the three samples are within similar range.

Given the large number of wells in the above three samples, Singer et al.(1997) assumed that the transmissivity distributions for the three samples are representative of the water-yielding capabilities of the Amabel, Lockport and Guelph Formations. The relatively high values of the geometric means of the three distributions suggest that the water-yielding capabilities of the three formations are good.

Sibul et al.(1980) described the Salina Formation as a high-capacity, water-supply source north of Kitchener-Waterloo. The authors also reported on substantial fracturing within the formation that was encountered in two test holes located south of Kitchener. Mud circulation could not be maintained in both test holes after approximately 1m of penetrating the bedrock. According to Sibul et al.(1980), the fracturing at both test holes is indicative of the high permeability of the Salina Formation.

Singer et al.(1997) identified a sample of 2,994 wells constructed within the Salina Formation in southern Ontario to determine the transmissivity distribution for the formation. The depths of these wells vary considerably due to large variations in overburden thickness. Once through the overburden, however, the wells penetrate generally less than 15 m into the Salina Formation. The minimum and maximum transmissivity values were estimated to range between 0.1 and 10,200 m^2/day, respectively. The 10 and 90 percentile values were estimated to range between 3 and 190 m^2/day, respectively, and the geometric mean of the sample's transmissivity distribution was estimated to be 28 m^2/day.

Given the large number of wells in the sample, Singer et al.(1997) assumed that the sample's transmissivity distribution is representative of the water-yielding capability of the Salina Formation. The relatively high value of the distribution's geometric mean suggests that the formation has a very good water-yielding capability.

A sample of 739 water wells was within the Bass Island Formation in southern Ontario by Singer et al.(1997) to determine the transmissivity distributions for the wells within the unit. The minimum and maximum transmissivity values were estimated to range between 0.4 and 14,220 m^2/day, respectively. The 10 and 90 percentile values were estimated to range between 5 and 180 m^2/day, respectively, and the geometric mean of the transmissivity distribution was estimated to be 31 m^2/day. Given the large number of wells in the sample, Singer et al.(1997) assumed that the sample's transmissivity distribution is representative of the water-yielding capability of the Bass Island Formation. The relatively high value of the distribution's geometric mean suggested that the unit has a very good water-yielding capability.

A sample of 1,069 water wells was selected within the Bois Blanc Formation in southern Ontario by Singer et al.(1997) to determine the transmissivity distributions for the wells within the unit. The minimum and maximum transmissivity values were estimated to range between 0.4 and 3,900 m^2/day, respectively. The 10 and 90 percentile values were estimated to range between 6 and 275 m^2/day, respectively, and the geometric mean of the sample's transmissivity distribution was estimated to be 40 m^2/day. Given the large number of wells in the sample, Singer et al.(1997) assumed that the sample's transmissivity distribution is representative of the water-yielding capability of the Bois Blanc Formation. The relatively high value of the distribution's geometric mean suggests the unit has an excellent water-yielding capability.

Data related to short-term pumping tests are available for 10,615 bedrock wells in the basin. The data indicate that 3,114 wells (29.3%) have specific capacities ranging from 1 to 5 l/min/m (Figure Gr-5), 4,713 wells (44.4%) have specific capacities between 5 and 25 l/min/m (Figure Gr-6), 1,208 wells (11.4%) have specific capacities between 25 and 50 l/min/m (Figure Gr-7), and the remaining 1,583 wells (14.9%) have specific capacities larger than 50 l/min/m (Figure Gr-8). These figures indicate that the Guelph, Lockport, Amabel, and Salina Formations are the major groundwater sources within the Grand River basin.

5.8 GROUNDWATER OCCURRENCE IN THE OVERBURDEN

Of a total of 26,323 well records on file with the Ministry of the Environment, 9,796 records (37%) are for wells completed in the overburden. This indicates that the overburden is a significant source of groundwater within the Grand River basin.

High water yielding deposits of extensive sands and gravels are found at different depths and locations within the basin. Sibul et al. (1980) identified a number of such deposits (aquifers), including:

S A sequence of fine to coarse sands and gravels (3 to 10 m thick and 15 to 50 m deep) extends from southern Waterloo Township through much of North Dumfries Township to Ayr.

S A sequence of fine to coarse gravels occurs at depths between 35 to 53 m in the vicinity of Ayr.

S A sequence, confined by lacustrine clays and till(s), of medium to coarse sands and gravels of outwash origin (8 to 9 m thick and 25 to 35 m deep) occurs to the east of the City of Cambridge.

- A sequence of basal outwash sands and gravels (about 6 m thick and 18 to 27 m beep) extends along the Grand River northeast of Paris.

- Permeable deposits, possibly contained in kame materials and inter-layered with till(s), occur in the vicinity of Elmira.

- Sequences of sand and gravel up to 25 m thick occur in the immediate vicinity of Elmira.

- Fine to medium sand, confined by tills and inter-glacial sediments, occur in the vicinity of St. Clements.

- Sand and gravel deposits inter-layered with till occur at varying depths above basal deposits between the Towns of Milverton and Wellesley.

- Complex sequences of inter-glacial materials (5 to 20 m thick) occur throughout much of Waterloo Township and are thickest west of Kitchener-Waterloo and in the vicinity of Baden.

- Medium sands and gravels at depths of 38 to 68 m occur in South Dumfries Township.

- Gravel deposits (3 to 6 m thick and 20 to 65 m deep), overlain by a complex of sediments consisting of fine sands, silts, clays and tills, occur to the north of St. George.

- Sand and gravel deposits overlain by clay (about 3 m thick and 17 to 40 m deep) occur south of St. George; and

- Several sand and gravel deposits (5 to 7 m thick and 5 m to 50 m deep) of relatively limited lateral and vertical extent occur west and northwest of Paris, west of Brantford, in the area southeast of Victoria Mills, and near Cayuga and north of Dunnville.

Data related to short-term pumping tests are available for 6,762 overburden wells in the basin. Of these,1,065 wells (15.7%) have specific capacities ranging from 1 to 5 l/min/m (Figure Gr- 9), 3,156 wells (46.7%) have specific capacities between 5 and 25 l/min/m (Figure Gr-10), 1,145 wells (16.9%) have specific capacities between 25 and 50 l/min/m (Figure Gr-11), and the remaining 1,396 wells (20.7%) have specific capacities larger than 50 l/min/m (Figure Gr-12).

5.9 SUGGESTED BEDROCK MONITORING AREAS

Figure Gr-13 shows the locations of bedrock wells with specific capacities of over 50 l/min/m and the boundaries of suggested areas for groundwater monitoring in the bedrock. The susceptibility of groundwater to contamination in these areas was determined based on information related to well yields, bedrock geology, and the thickness and type of overburden materials above the bedrock (Figures Gr-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, six areas (A, B, C, D, E, and F) are proposed for groundwater monitoring within the bedrock. Groundwater susceptibility to contamination within areas (A) and a part of area (E) is high, within areas (B, D, and F) and a part of area (E) is low, and within area (C) and the remaining part of area (E) is variable (Figure Gr-15).

Area (A) is underlain by the Bass Island, Oriskany and Bois Blanc Formations; areas (B and C) are underlain by the Salina Formation; area (D) is underlain by the Bois Blanc and Bass Island Formations; Area (E) is underlain by the Amabel, Lockport, and Guelph Formations; and area (F) is underlain by the Salina, Bass Island, Bois Blanc, and Amherstburg-Onondaga Formations.

Area (A) is located in the lower part of the basin along the southwestern topographic divide, Area (B) extends between Caledonia and the southwestern topographic divide, Area (C) extends from Paris and Brantford in the northeast to the southwestern topographic divide, Area (D) is located along the western topographic divide and to the west of area (C), Area (E) extends along the northeastern part of the basin from Brantford to Dundalk, and Area (F) is located in the northwestern part of the basin.

5.10 SUGGESTED OVERBURDEN MONITORING AREAS

Figure Gr-16 shows the locations of overburden wells within the Grand River basin which have specific capacities over 50 and 250 l/min/m. It also shows the boundaries of suggested areas for groundwater monitoring within the overburden. Two areas have been identified within the Grand River basin for monitoring groundwater in the overburden . The first area, which has been *highly recommended* for groundwater monitoring within the overburden, is characterized by a large number of wells with high specific capacities (Figure Gr - 16). Some of these wells have specific capacities between 50 and 250 l/min/m and the others have specific capacities of more than 250 l/min/m. The second area, which was *recommended* for monitoring, has many wells with specific capacities over 50 l/min/m.

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 well yields, overburden geology, and the thickness and type of overburden materials (Figures Gr-17 and Gr-18).

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 varies from low to high.

5.11 HISTORICAL MONITORING WELLS

Fifteen bedrock wells, 16 overburden wells, and two wells of unknown type were used in the past for monitoring groundwater in the Grand River basin. The types and locations of these wells are as follows:

S	Well No. 32	An overburden well, 36 m deep, and located in Waterloo County.
S	Well No. 33	An overburden well,18.3 m deep, and located in Waterloo County.
S	Well No. 34	A bedrock well, 112.7 m deep, and located in Waterloo County, City of Kitchener.
S	Well No. 35	A bedrock well, 59.74 m deep, and located in Waterloo County, City of Kitchener.
S	Well No. 46	An overburden well, 10.7 m deep, and located in Dufferin County within Concession 4, Lot 29.
S	Well No. 59	A bedrock well, 61.57 m deep, and located in Waterloo County, City of Kitchener.
S	Well No. 64	A bedrock well, 30.5 m deep, located in Haldimand County within the lower part of the basin.
S	Well No. 82	An overburden well, 39.6 m deep, and located in

		Waterloo County, City of Kitchener.
S	Well No. 116	An overburden well, 29.6 m deep, and located in Waterloo County.
S	Well No. 117	An overburden well, 41.45 m deep, and located within Waterloo County.
S	Well No. 124	An overburden well, 9.75 m deep, located in Brant County within Concession 1, Lot 2.
S	Well No. 131	A bedrock well, 42.06 m deep, and located in Wellington County.
S	Well No. 213	An overburden well, 3.35 m deep, and located in Wellington County.
S	Well No. 247	An overburden well, 36.9 m deep, and located within Waterloo County.
S	Well No. 372	An overburden well, 9.45 m deep, and located in Oxford County within Concession 10, Lot 8.
S	Well No. 395	An overburden well, 15.24 m deep, and located in Waterloo County within Concession 12, Lot 29.
S	Well No. 396	A bedrock well, 66.75 m deep, and located in Waterloo County.
S	Well No. 397	A bedrock well, 19.8 m deep, and located in Wellington County, Concession 9, Lot 4.
S	Well No. 432	An overburden well, 32 m deep, and located in Wellington County within Concession 4, Lot 4.
S	Well No. 437	A bedrock well, 15.24 m deep, and located in Halton Region, Concession 1, Lot 26.
S	Well No. 438	A bedrock well, 25.9 m deep, and located in Halton Region, Concession 7, Lot 31.
S	Well No. 439	An overburden well, 15.54 m deep, and located in Halton Region, Concession 1, Lot 24.
S	Well No. 440	A bedrock well, 9.44 m deep, and located in Wellington County within Concession 5, Lot 1.
S	Well No. 443	A bedrock well, 17.68 m deep, and located in Halton Region, Concession 4, Lot 26. Piezometers 444, 445, 446, and 447 are within the well.
S	Well No. 514	An overburden well, 15.54 m deep, and located within Waterloo County.
S	Well No. 524	An overburden well, 9.75 m deep, and located within Waterloo County.
S	Well No. 532	A bedrock well, 67.36 m deep, and located in Wellington County, Concession 5, Lot 8.
S	Well No. 535	an overburden Well, 12.19 m deep, and located within Waterloo County.
S	Well No. 536	A bedrock well, 84.43 m deep, and located in Wellington County, Concession 11, Lot 16.

S	Well No. 537	A bedrock well, 108.5 m deep, and located in Wellington County, Concession 1, Lot 11.
S	Well No. 544	A bedrock well, 82.6 m deep, and located in Wellington County, Concession 7, Lot 7.
S	Well no. 560	A well of unknown type, 13.1 m deep, and located in Haldimand County, Concession 9, Lot 9.
S	Well No. 561	A well of unknown type, 13.72 m deep, and located close to well No. 560.

Figure Gr-19 shows the locations of the historical monitoring wells and Appendix I gives the geographic coordinates of these wells.

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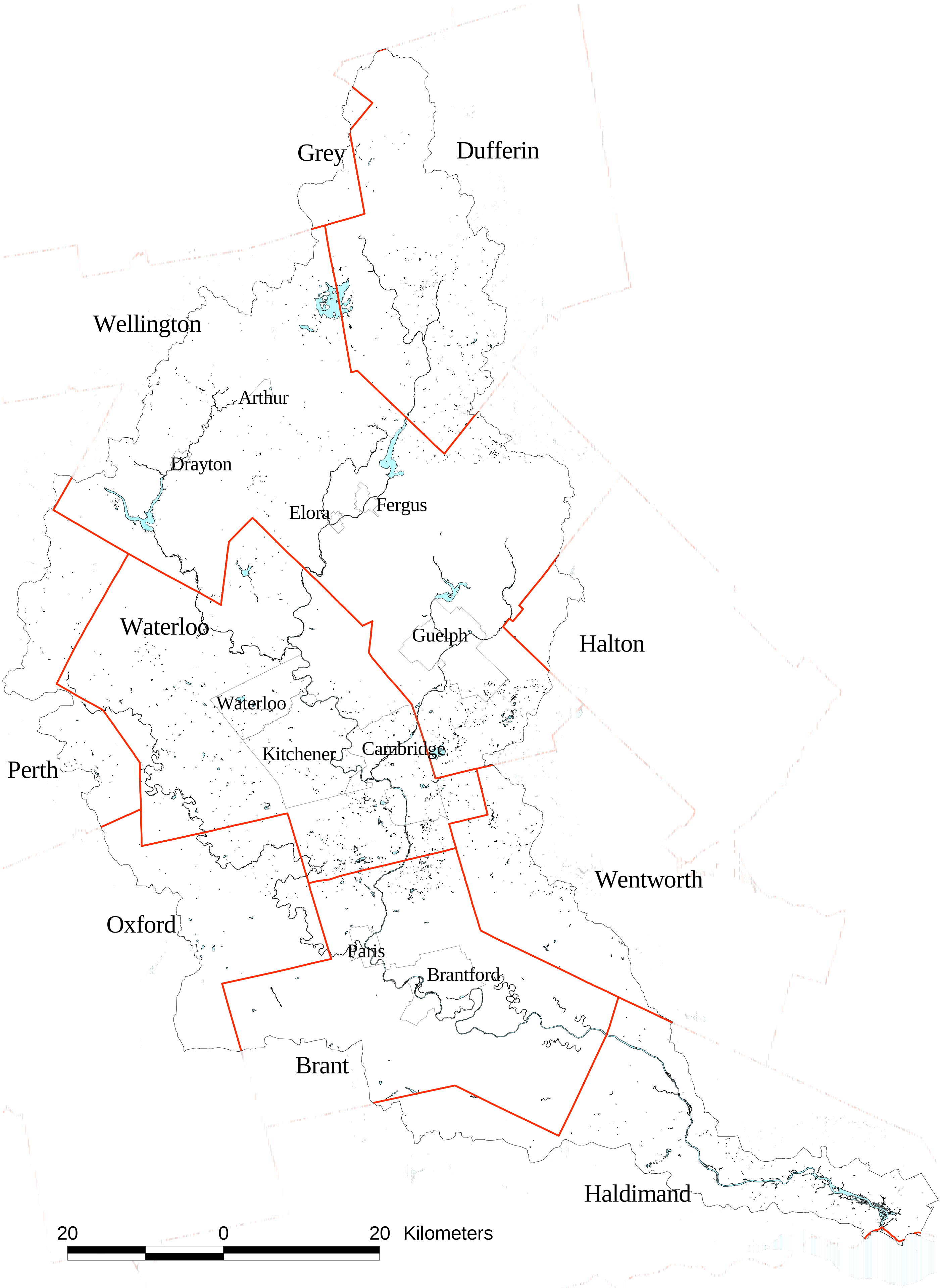
FIGURES

Key Map - Gr	A transparency to be used with other figures for orientation purposes.
Figure Gr - 1	Bedrock topography in the Grand River drainage basin.
Figure Gr - 2	Bedrock geology in the the Grand River drainage basin.
Figure Gr - 3	Overburden thickness in the Grand River drainage basin.
Figure Gr - 4	Overburden geology in Grand River drainage basin.
Figure Gr - 5	Bedrock wells with specific capacities equal to or less than 5 l/min/m.
Figure Gr - 6	Bedrock wells with specific capacities between 5 and 25 l/min/m.
Figure Gr - 7	Bedrock wells with specific capacities between 25 and 50 l/min/m.
Figure Gr - 8	Bedrock wells with specific capacities higher than 50 l/min/m.
Figure Gr - 9	Overburden wells with specific capacities equal to or less than 5 l/min/m.



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

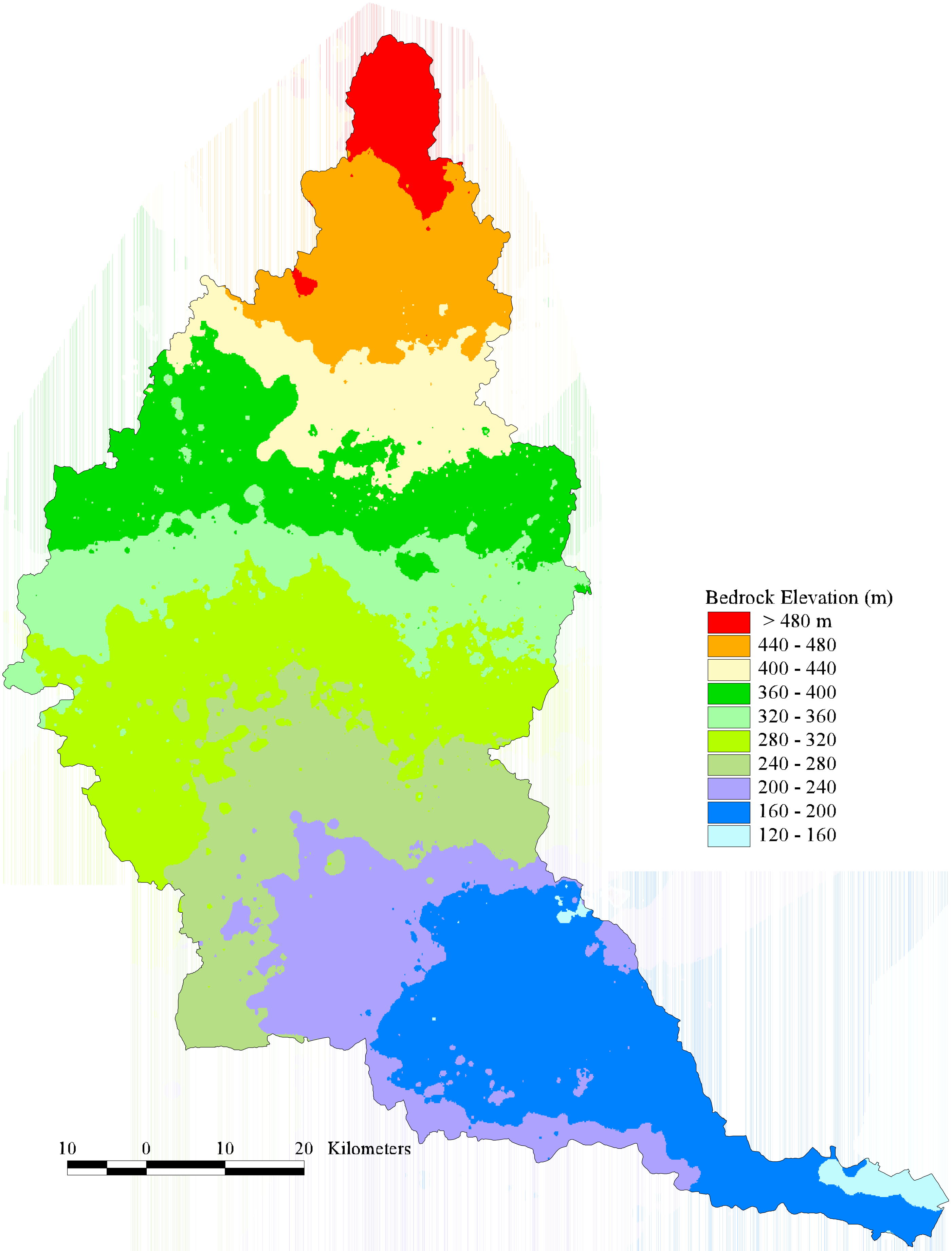


Figure Gr-1. Bedrock topography in the Grand River drainage basin.

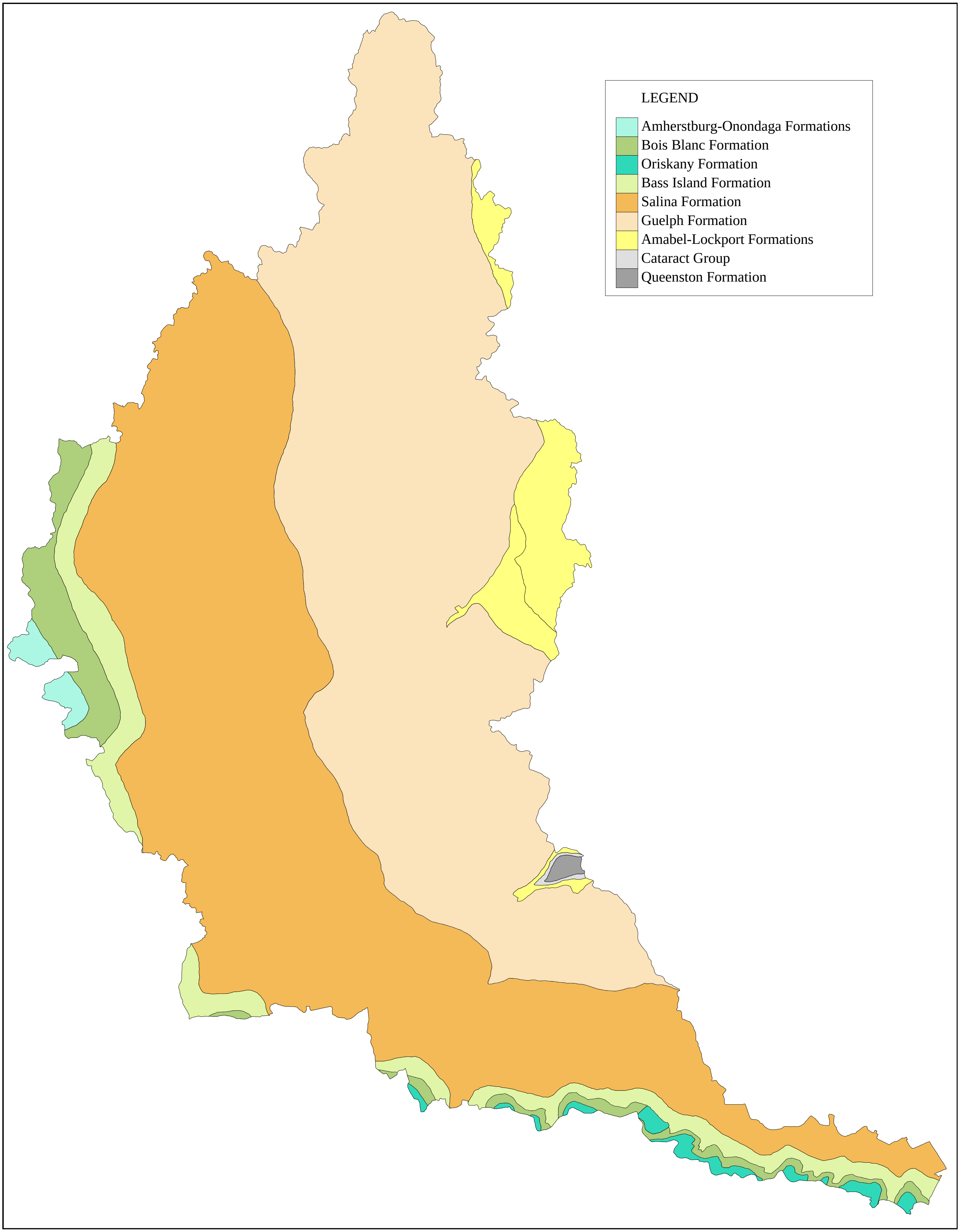


Figure Gr-2. Bedrock geology in the Grand River drainage basin.

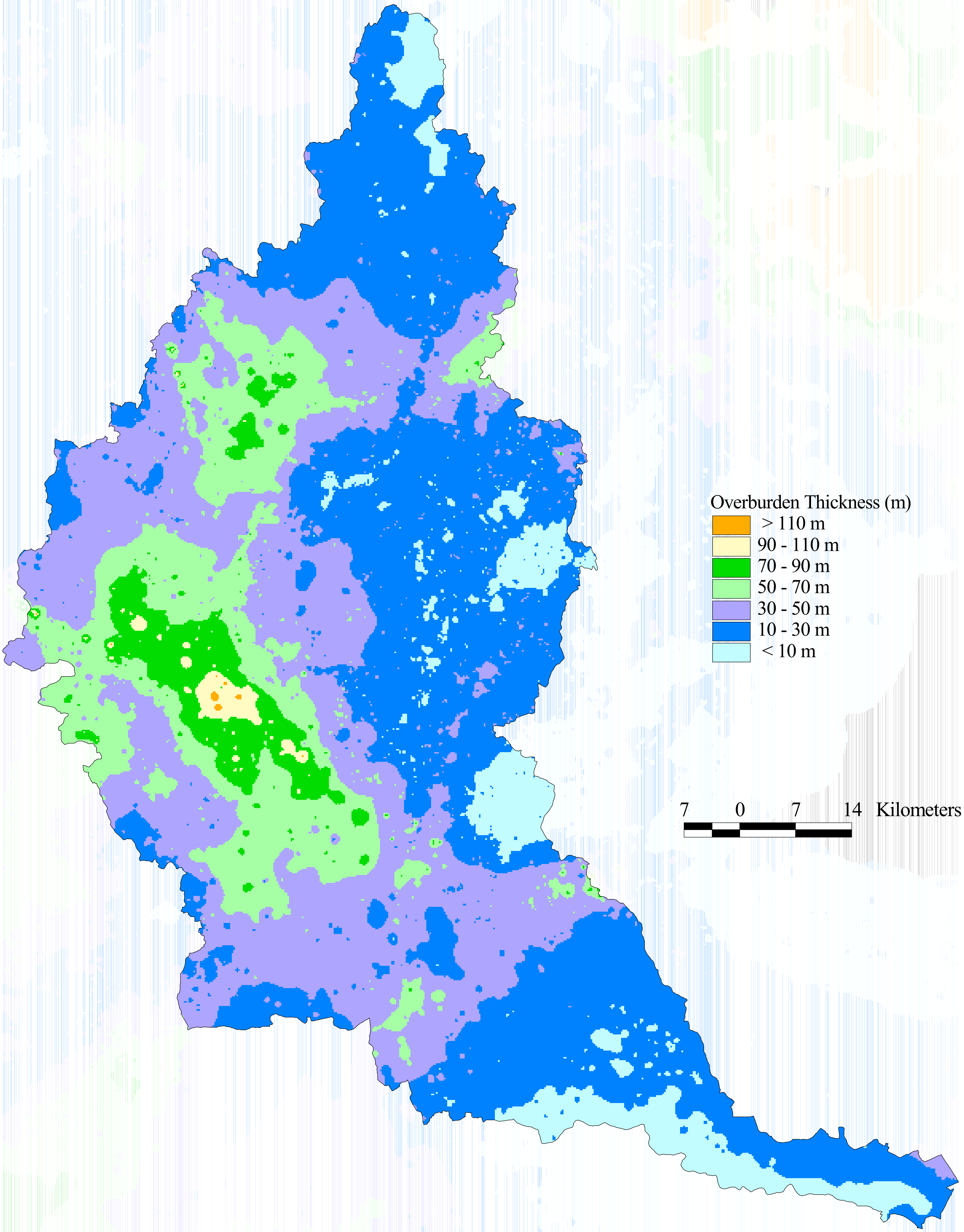


Figure Gr-3. Overburden thickness in the Grand River drainage basin.

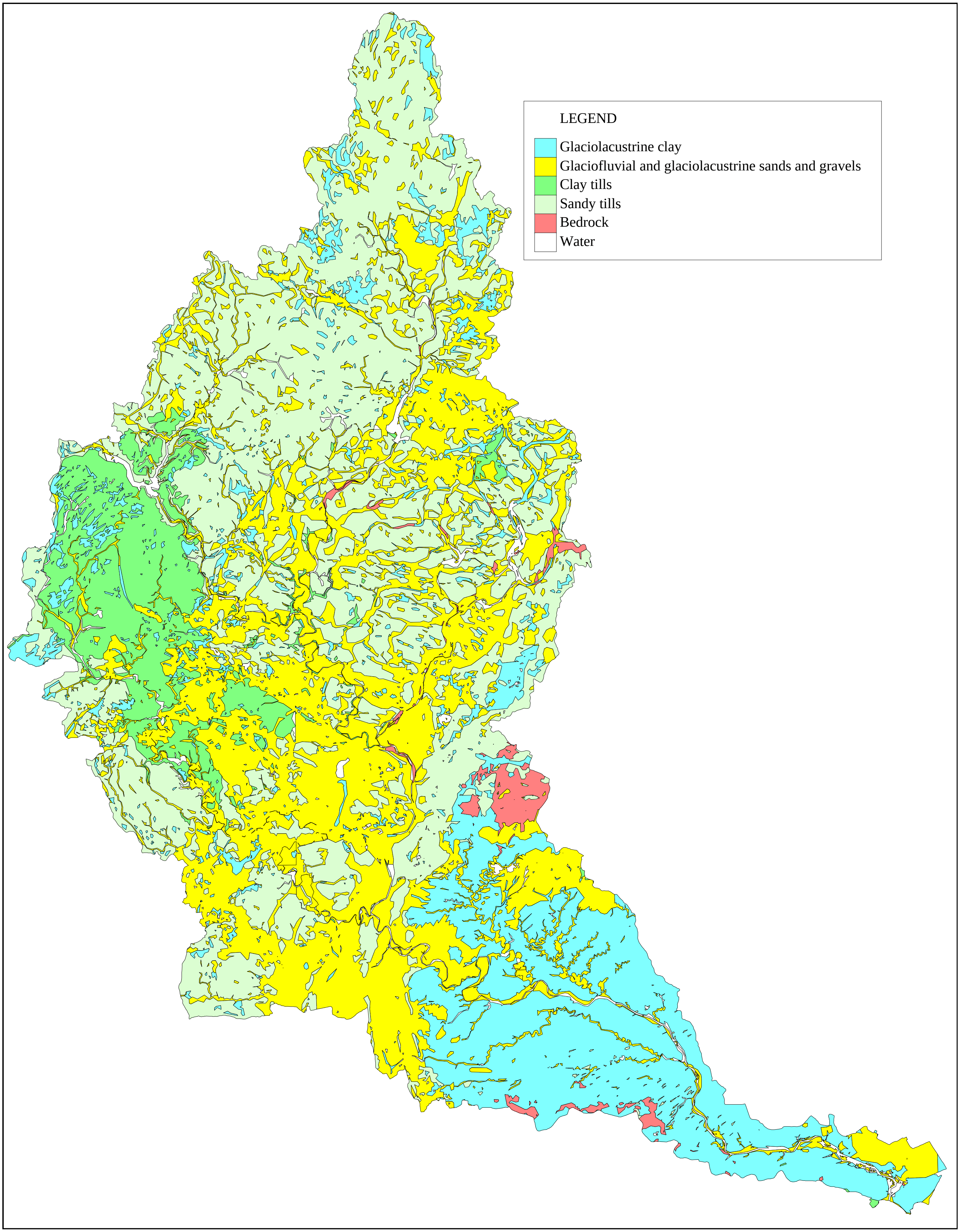


Figure Gr-4. Overburden geology in the Grand River drainage basin.

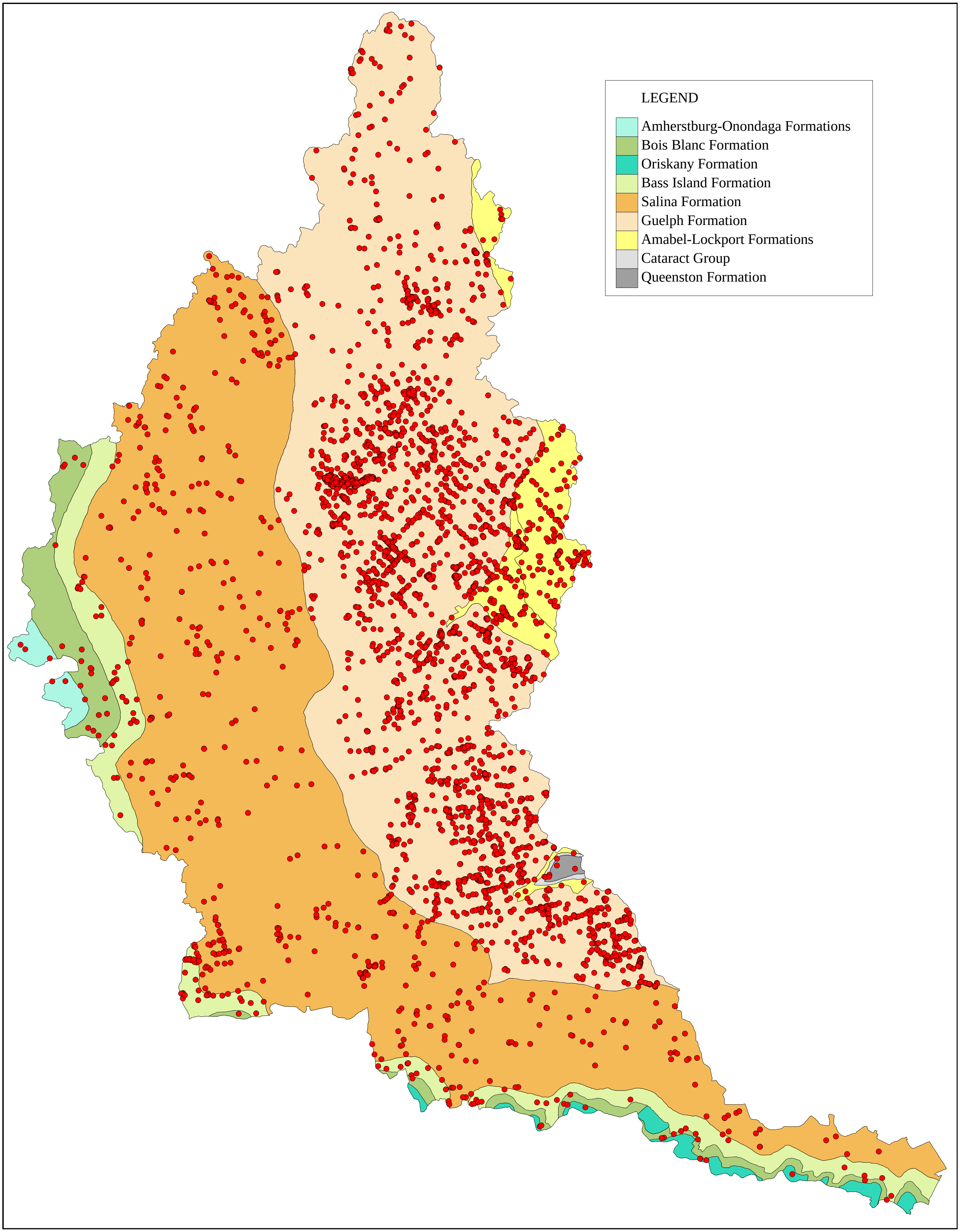


Figure Gr-5. Bedrock wells with specific capacities equal to or less than 5 l/min/m.

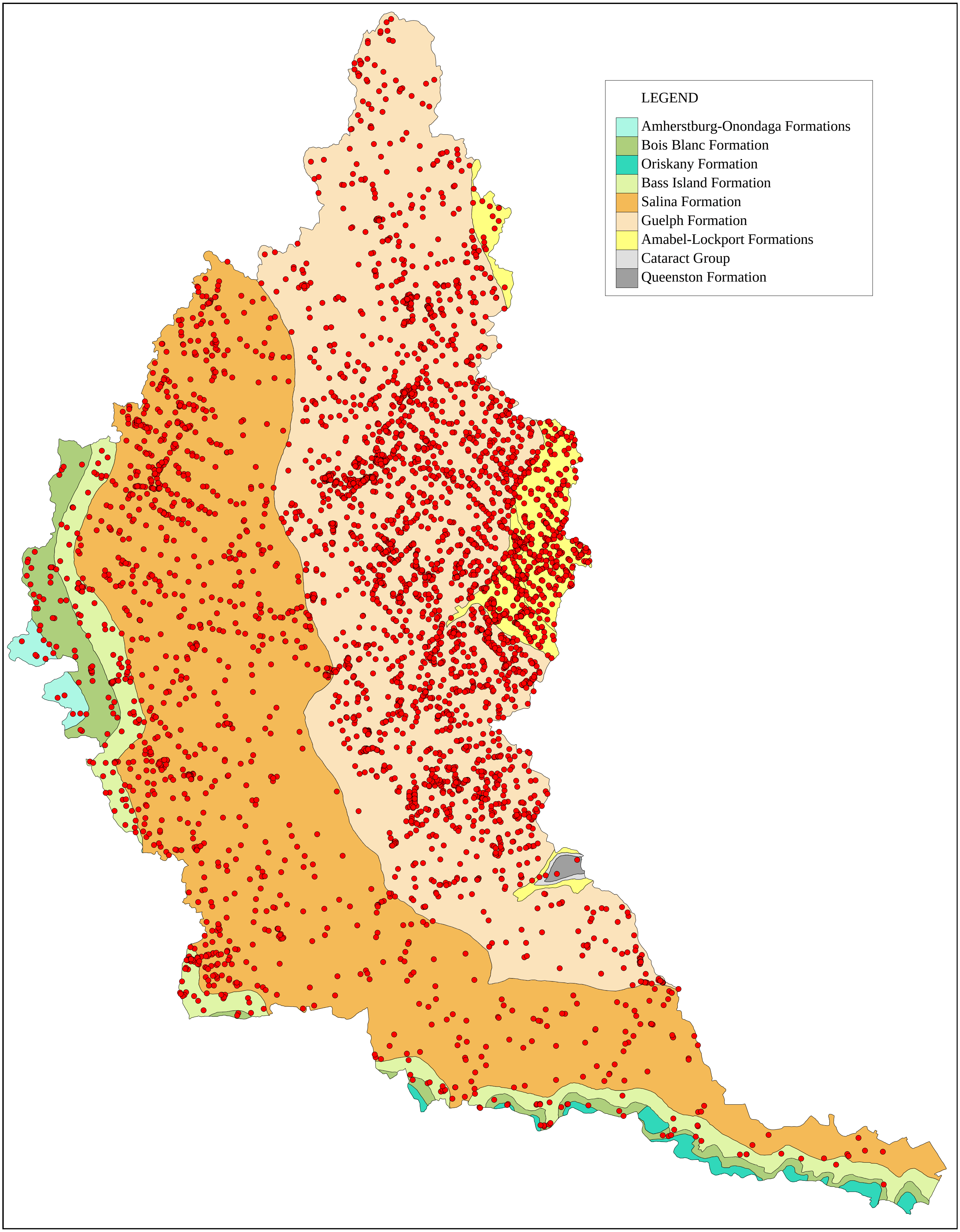


Figure Gr-6. Bedrock wells with specific capacities between 5 and 25 l/min/m.

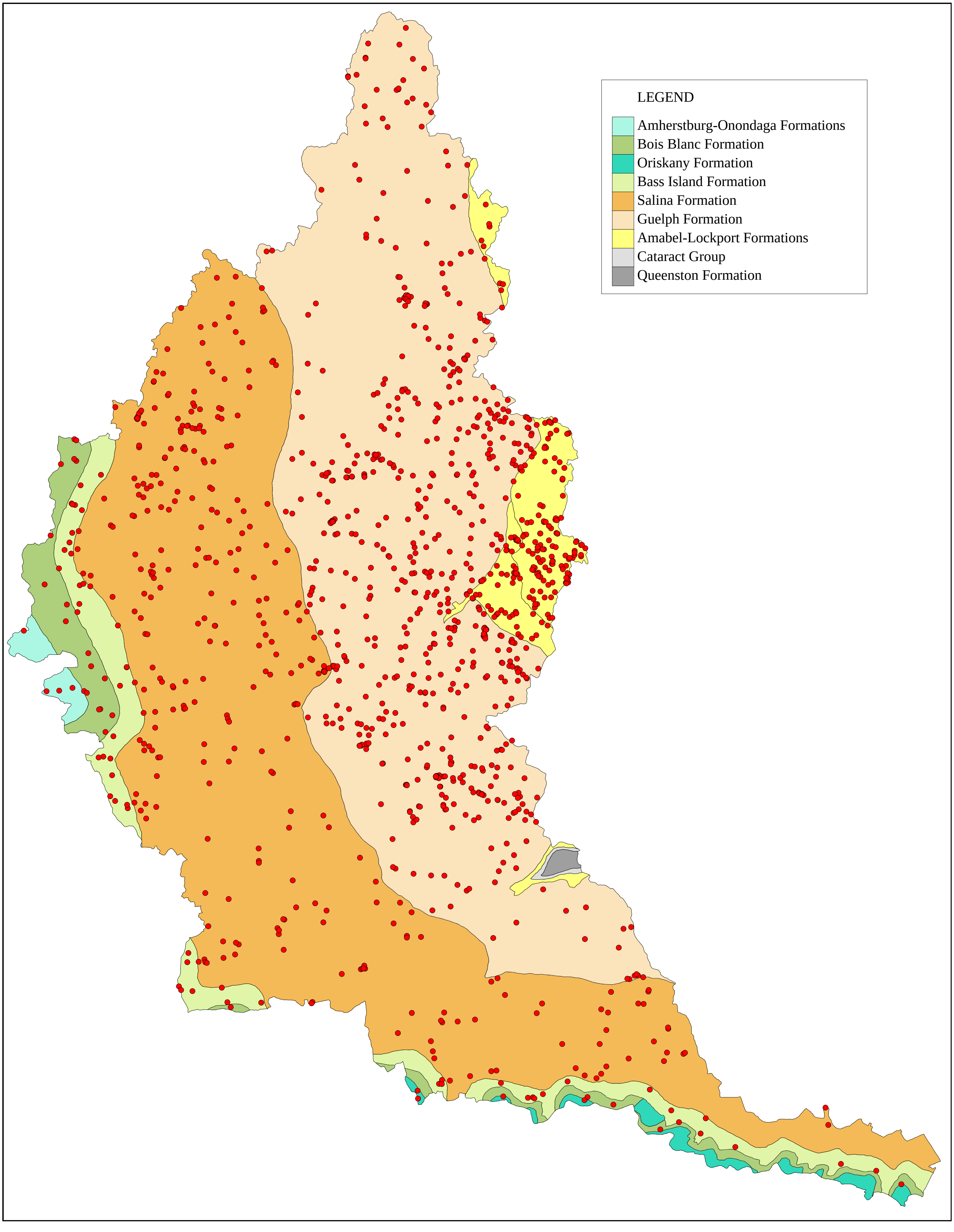


Figure Gr-7. Bedrock wells with specific capacities between 25 and 50 l/min/m.

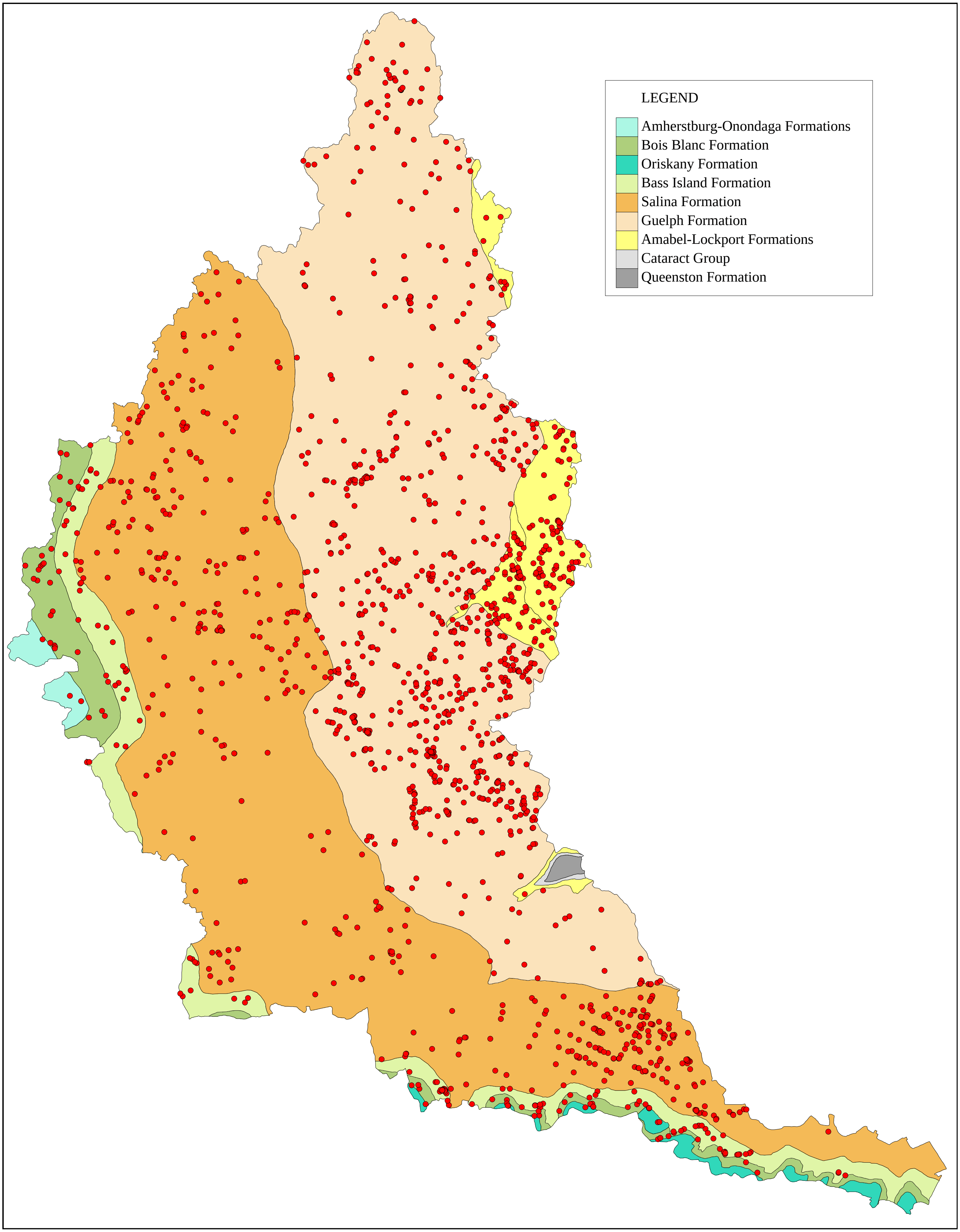


Figure Gr-8. Bedrock wells with specific capacities higher than 50 l/min/m.

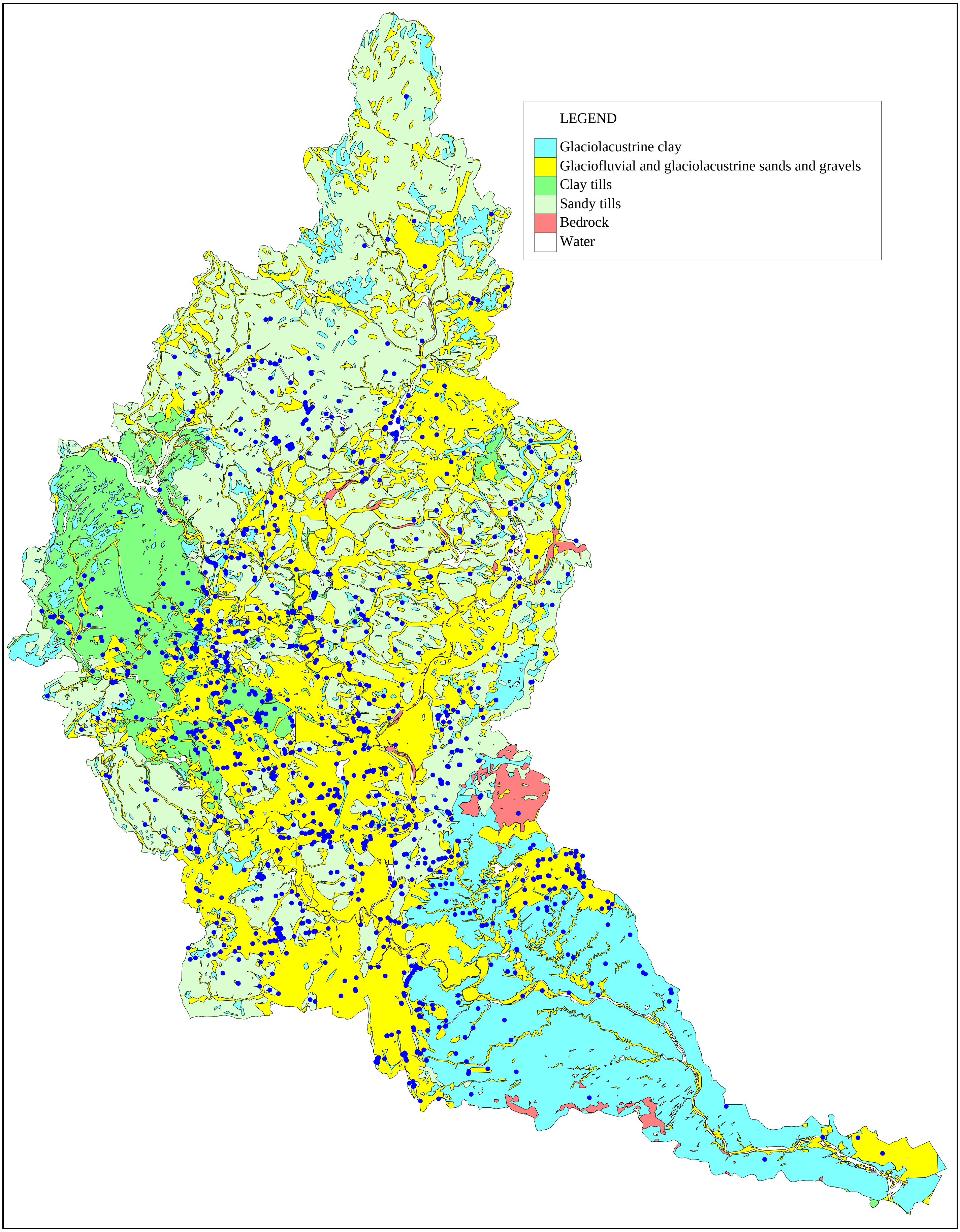


Figure Gr-9. Overburden wells with specific capacities equal to or less than 5 l/min/m.

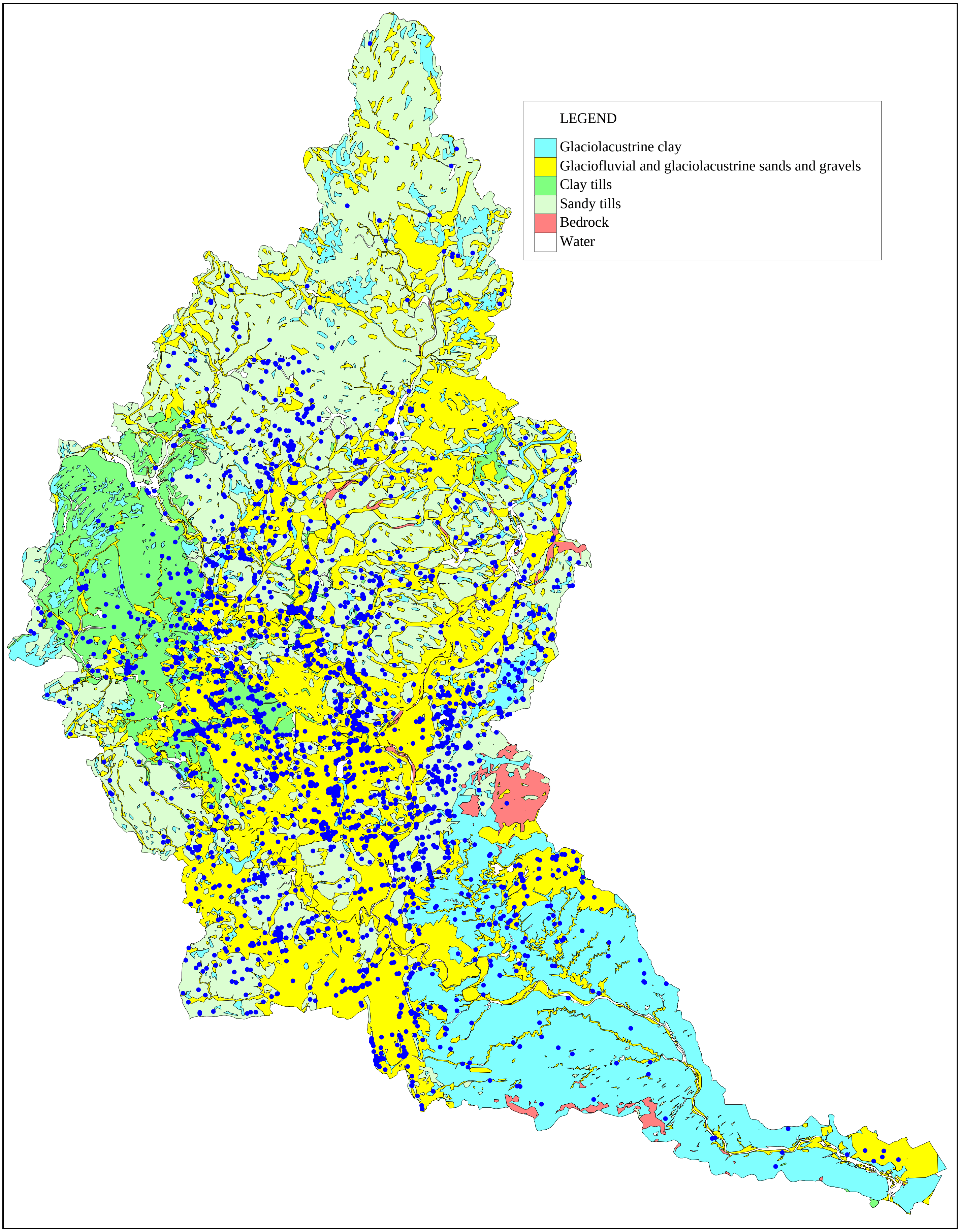


Figure Gr-10. Overburden wells with specific capacities between 5 and 25 l/min/m.

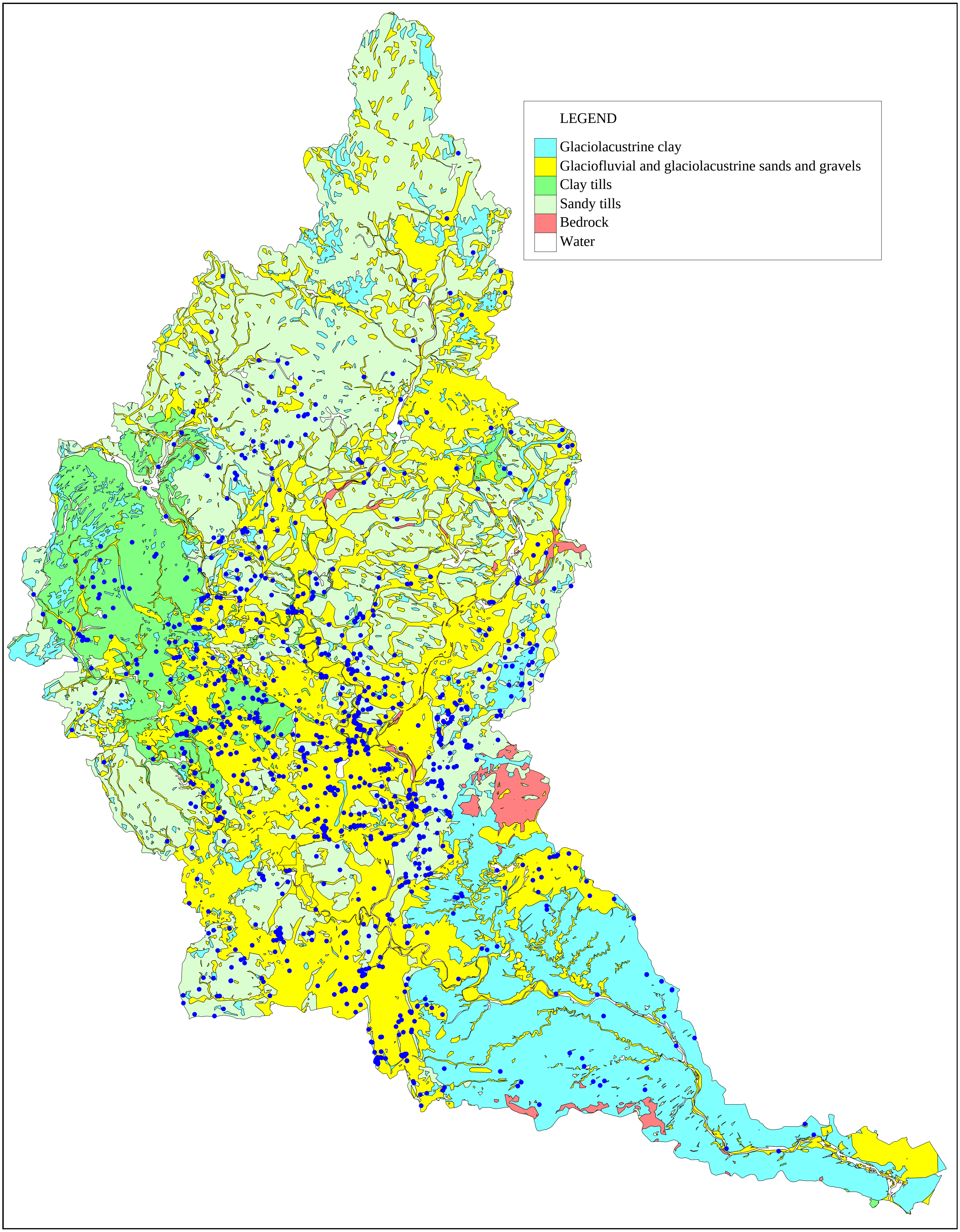


Figure Gr-11. Overburden wells with specific capacities between 25 and 50 l/min/m.

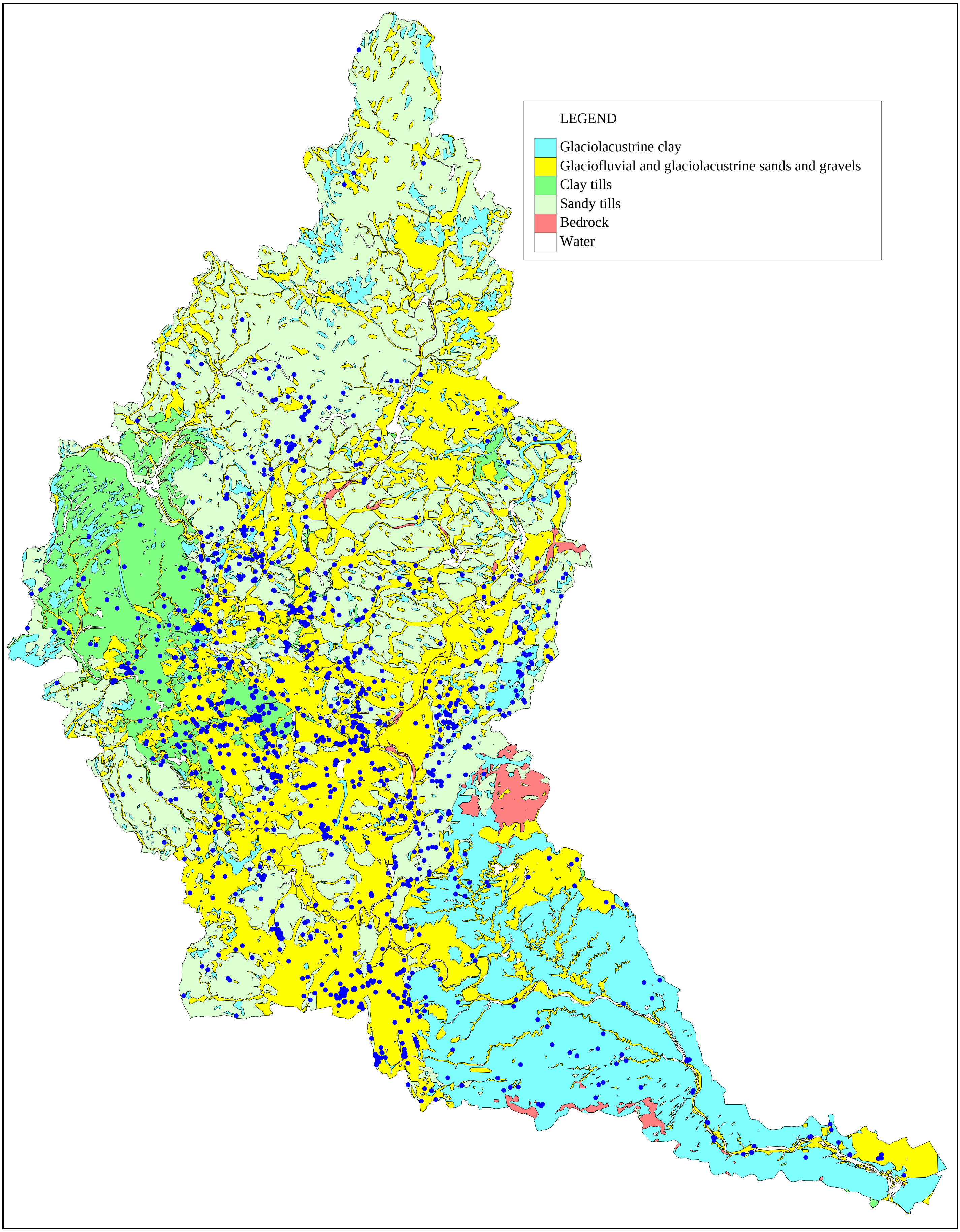


Figure Gr-12. Overburden wells with specific capacities higher than 50 l/min/m.

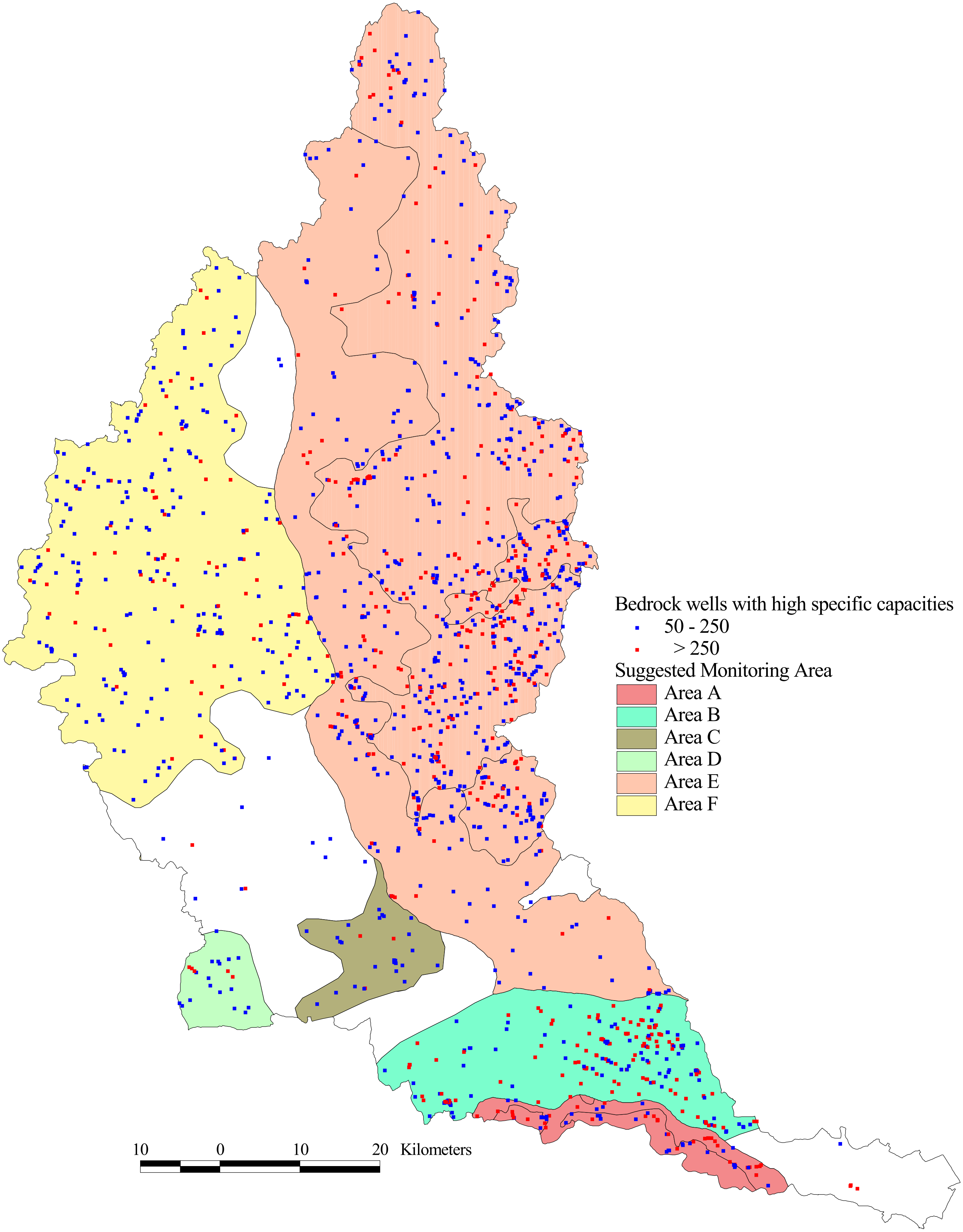


Figure Gr-13. Suggested areas for monitoring groundwater in the bedrock.

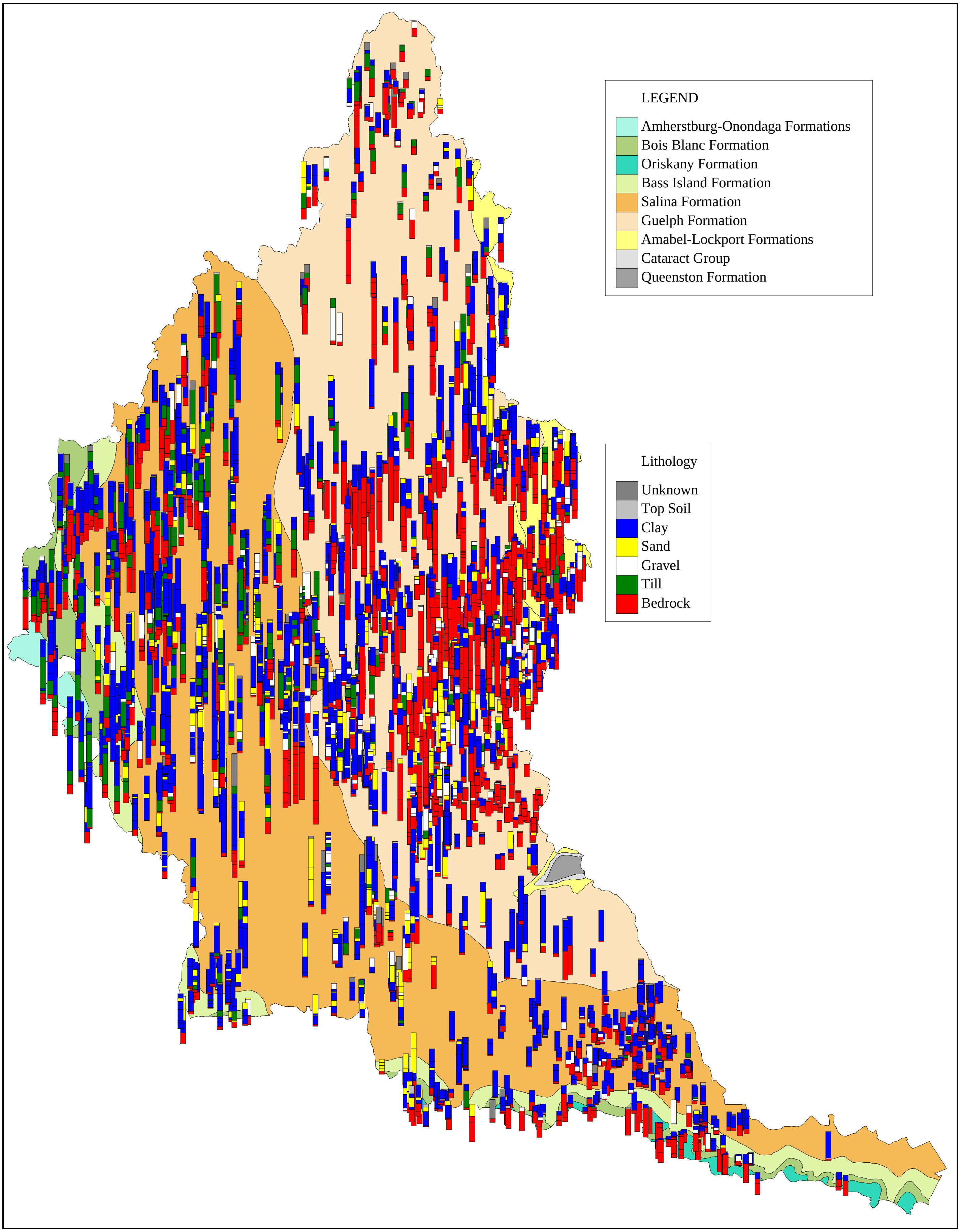


Figure Gr-14. Panel diagram showing the geologic logs of bedrock wells with specific capacities higher than 50 l/min/m.

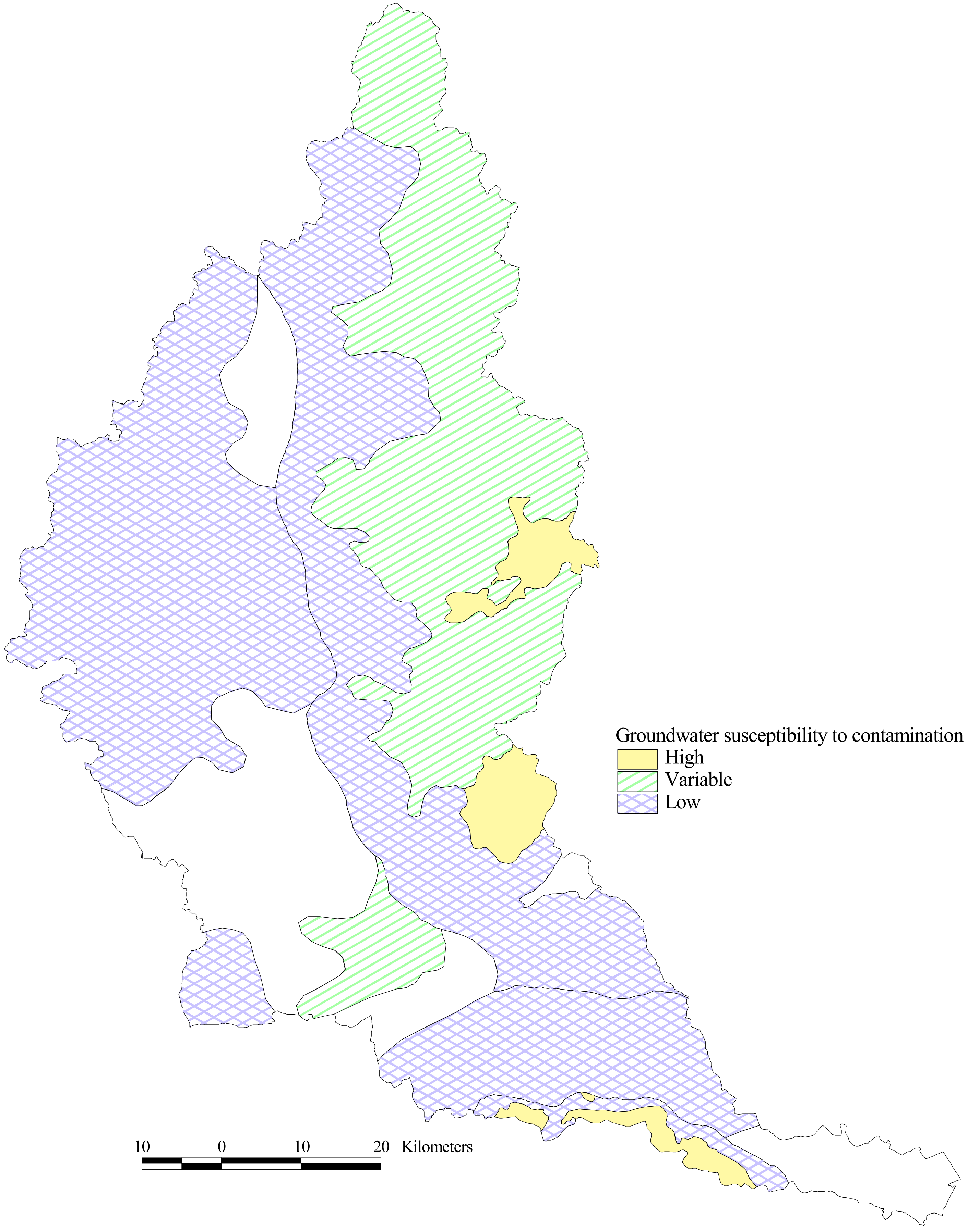


Figure Gr-15. Susceptibility of groundwater to contamination within areas suggested for monitoring groundwater in the bedrock.

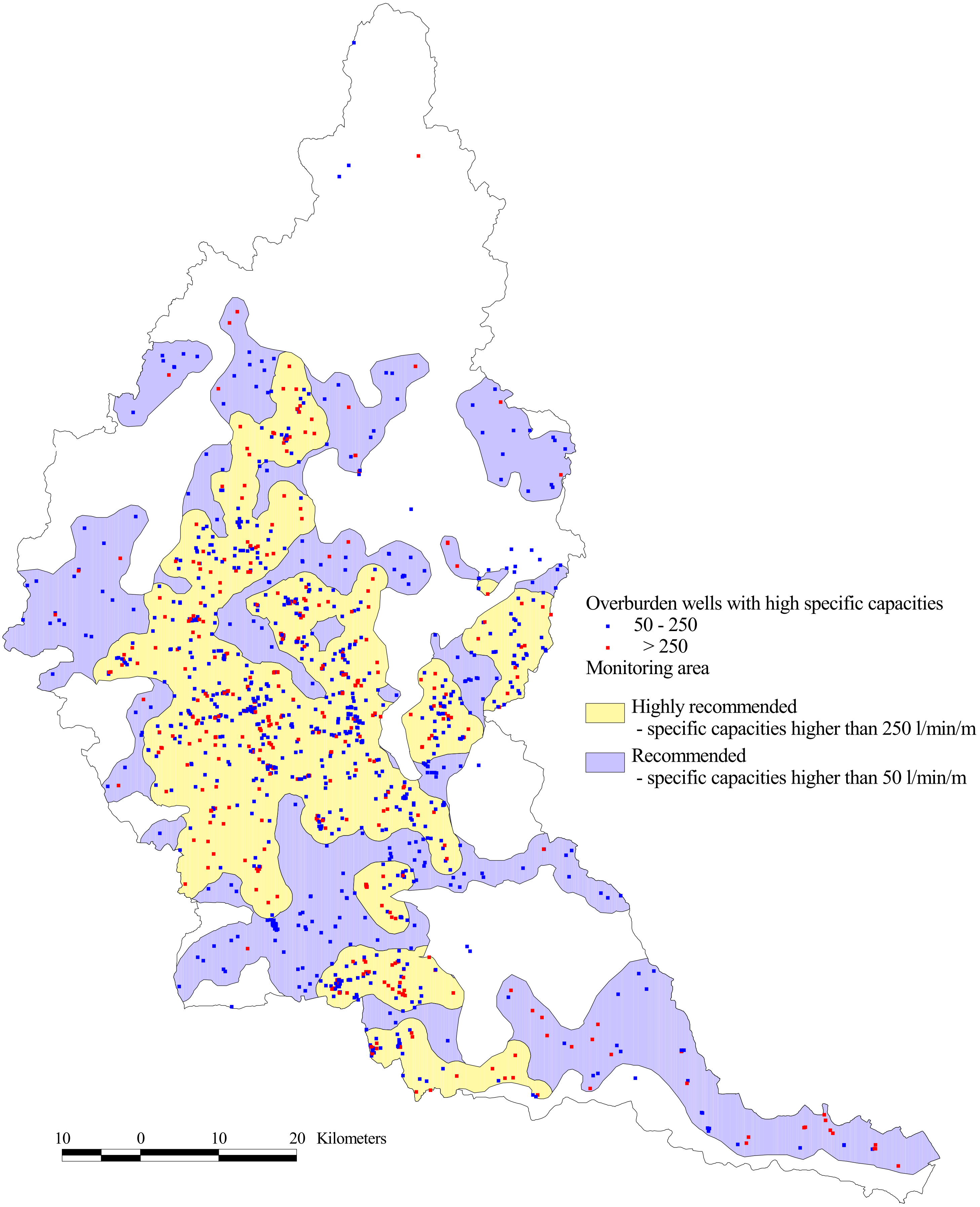


Figure Gr-16. Suggested areas for monitoring groundwater in the overburden.

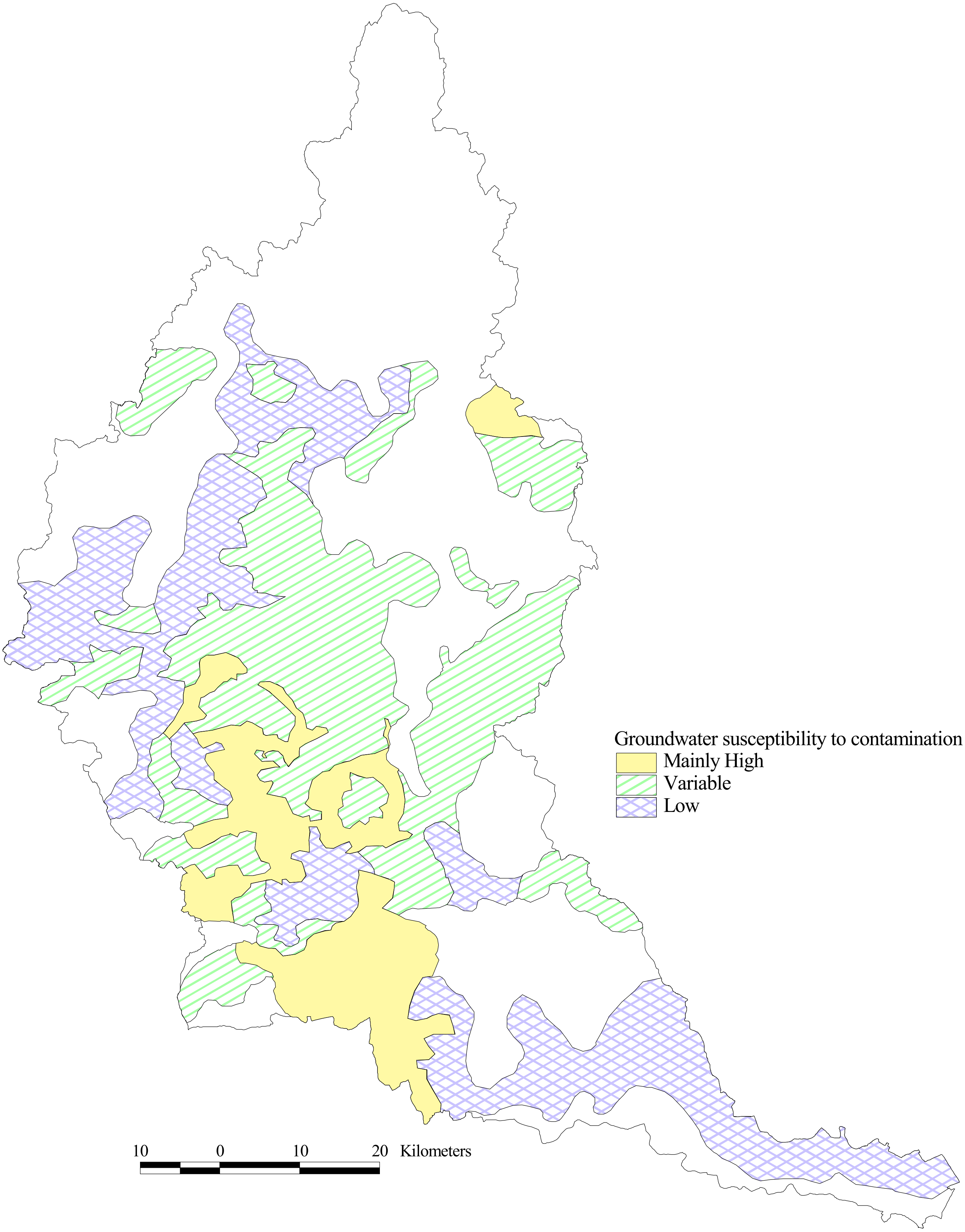


Figure Gr-17. Susceptibility of groundwater to contamination within areas suggested for monitoring groundwater in the overburden.

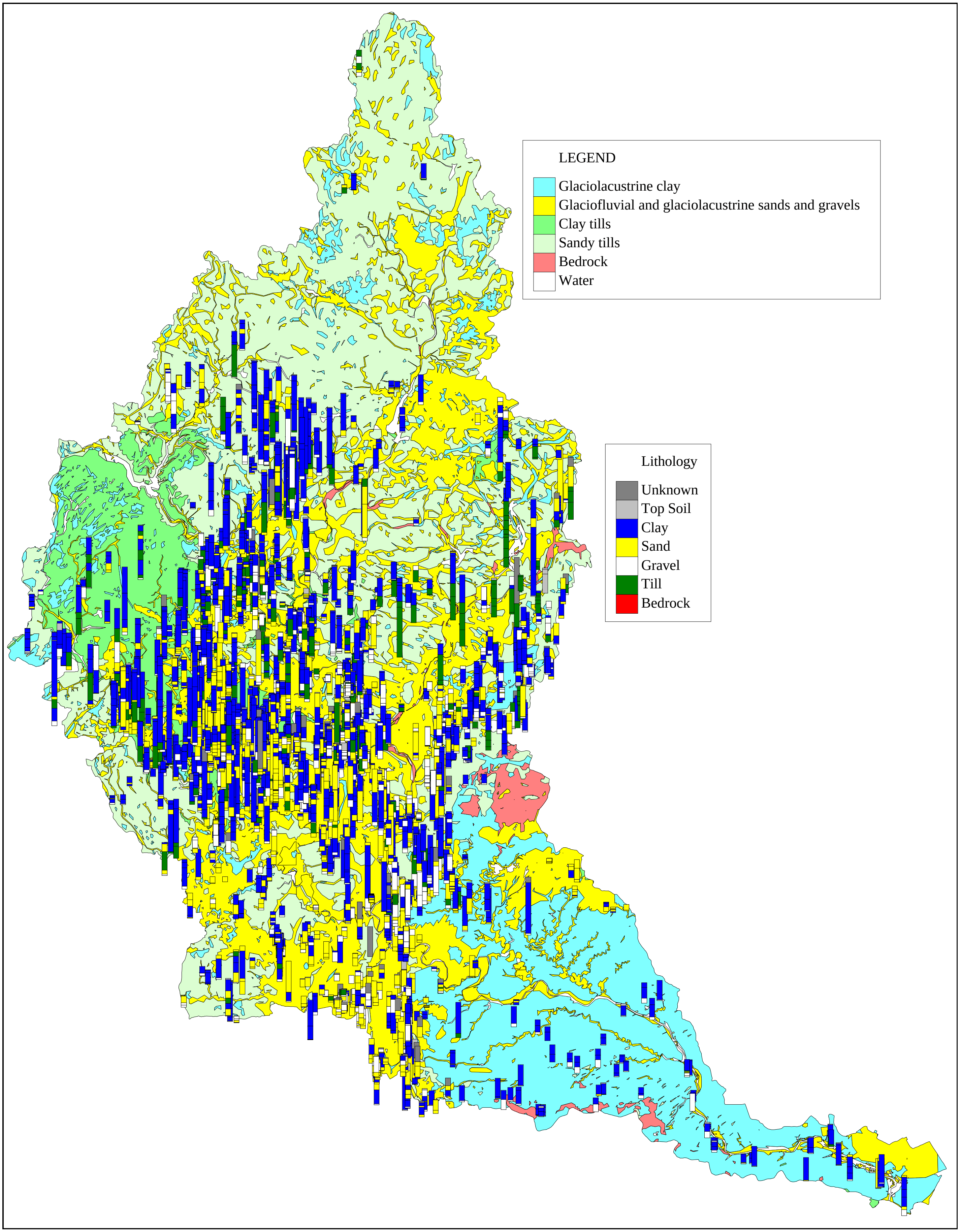


Figure Gr-18. Panel diagram showing the geologic logs of overburden wells with specific capacities higher than 50 l/min/m.

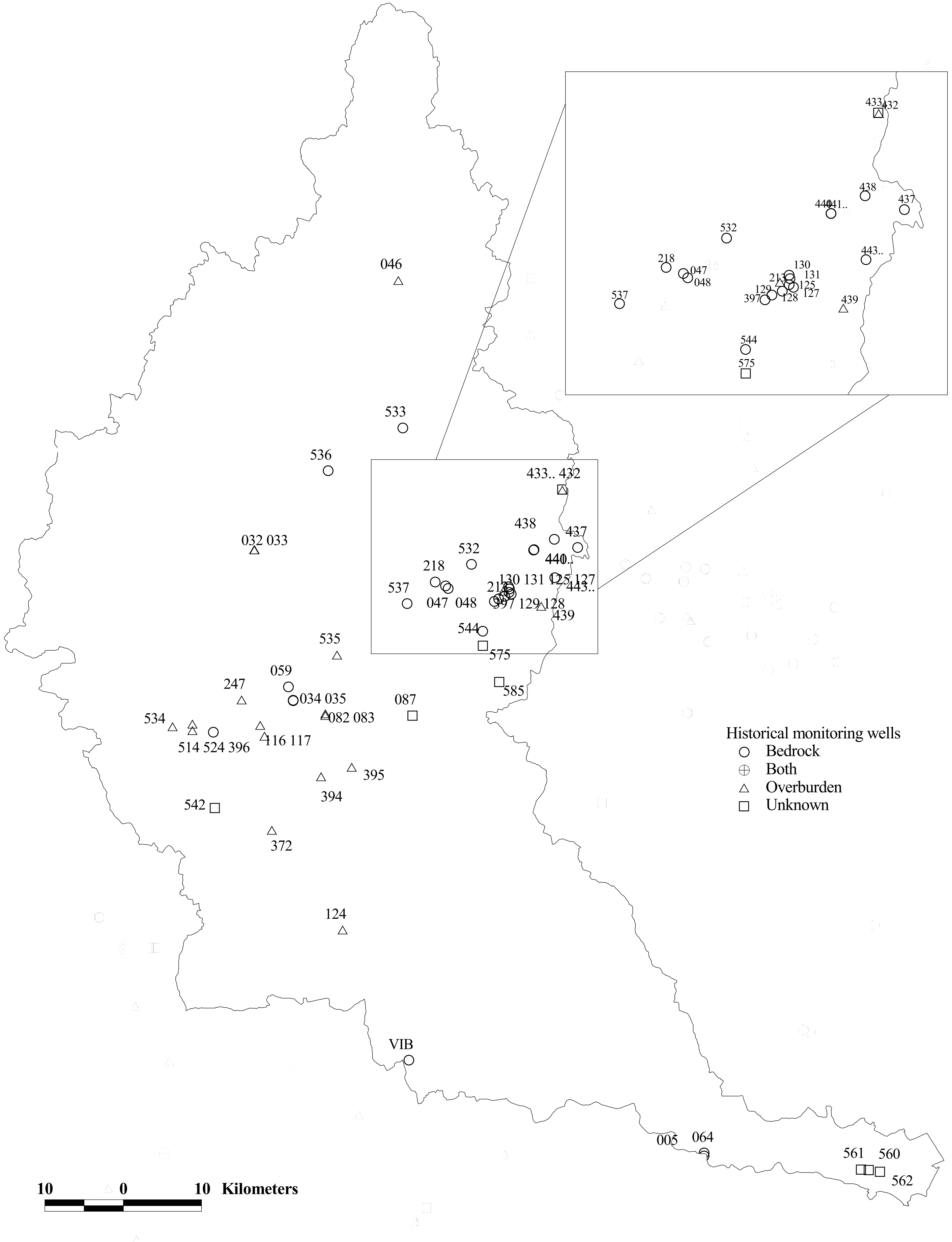


Figure Gr-19. Locations of historical monitoring wells in the Grand River drainage basin.