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# Surficial Geology and Hydrogeology of the Town of Randolph, Vermont

by

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# Report on Surficial Mapping and Interpretations of Groundwater Hydrology in Randolph, Vermont

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**Introduction**

This report describes the results of mapping surficial geologic materials at a scale of 1:24,000 primarily in the valley of the Second Branch of the White River in the town of Randolph, Vermont during the summer of 2010 (Fig. 1). The geologic map presented here includes mapping completed by Larsen (2002) as part of a project focused on mapping the Third Branch of the White River. The Randolph 15-minute quadrangle was mapped by Stewart (1956–1966).

A major objective of this work was to elucidate the three-dimensional distribution of surficial materials in the mapped area, the decipher the depositional environment of glaciofluvial and glaciolacustrine sediments, and to interpret the late Pleistocene and early Holocene history of the area. An addition objective of this work was to use this understanding of the distribution of surficial materials across the area to better understand the groundwater hydrology of the town.

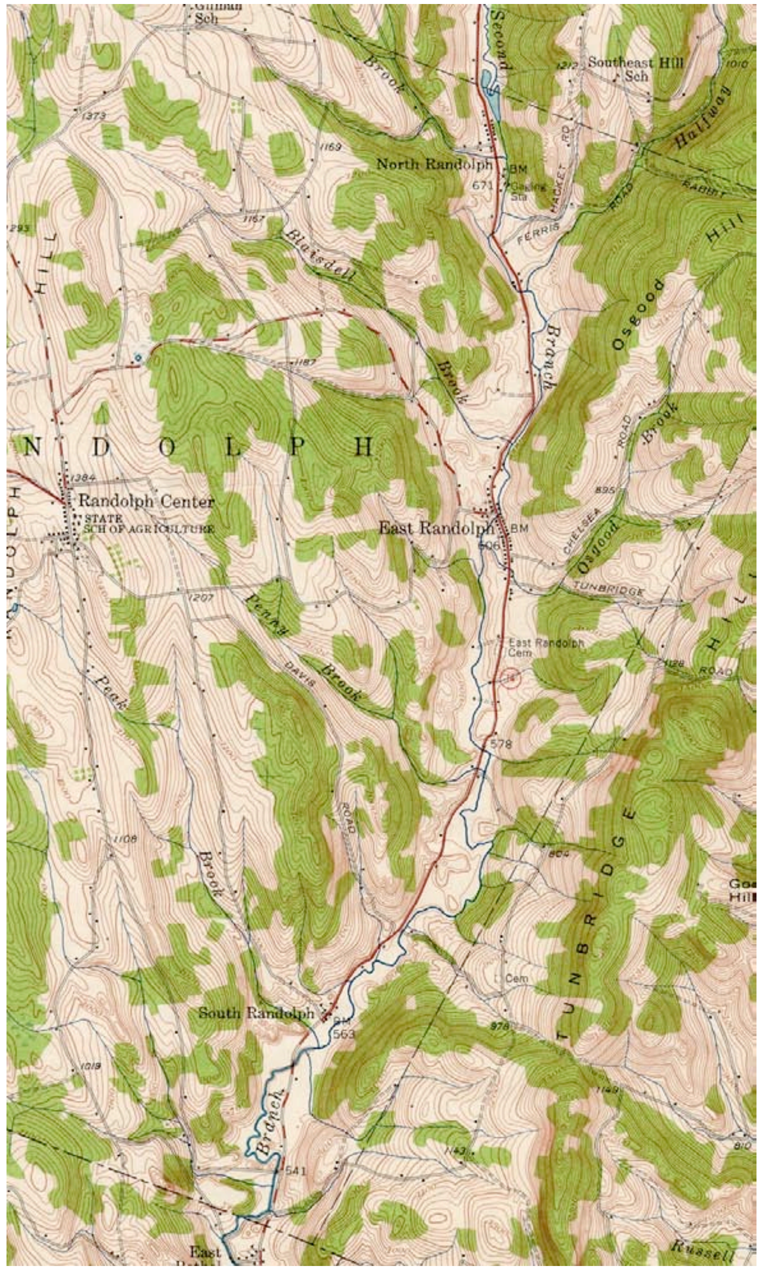


**Figure 1: Topographic map of the mapping area that is the focus of this report, the valley occupied by the Second Branch of the White River and its tributaries in Randolph, Vermont. Glaciofluvial and glaciolacustrine surficial materials occur almost exclusively in the valley bottoms where mapping efforts were focused.**

The following materials are submitted as the final products of this project:

(1) A surficial geologic map of the area showing geologic contacts, the location of field observations, and an explanation of mapping units;

(2) Geologic cross-sections of East Randolph and North Randolph as part of this report and as separate Adobe Illustrator files;

(3) An isopach map of the entire town depicting the thickness of surficial geologic materials (depth to bedrock) based on field mapping and water well data;

(4) A piezometric surface map of the entire town that contours the water table and shows representative flow lines (a groundwater flow net);

(5) Designations of surficial mapping units that provide good recharge to both bedrock and surficial aquifers, as well as potential shallow aquifers;

(6) A file containing location information and descriptions of field sites.

Mapping was completed using the U.S.G.S. Randolph Center quadrangle map (1:24,000) as the base map. A more recent topographic base map at the same scale proved impossible to use in the field as it fails to accurately depict landforms and cultural features. Surficial materials were sampled using an ~1 m-long soil probe and soil auger. Map locations were fixed using a GPS meter utilizing the NAD27 coordinate system that is the basis of the grid system on the Randolph Center map. In all locations and instances the NAD27 locations gleaned from the GPS meter were consistent with the landforms and cultural features shown in the map. In almost all areas the stated GPS meter accuracy (horizontal location) was within 5 m, considerably less than the width of a pencil point on a 1:24,000 scale map. Bedrock outcrops were also mapped where they were encountered on traverses, but no attempt was made to map all bedrock outcrops. Outcrops were inspected for striations or other indicators of ice flow direction. Areas where surficial materials were sampled and described are shown on the geologic map as points. Areas where additional observations and measurements were made were given field identification numbers and recorded as GPS waypoints. Every effort was made to traverse all parts of town where one could reasonably expect to find materials other than till. Geologic contacts that could be located with certainty are shown with solid lines. Areas where contacts have been interpolated or extrapolated with less certainty are shown with dashed lines.

**Significant Findings/Executive Summary**

Bedrock outcrops are widely distributed across most of the area, particularly above the elevation of the glacial lake that once occupied the valley (~740–770 ft). No glacially smoothed or striated outcrop surfaces were observed, even where bedrock was freshly exposed. No bedrock exposed in the valley bottom of the Second Branch suggesting that the bedrock surface here is buried by a significant thickness of surficial materials.

Glacial till in the Randolph area is ubiquitous in areas above the elevation of the glacial lake that occupied the valleys (~740–770 ft) and directly overlies bedrock. In all exposures where it was observed it is gray, compact, and contains a large percentage of fine (clay, silt, and sand-sized) sediment. In most areas till thickness is less than 10 m, but exposures in some landslides and well logs indicate that till has accumulated to thicknesses of 20 to 30 m or more in restricted areas.

An segmented esker system occurs in the Second Branch of the White River valley and is apparently continuous with the esker in the Steven's Branch of the Winooski River approximately xx km north of Randolph mapped by Wright (1998). In one area north of East Randolph exposures in pits are good enough to show that this esker is braided. This esker is the primary source of sand and gravel in the Second Branch Valley. In the southern part of town this esker is completely largely or completely buried by younger glacial lake sediments.

Glacial lake sediments are widely distributed at elevations below 740–770 ft and overlie bedrock, till, and ice-contact sediments. These sediments were deposited in an arm of Glacial Lake Hitchcock, the large glacial lake that occupied the Connecticut River valley. Surface exposures consist mostly of varved silt and clay, but also include very fine sand. Several good sections were observed, but no detailed measurements were made. Sections generally fine upwards from underlying till or ice-contact sediments. At least two areas are interpreted to be deltas deposited by tributaries that flowed into this lake. Across the mapped area glacial lake bottom sediments frequently occur at elevations near the surface elevation of the lake, sometimes overlain by a thin cover of alluvium, indicating that these sediments largely filled in the lake.

Old stream alluvium occurs on terraces and fans deposited on top of lake bottom sediments at elevations ranging from the old elevation of Glacial Lake Hitchcock to the modern stream elevation. These sediments range in thickness from less than half a meter to 2–3 m and have, in some places, been used as a source of sand and gravel.

**Description of the Mapping Units**

The Randolph Surficial Geologic Map is a compilation of mapping completed by Larsen () along the Third Branch of the White River and mapping recently completed by the author along the Second Branch of the White River. The mapping units used on the Randolph Surficial Geologic Map are those originally used by Larsen (). The units described below are arranged in geologic order, from oldest to youngest.

*Bedrock Outcrops*

The bedrock across the town consists of gray, weakly metamorphosed clastic sedimentary rocks (primarily sandstone, siltstone, and shale often with a significant detrital calcite component) that were originally deposited as turbidites (Fig. 2). The meta-sandstone units are stronger and are the units comprising cliffs and most outcrops in the woods and hilltops. Prominent joints in these units outline individual outcrops and are the principal porosity (albeit secondary porosity) in these rocks (Fig. 2). The joints and lesser fractures that intersect Earth's surface or are in contact with saturated surficial materials are the primary source of recharge to the bedrock aquifer. The metamorphosed siltstone and shale units (now medium to dark gray slates and phyllites) are weak and rarely outcrop except where they're thin and sandwiched between meta-sandstone beds.

**Figure 2: Bedrock outcrop of Devonian age Waits River Formation along Snows Brook, North Randolph. Prominent compositional layering in the rock (light/dark layers) is original sand/silt bedding ($S_0$) produced by turbidite flows. The foliation in the rock is weak and not visible in the photograph. Joints are common and both cross-cut and parallel bedding.**

Bedrock outcrops were mapped when they were encountered during traverses, however no attempt was made to map all contacts. All outcrops were inspected for signs of glacial abrasion, but none displayed glacially smoothed or striated surfaces, even where recently exposed by stream erosion. This is the only field site mapped by the author where not a single glacially striated outcrop was found. This is most likely a result of the relative weakness of the rock, the carbonate content of the rock which makes it particularly susceptible to weathering, and possibly the paucity of abrasive tools (clasts) in the overlying till that is primarily composed of comminuted local bedrock (see below).

*Glacial Till:*

Glacial till directly overlies the bedrock and, in the Randolph area, is the ubiquitous surficial material in areas above the elevation of the glacial lake that occupied the valleys (~740–770 ft, see below). In all exposures where it was observed it is gray, compact, and contains a large percentage of fine (clay, silt, and sand-sized) sediment (Fig. 3). In most areas till thickness is less than 10 m, but exposures in some landslides and well logs indicate that till has accumulated to thicknesses of 20 to 30 m or more in restricted areas.

**Figure 3: Glacial till exposed along a small (2 m high) landslide along Snows Brook, North Randolph. Till is gray, compact, and contains a high percentage of fine-grained sediments that are the matrix to abundant larger clasts largely derived from the underlying bedrock, i.e. relatively few clasts are erratic.**

No attempt was made to systematically measure the composition of the till by either grain size or composition. However, casual observations of both fresh till exposures (landslides along streams) and loose clasts in the woods revealed relatively few erratics. Large boulders that have weathered out of the till were encountered in some places, but most appeared to have traveled relatively short distances from the source (Fig. 4).

**Figure 4: Large isolated boulder with folded layering has weathered out of till on the west side of the Second Branch valley between East and South Randolph.**

*Ice-Contact Deposits*

An segmented esker system occurs in the Second Branch of the White River valley. Several segments of this esker occur as distinct ridges in North Randolph. Farther south (East Randolph) the esker is partially or fully buried by younger lake bottom sediments, but still crests above the elevation of the river. Still farther south (South Randolph) the esker is completely buried by younger sediments and does not extend above the grade of the river. This esker continues north into Brookfield (Larsen et al., 2003) and is apparently continuous with the esker in the same valley north of the drainage divide with the Steven's Branch of the Winooski River (Williamstown Gulf) mapped by Wright (1999a, 1999b). The esker has been extensively quarried in several working and abandoned pits and is the primary source of sand and gravel in the Second Branch Valley. Exposures are good enough in pits just north of East Randolph to indicate that this esker is braided in some places, i.e. at least two ridges of coarse sand and gravel interweave. This pattern, however, is not apparent in the map pattern as one of the known branches is overlain by lake bottom sediments and consequently doesn't appear on the map (Fig. 5). Current exposures in the pits show coarse sand and gravel (the esker tunnel facies) overlain by both ice-proximal (sand and fine gravel) and ice-distal (sand, silt, and clay) lacustrine deposits (Fig. 5).

**Figure 5: Crest of esker exposed in a pit ~1.4 km north of East Randolph. Layers of coarse sand and pebble, cobble gravel were deposited in the esker tunnel beneath the retreating ice sheet. The overlying medium to fine sand that drapes the esker gravel was deposited after the ice sheet retreated and the mouth of the esker tunnel was still close by and showering the esker and lake bottom with sand. Orange coloration comes from iron oxide hydroxide precipitated by groundwater on the surfaces of sediment. The crest of the esker lies approximately 10 m above the elevation of the Second Branch at this exposure. The nearest located water well indicates that the esker gravels may extend as much as 25 m below the bottom of the pit before encountering bedrock.**

One moderate-sized kettle pond was mapped adjacent to the esker in North Randolph (west side of esker segment immediately south of the Brookfield town line) and one other very small kettle was mapped in East Randolph. Further evidence of collapsed sediments is visible in a gravel pit ~0.5 km south of North Randolph (Fig. 6). Following the model developed by Larsen (1987b), these kettles likely formed when stagnant tongues of ice on either side of the esker tunnel mouth were buried by sediment disgorged from the mouth of the esker tunnel.

This esker and associated ice-proximal sediments host the most voluminous aquifer in the Second Branch valley. Much, if not most, of the esker is below the grade of the river, hence below the water table.

In the southern part of town the esker is largely confined by overlying fine-grained glaciolacustrine sediments and in these areas may receive most of its recharge from the underlying bedrock.

**Figure 6: Esker and collapsed ice-proximal lacustrine sediments visible in pit ~0.5 km south of North Randolph. Unquarried esker segment comprises the wooded ridge visible behind the machinery. While a fault is not visible in the current exposure, bedding, steeply inclined towards the esker, suggests that these layers of medium to coarse sand and pebble gravel were originally deposited on stagnant ice and have been down-dropped as that ice melted.**

*Lake Bottom Sediments*

Lake bottom sediments shown on the geologic map are dominated by deposits of varved silt and clay and very fine sand. It has long been recognized that the Connecticut River valley and its tributaries were occupied by a long, thin lake, Glacial Lake Hitchcock, during the retreat of the Laurentide Ice Sheet (e.g. Larsen, 1987a; Koteff and Larsen, 1989). Detailed work in both the Second and Third Branch valleys by Larsen and others (2003) and the current work indicates that an arm of Glacial Lake Hitchcock extended up both the Second and Third Branch valleys of the White River to an elevation of between 740–770 ft asl. This range of elevations reflects isostatic uplift to the NNW since the lake drained and was determined by observing the maximum elevation of lake bottom sediments in the valley and two landforms interpreted to be deltas deposited by tributaries that flowed into this lake. These sediments directly overlie ice-contact esker sediments in the valley bottom, but elsewhere directly overlie both till and bedrock.

Extensive areas of the valley are underlain by these lake bottom sediments although in many areas these sediments are overlain by a thin veneer of alluvium. Good sections were observed in both excavations and landslides along streams (Figs. 7, 8) but none were measured in detail. The lake bottom sediments generally fine upwards, especially in the valley bottom where they overlie esker deposits. Typically the esker sediments are overlain first by coarse sand/pebble gravel deposited in subaqueous fans at the mouth of the esker tunnel. With continued retreat of the ice the section is dominated by fine sand (Fig. 7). Much of this sand is composed of calcite derived from the underlying Waits River Formation. Groundwater has both dissolved and precipitated this calcite within the sediments forming many concretions (Fig. 7). Larsen (in Larsen et al., 2003) has measured one detailed section exposed along the Second Branch between East and North Randolph which is reproduced here (Fig. 9). Much of the section consists of fine sand and silt with thin intervals of silt/clay varves. This variability may in part may reflect long-term ice retreat up the valley (i.e. the distance from the esker tunnel mouth), but may also reflect (1) shorter term variations in the position of the ice front up and down the valley, (2) yearly variations in

**Figure 7: Fine, horizontally bedded lacustrine sand exposed in a pit (East Randolph) above esker gravels (now excavated). Most of the sand was likely sourced from the esker tunnel once the ice sheet had retreated a short distance up the valley. The many concretions protruding from the excavated face consist of calcite-cemented sand. The underlying bedrock, the Waits River formation, contains many calcite-rich layers and is the source of the calcite sediment in these deposits that has been dissolved and later precipitated by groundwater.**

**Figure 8: Thick, well laminated, horizontally bedded silt/clay varved lacustrine sediment exposed in an excavation 2.2 km north of South Randolph. Section lies above and west of coarse esker sediments (now excavated). Silt/clay varve couplets thin quickly up-section.**

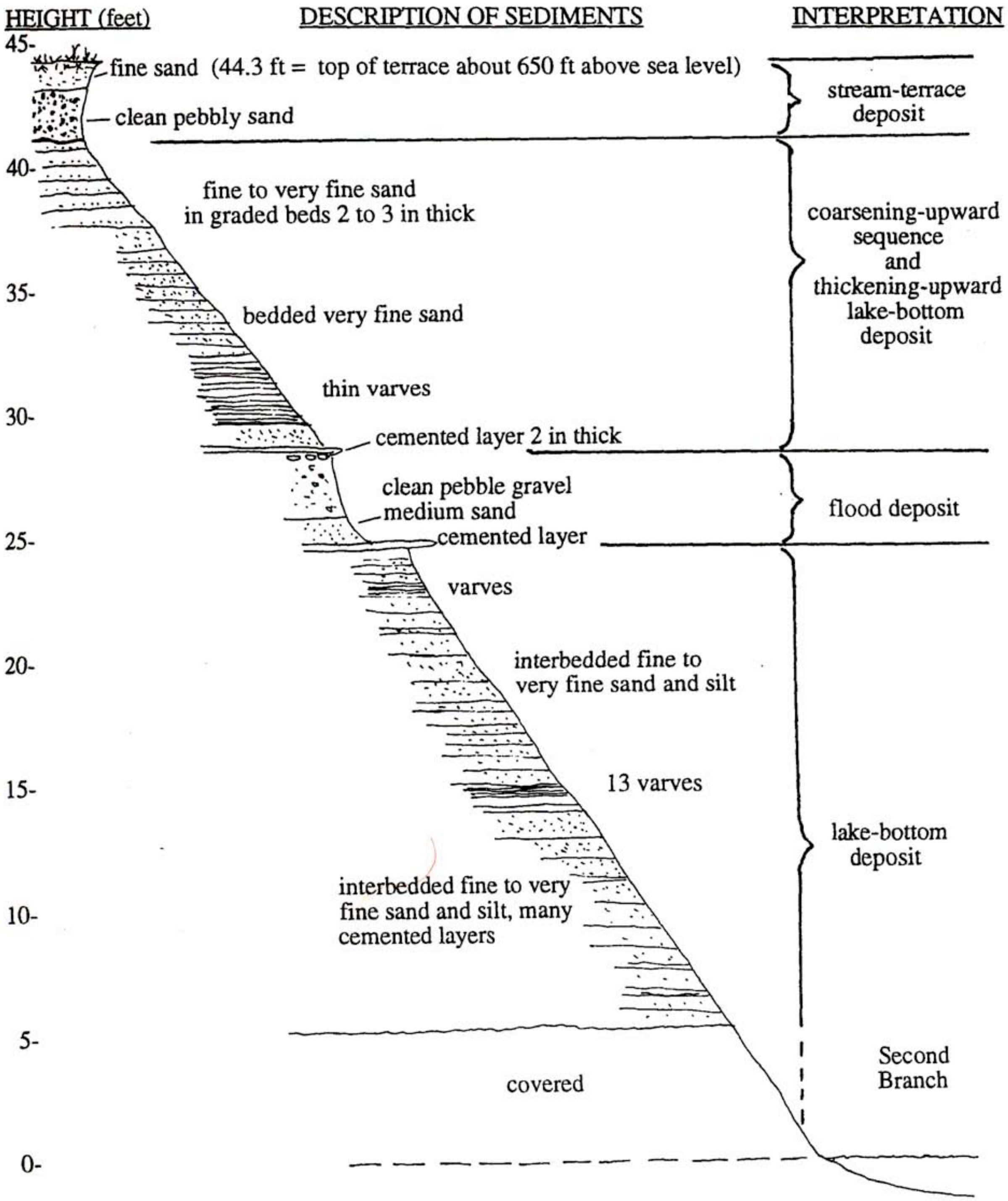


**Figure 9: High cut bank section measured by Larsen along a sharp meander bend in the Second Branch of the White River ~2 km south of North Randolph (Larsen et al, 2003, Fig. 13). Section typifies many of the lake bottom sediments. Sand lower in the section is probably sourced from the esker tunnel. Sand higher in the section may be from nearby tributary streams. Stream terrace gravels shown on the section underlie many terraces in the valley and formed by downcutting of the Second Branch river after Glacial Lake Hitchcock drained.**

temperature/rainfall, and (3) variations in the contribution from local sources (streams draining the nearby hillsides). Individual silt/clay couplets (varves) vary in thickness from several centimeters to over a meter (Fig. 8) reflecting some of these same variables.

Across the mapped area glacial lake bottom sediments frequently occur at elevations near the surface elevation of the lake, sometimes overlain by a thin cover of alluvium. This suggests that during the course of the lake's existence sediments largely filled in the narrow valley the lake occupied. If the filling wasn't complete, then the lake that existed here was extremely shallow. The outlet of Glacial Lake Winooski at the drainage divide between the Second Branch of the White River and the Steven's Branch of the Winooski River certainly provided a significant flow of water and eroded sediments down the Second Branch valley and into this arm of Glacial Lake Hitchcock for 200 to 300 hundred years, the lifetime of Glacial Lake Winooski.

Most of the lake-bottom deposits have hydraulic conductivities that are too low to make good aquifers. However, as noted earlier, these same deposits effectively confine any underlying aquifers consisting of coarse ice-contact sand and gravel.

*Deltaic Deposits*

Mapped deltaic deposits consist largely of coarse sand and pebble/cobble gravel deposited in the foreset and topset beds of deltas. Two areas were identified as deltaic deposits based on the shape of the landform, elevation of the top terrace surface, sediments comprising the landform visible at the surface and in well logs, and position along the valley side where modern tributaries enter the valley. These same tributaries, Osgood Brook in East Randolph and Halfway Brook ~1 km south of North Randolph, have incised channels through these deltaic deposits. No exposures of the internal sediment structures were visible while mapping to confirm that these landforms are indeed deltas. The elevation of the terrace surface on both these landforms (~720–740 ft asl for the Osgood Brook "delta" and 740–760 ft asl for the Halfway Brook "delta") suggest that those were the elevations of Glacial Lake Hitchcock in the this part of the Second Branch valley.

Similar landforms on the west side of the valley, e.g. where Blaisdell Brook and Peak Brook enter the valley, are not deltas, but instead consist of a relatively thin cover of alluvium deposited over lake bottom sediments. These have been mapped as Fan Terrace deposits (see below). The finer-grained bottom set beds associated with these deltas have been grouped with the lake bottom sediments.

While restricted in their aerial extent, deltaic deposits can be excellent aquifers although significant volumes of this material may lie below the water table because they have been deeply incised and consequently drained by modern streams.

*Fan Terrace Deposits*

Fan Terrace deposits consist of poorly sorted to moderately well sorted pebble gravel, pebbly sand, and sand (alluvium) deposited by streams as alluvial fans and broad aprons directly on lake bottom deposits (1) shortly after the lake drained or (2) once the lake was largely filled with sediments and before modern streams were entrenched (Fig. 10). Auger holes indicate that the thickness of these deposits ranges from several 10's of cm to over a meter (the length of the auger). Fan Terrace deposits generally occur in fan-shaped deposits adjacent to a tributary valley, but are otherwise identical to Stream Terrace deposits (see below). The finer-grained silts and clays deposited at the toe of these fans have been grouped with the lake bottom sediments.

Fan Terrace deposits may form thin perched aquifers, but are generally too thin to provide reliable sources of groundwater and they are also susceptible to contamination from agricultural chemicals and septic waste (Fig. 10).

**Figure 10: Fan Terrace deposit consisting of thin alluvium deposited on lake bottom sediments above Penny Brook on the Gifford farm between South Randolph and East Randolph. Penny Brook has incised its modern channel through these deposits. View looks northwest with the stream channel below the line of trees at the edge of the corn field.**

*Stream Terrace Deposits*

Stream Terrace deposits are old stream alluvium deposited on terraces at elevations above the modern flood plain of the Second Branch river. They consist of mostly coarse-grained sediments, e.g. moderately well to poorly sorted pebble-cobble gravel and sand. Stream-terrace deposits vary in thickness from several tens of cm to 2–3 m and generally overlie older lake bottom sediments. As noted earlier, this are of Glacial Lake Hitchcock largely filled with lake bottom sediments. The stream terrace deposits are sediments deposited after the lake shoaled. The Second Branch as well as it tributaries left a veneer of alluvium on top of the lake bottom deposits. When Glacial Lake Hitchcock eventually drained, these streams began incising channels through the underlying lacustrine sediments and left a thin mantle of alluvium along terraces at elevations ranging from the old bottom of the lake to the modern flood plain of the Second Branch river. These sediments have been quarried from several small pits and it is likely that other deposits have been completely removed.

Similar to the Fan Terrace deposits, Stream Terrace deposits may form thin perched aquifers, but are generally too thin to provide reliable sources of groundwater. They are also susceptible to contamination from agricultural chemicals and septic waste.

*Alluvial Fan Deposits*

Several small alluvial fans occur in the area. They consist of fan-shaped deposits of poorly sorted to moderately well sorted pebble-cobble gravel, pebble gravel, pebbly sand, sand, silt, and clay deposited by streams (frequently intermittent) where they slow down when encountering old terraces or the modern flood plain of the Second Branch river. Studies elsewhere in Vermont indicate that alluvial fans similar to these have been active episodically throughout the Holocene (Bierman, Jennings).

While of small aerial extent, these fans are good potential aquifers, especially where they are not being actively used for grazing or other agricultural purposes.

*Alluvium*

Areas mapped as alluvium are underlain by sediments deposited in the modern channel and flood plain of the Second Branch river and some of its larger tributaries. These sediments are indistinguishable from Stream Terrace deposits as they were deposited by the same streams, but at lower elevations. Alluvium occurs as generally thin deposits (~1–3 m) over lake bottom or ice-contact sediments. While bedrock is frequently exposed along tributary streams, alluvium is rarely deposited directly over bedrock in the Second Branch valley. As with the Fan Terrace and Stream Terrace deposits, much of the modern Alluvium is currently being used for agriculture (pasture, row crops, meadows, and grazing).

Despite its limited thickness, alluvium can be a good shallow aquifer material as some thickness of it is usually saturated all year round as opposed to perched aquifers occurring in Fan Terrace and old Stream Terrace materials. These aquifers are, however, susceptible to contamination from human or farm waste and can also pull in river water if they are located close to the river and pumped too hard.

**Description of the Geologic Cross-sections**

Geologic cross-sections have been drawn across the Second Branch valley in both North Randolph and East Randolph utilizing water well logs from located water wells to constrain the depth to bedrock and the composition and thickness of the surficial materials. Most of the water well logs are of poor quality meaning that it is impossible to gain any detailed stratigraphic information from them. Nevertheless, it is usually possible to glean the composition of the primary surficial material encountered while drilling and rarely contacts between different types of surficial materials can be discerned. All cross-sections are drawn with a 2.5x vertical exaggeration and end points located with NAD27 UTM coordinates.

*East Randolph Cross-section (A–A')*

The East Randolph cross-section traverses the village just south of the intersection of Routes 14 and 66 and extends up both sides of the valley (Fig. 11). While many wells exist in the village, only two could be directly used for the section, but the stratigraphy and depth to bedrock in other village wells is similar to those used for the section. A buried bedrock ridge is shown in the cross-section (Fig. 11). Ledge is exposed in the stream and other well logs to the south along Route 14 also indicate that bedrock lies close to the surface. Till cover on the valley sides is generally thin and discontinuous and is not shown as a separate unit on the cross-section. Similarly, till is not clearly recorded in most of the well logs and is consequently not shown on the cross-section although it is assumed to overlie bedrock in all areas that were not scoured by subglacial streams.

Esker gravels are logged in a "gravel" well (Well 139) <50 m north of Well 9587 and are shown in the cross-section, although the log of Well 9587 indicates only lake bottom sediments extending to bedrock. It's unclear whether the cross-section cuts through a gap between esker segments or the well log fails to record esker sediments. While shown with a sharp contact, there is usually a gradual fining upwards stratigraphic transition between the coarse-grained sediments deposited in the esker tunnel, the ice-proximal subaqueous fan sediments, and the ice-distal fine sand, and eventual varved silt clay lake bottom sediments. The well logs and surface mapping indicate that fine-grained lake bottom sediments comprise a large volume of the valley fill. These sediments are capped by a thin layer of either old or modern alluvium.

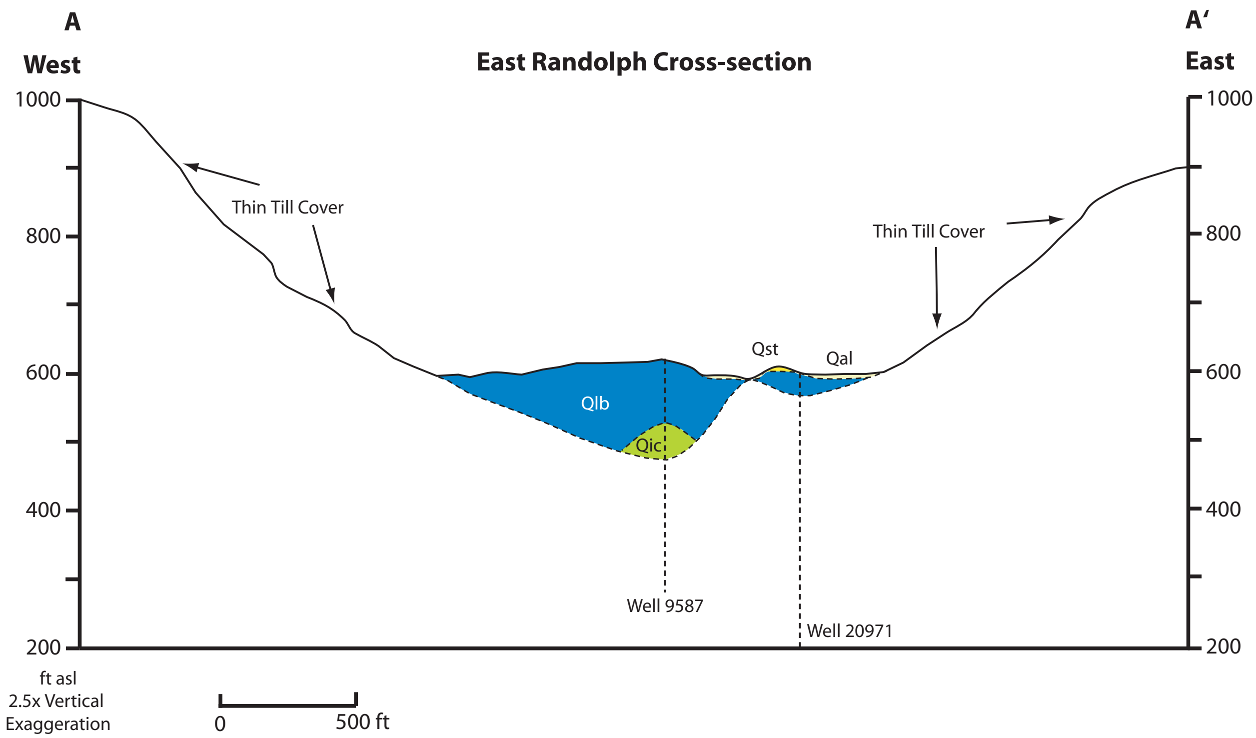


**Figure 11: West–East cross-section across the Second Branch valley through the village of East Randolph. A buried bedrock ridge crests in the stream valley where bedrock is exposed. Esker gravels (Qic) are overlain by a large volume of much finer (sand, silt, clay) lake bottom sediments (Qlb). A thin veneer of either old (Qst) or modern alluvium (Qal) overlies the lake bottom sediments. Western end of cross-section (A) located at 695545 E, 4867860 N. Eastern end of cross-section (A') located at 696740 E, 4867880 N.**

*North Randolph Cross-section (B–B')*

The North Randolph cross-section extends through the village of North Randolph and crosses both Snows Brook and the Second Branch of the White River (Fig. 12). The discontinuous and generally thin till cover that mantles the bedrock on the steeply sloping valley sides is not depicted in the cross-section. Till is similarly not shown beneath the valley bottom but likely exists above the bedrock surface in all locations where the bedrock is not directly overlain by esker gravels. Three water wells were used (Wells 300, 499, and 525) and indicate that the bedrock surface lies at least 111 feet (~35 m) below the terrace on which the village is built. All three wells ignore the old alluvium capping the terrace, but report sand and clay (lake-bottom sediments) extending down to bedrock. There is no indication in the well logs that an esker segment lies along the cross-section, but a well ~150–200 m north of the cross-section does bottom in gravel, most likely part of an esker segment. The form of this esker segment to the north is shown on the cross-section with a dashed line. As noted earlier, terrace surfaces are capped with alluvium.

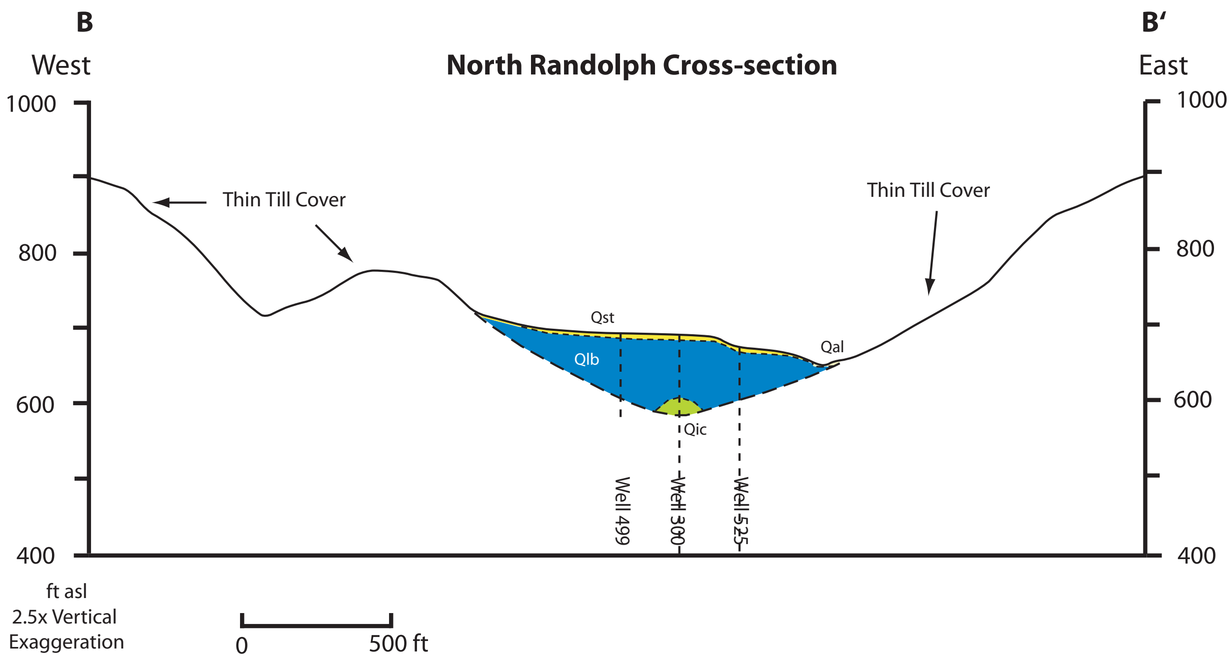


**Figure 12: West–East cross-section across the Second Branch valley through the village of North Randolph. Well logs indicate a simple bedrock valley geometry with the deepest part of the valley well west of the current stream channel. Esker gravels shown in the cross-section (Qic) aren't logged in Well 300, but are logged in a well a short distance to the north. The bulk of the valley fill consists of fine sand, silt, and clay deposited in a lake bottom environment (Qlb). Both modern alluvium (Qal) and older alluvium on higher terraces (Qst) occur as thin cover over the lake bottom sediments. Western end of cross-section (B) located at 695480 E, 4871525 N. Eastern end of cross-section (B') located at 696470 E, 4871755 N.**

## Interpretation of the Late Pleistocene/Holocene History of the Area

The geometry, stratigraphy, and internal structure of glacial sediments and landforms allow the following interpretation of the area's glacial history. This history of deglaciation is consistent with that worked out by Larsen (1972, 1987a, 1987b), Wright (1998, 1999), and Larsen and others (2003) for central Vermont. As noted earlier, no glacially striated surfaces were observed in the area. However, NW–SE striations measured by Larsen (????), striations measured along the crest of the Northfield Range (e.g. 299 at summit of Mount Cushman, Rochester, Vermont), and the Barre granite indicator fan (Larsen, 1972, Larsen et al. 2003) all indicate that the Laurentide ice sheet flowed from NW to SE across the mountains when it was thick enough to bury the underlying topography. When the ice sheet thinned, its direction of flow was to the south, guided by the generally N–S orientation of the valleys in the region.

Across the region the ice sheet left a discontinuous and generally thin (<10 m thick) layer of basal or lodgement till. However, water well logs indicate that thick layers (>30 m in some areas) of what is most likely till occur and likely fill old stream valleys that have not been re-excavated by Holocene stream erosion. This till is largely comprised of comminuted fragments of the underlying Waits River formation with relatively few erratics. The generally weak bedrock has been finely ground by the moving ice creating a till that is rich in fines. This till is dense and relatively strong when dry, but is prone to extensive slope failure where it is eroded by streams.

A segmented esker system occurs in the Second Branch valley. Segmented eskers form when subglacial tunnels discontinuously fill with sediments, most likely in response to high-discharge events within the glacier. The same esker system extends down the Stevens Branch valley to the north (Wright, 1998, 1999). Cross-bedding in the esker gravels indicate that subglacial stream flow was to the south. This subglacial tunnel system was active as the ice sheet retreated northwards up the Second Branch valley. Sediments were likely permanently deposited in the tunnel only within a few kilometers of its mouth, meaning that these ice-tunnel sediments are time transgressive and were deposited along a reach of the tunnel system that retreated northward with the retreating glacial margin, i.e. the sediments in the esker become younger to the north.

The ice sheet formed the northern boundary of an arm of Glacial Lake Hitchcock, a boundary that encroached northward up the White River valley as the ice sheet retreated (Larsen, 1987a, Koteff and Larsen, 1989). Icebergs were likely common along this calving glacial margin. Deltas in the Second Branch valley and the distribution of lake bottom sediments indicate that this lake reached an elevation of 740–770 ft asl. A fining upward sequence of sediments was deposited on top of the esker. These generally include ice-proximal subaqueous fan deposits that grade into fine sand deposits. Ice-distal deposits largely consist of varved silt and clay. As noted earlier, the vertical extent of these lake bottom sediments to elevations close to that of the lake surface indicates that the valley was largely filled in with sediments during its history.

Once the lake filled in stream deposits began to form along what was once the lake bottom. While the modern Second Branch stream is small, the outlet of Glacial Lake Winooski was at the drainage divide between the Second Branch and the Steven’s Branch of the Winooski River (~15 km north of North Randolph) and was the source of considerable discharge for 200–300 year history of Glacial Lake Winooski (Larsen et al., 2003). Eventually, once Glacial Lake Hitchcock drained the Second Branch began to downcut through the lake bottom sediments. Terraces mantled with old stream alluvium occur at all elevations between the old lake level and the modern stream channel.

In the upland areas, Holocene erosion has focused on old bedrock valleys. However, some old valleys are completely filled in with till. In most areas the Second Branch is flowing on old lake bottom sediments or esker sediments. In very few areas is bedrock close to the surface in the Second Branch Valley (Fig. 11).

**Description of the Isopach Map**

An isopach map was prepared for the town of Randolph using the “depth to bedrock” recorded for located water wells. These data are generally much more reliable than the water table measurements or records of the types of surficial materials encountered when drilling. The thickness of surficial materials was contoured using a 20 foot contour interval. All contour lines are dashed and considered very approximate as considerable interpolation and extrapolation of surficial material depth was needed between and beyond the relatively sparse population of wells.

Most of the upland areas (above the elevation of Glacial Lake Hitchcock) have a relatively thin and discontinuous cover of till (<10 m). However, isolated wells and sometimes groups of wells recorded thick (>30 m) accumulations of what is presumed to be till. These most likely represent old stream valleys that were filled with till and have not yet been re-excavated by Holocene stream erosion.

The valleys of the Second Branch, Third Branch, and Ayers Branch and related tributaries are all underlain by considerable thicknesses of glaciofluvial and glaciolacustrine sediments. In many areas these materials exceed 30 meters.

**Description of the Piezometric Surface Map**

The piezometric groundwater surface (water table) was contoured (100-foot contour interval) using both the surface water hydrology and data from a subset of located water wells. In most areas these water table contours closely mimic the land surface topographic contours. The original intention of this work was to utilize measurements of static water table elevations in wells to gain insight regarding the flow of groundwater through the fractured bedrock that underlies all of the town. However, almost half of these measurements (1) place the static water table significantly above the elevation of the land surface where the well is located or (2) place the static water table significantly below the elevation of nearby streams or ponds that are zones of groundwater discharge. Consequently, many of these well data were ignored when constructing the water table contours. Static water table elevations above the ground surface can result from wells tapping confined aquifers with a hydraulic head above the ground surface elevation, but normally produce flowing wells. Most of these water-table-above-the-ground-surface data probably result from incorrectly recording or measuring the elevation of the ground surface at the well head. Static water table elevations significantly below local surface water elevations may result from measuring the water table in wells before that elevation has stabilized or from wells tapping water-filled fractures that are isolated from the surface water aquifer, a confined aquifer with a hydraulic head well below that of the surface aquifer.

**Groundwater Recharge/Discharge Maps**

*Recharge Potential to Bedrock*

Within the town of Randolph bedrock water wells predominate, even in areas where relatively shallow, high-yield surficial aquifers exist. Most of these wells are utilizing fractured bedrock aquifers (a form of secondary porosity) as little primary porosity exists in the recrystallized metamorphic rock that underlies the town. These aquifers are recharged where open fractures intersect Earth’s surface or, most commonly, saturated till in the upland areas above the level of Glacial Lake Hitchcock. As noted on the geologic map these areas of relatively thin till (Qt) cover most of town.

Relatively little recharge takes place in the valley bottoms. The fine-grained lake bottom sediments have low hydraulic conductivities and, even when saturated with water, do not transmit much water to the underlying bedrock. Furthermore, in most parts of the valley bottom, the bedrock is actually discharging water to the overlying sediments. This is the major source of recharge to the ice-contact aquifer noted below.

*Discharge Areas/Potential Shallow Aquifers*

As noted on the Piezometric surface map, most groundwater in the thin till cover and underlying fractured bedrock travels relatively short distances before discharging to small streams. During the dry months of the summer/early fall, the water table may drop sufficiently that many of these streams dry up and bedrock discharge is restricted to the larger streams in more deeply incised valleys. Groundwater following longer flow paths through the fractured bedrock generally discharges along the valley bottom. In most places this discharged water flows into the overlying surficial materials either slowly or quickly depending on the hydraulic conductivity of these materials. The discontinuous esker system and overlying ice-proximal sediments is the major recipient of these discharged waters. Those same sediments also receive recharge from the surface where they're exposed north of East Randolph, but to the south of East Randolph, they're generally buried by lake bottom sediments and effectively confined where the thickness of those sediments is large and the hydraulic conductivity of those sediments is low.

*Recharge Potential of Overburden Aquifers*

The primary overburden aquifers lie in the esker gravels and overlying ice proximal finer gravels and sands. Where these are exposed at the surface (Qic, generally north of East Randolph), they are recharged at the surface. Farther south, as noted above, these ice-contact sediments are covered by younger lake bottom sediments that have low hydraulic conductivities.

Much of the valley bottom is underlain by alluvium deposited by either the modern stream (Qal) or by the Second Branch earlier in the Holocene on terraces (Qst). This alluvium is very porous and permeable and provides an excellent recharge material. However, this alluvium lies unconformably on much finer-grained lake bottom sediments. Therefore, that recharged water flows downward only short distances (usually <2 m) before encountering silts and clays. While some of this water will slowly seep into these fine sediments, most pools up above them forming a thin perched aquifer and travels laterally through the alluvium until it discharges into the Second Branch or one of its tributaries.

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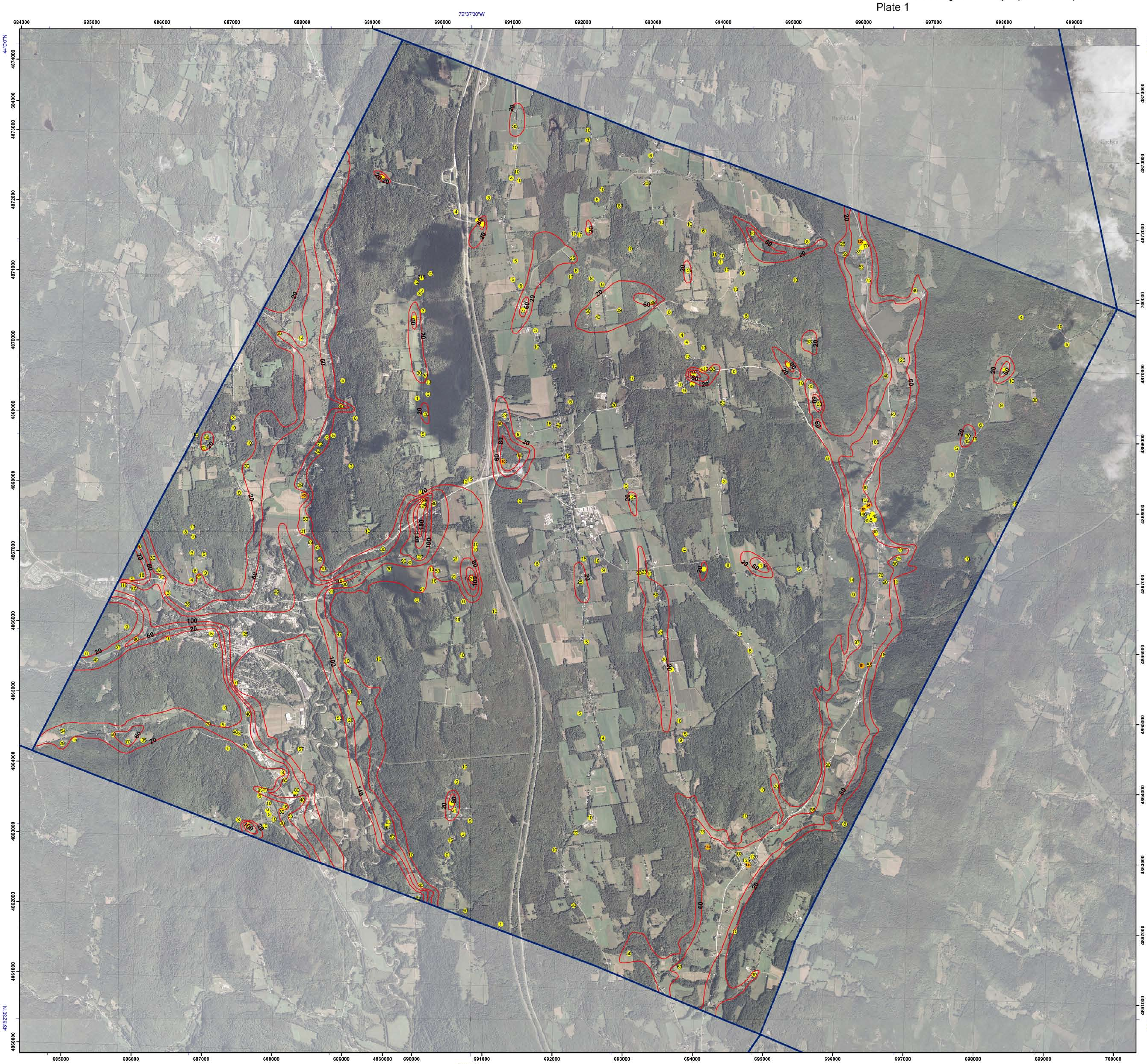
Vermont Geological Survey Open File Report VG11-2
Plate 1



Base map: NAIP 1m color orthophoto (2003)
Quadrangle names printed in blue.
Coordinate System: Vermont State Plane, meters, NAD 83.
Geographic coordinates shown at topo corners are in NAD 83.
Grid overlay on map is VSP Zone 18N, NAD 83.
Project supported in part by the Town of Randolph, VT.
Digitization and cartography: Marjorie Gale
Date: March 2011

0 0.5 1 2 Miles
0 0.5 1 2 3 Kilometers
SCALE 1:24,000

MN N
Magnetic declination
15.5 degrees west, 1968

## LEGEND

| | |
|---|---|
| (red line) | Depth to bedrock contour (ft) |
| (yellow dot) | Rock Well with E911 or GPS address |
| (orange dot) | Gravel Well with E911 or GPS address |
| (blue box) | Town Boundary |

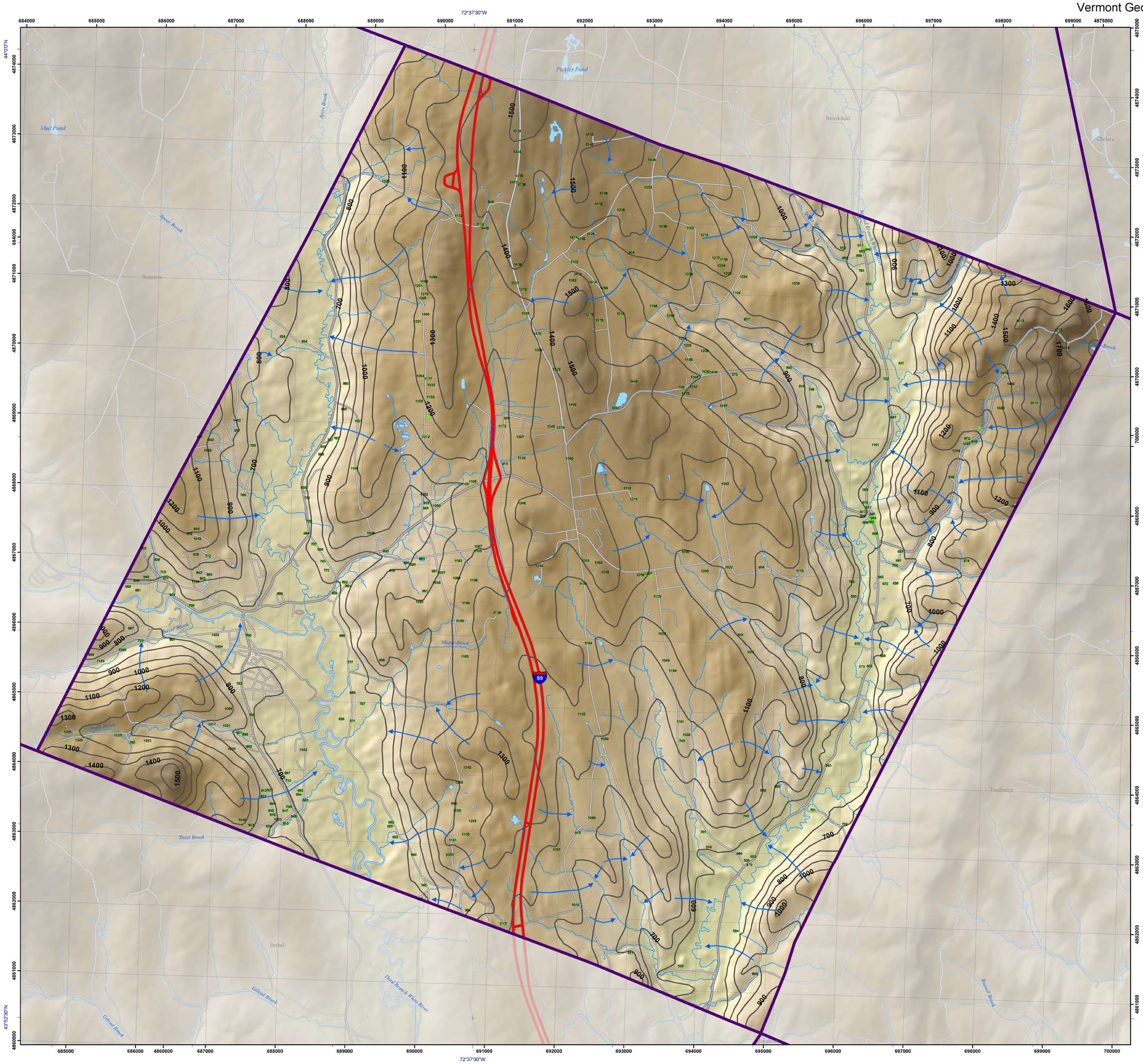
Location of Study Area


Published by:
Vermont Geological Survey
103 South Main St., Logue Cottage
Waterbury, Vermont 05671-2420
http://www.anr.state.vt.us/dec/geo/vgs.htm
Laurence Becker, State Geologist


# Depth to Bedrock in the Town of Randolph, Vermont


by
Stephen Wright
2011


VERMONT
AGENCY OF NATURAL RESOURCES
Vermont Geological Survey




## LEGEND

- Inferred groundwater flow lines
- Potentiometric surface, 100' contour interval
- Water well, labelled by static water elevation in feet
  green - bedrock well, yellow - gravel well
- Lake/Pond/Stream
- Roads
- Town Boundary

Vermont DEM (30 meter) Layer File, VT ANR and VCGI Elevation Model
Res: 1 : 0.991

**Value**

High : 4381

Low : 69

**Hillshade**

**Value**

High : 254

Low : 0

## EXPLANATION

The elevation of the static water level in bedrock wells is reported in the well log data and contoured on the Potentiometric Surface and Inferred Groundwater Flow Lines map. The static level of water in a well is a useful parameter as it is a factor in determining the amount of water that is stored in the well bore, and thus, available to be pumped into a house or other structure using the water. These data were contoured using a 100 ft contour interval and control points are the well points, thus the contours are approximate. The reported static level for a well may be unreliable if the measurement was made before a well had completely recovered from pumping. In general, static water levels also exhibit seasonal fluctuations and the date of data collection also affects the potentiometric surface interpretation.

Groundwater flows down the hydraulic gradient from a high potentiometric level to a low potentiometric level. Flow lines can be drawn on a potentiometric surface map and are drawn at right angles to the potentiometric contours. A glance at the groundwater flow lines reveals the general path of groundwater flow from regions of higher potential to regions of lower potential. The potentiometric surface map and the accompanying flow lines show very general directions or pathways of recharge from higher regions in an aquifer to regions of discharge in lower portions of an aquifer. Flow lines commonly mimic the topography.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Base map from VT ANR Hillshade(24k).
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Grid overlay on map is VSP Zone 18N, NAD 83.
Project supported in part by the Town of Randolph, VT.
Digitization and cartography: Marjorie Gale
Date: March 2011

0 0.5 1 2 3 Miles

0 0.5 1 2 3 4 5 Kilometers

SCALE 1:24,000

MN N

Magnetic declination
15.5 degrees west, 1968

# Potentiometric Surface and Inferred Gropundwater Flow Lines, Town of Randolph, Vermont

by
Stephen Wright
2011

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Vermont Geological Survey

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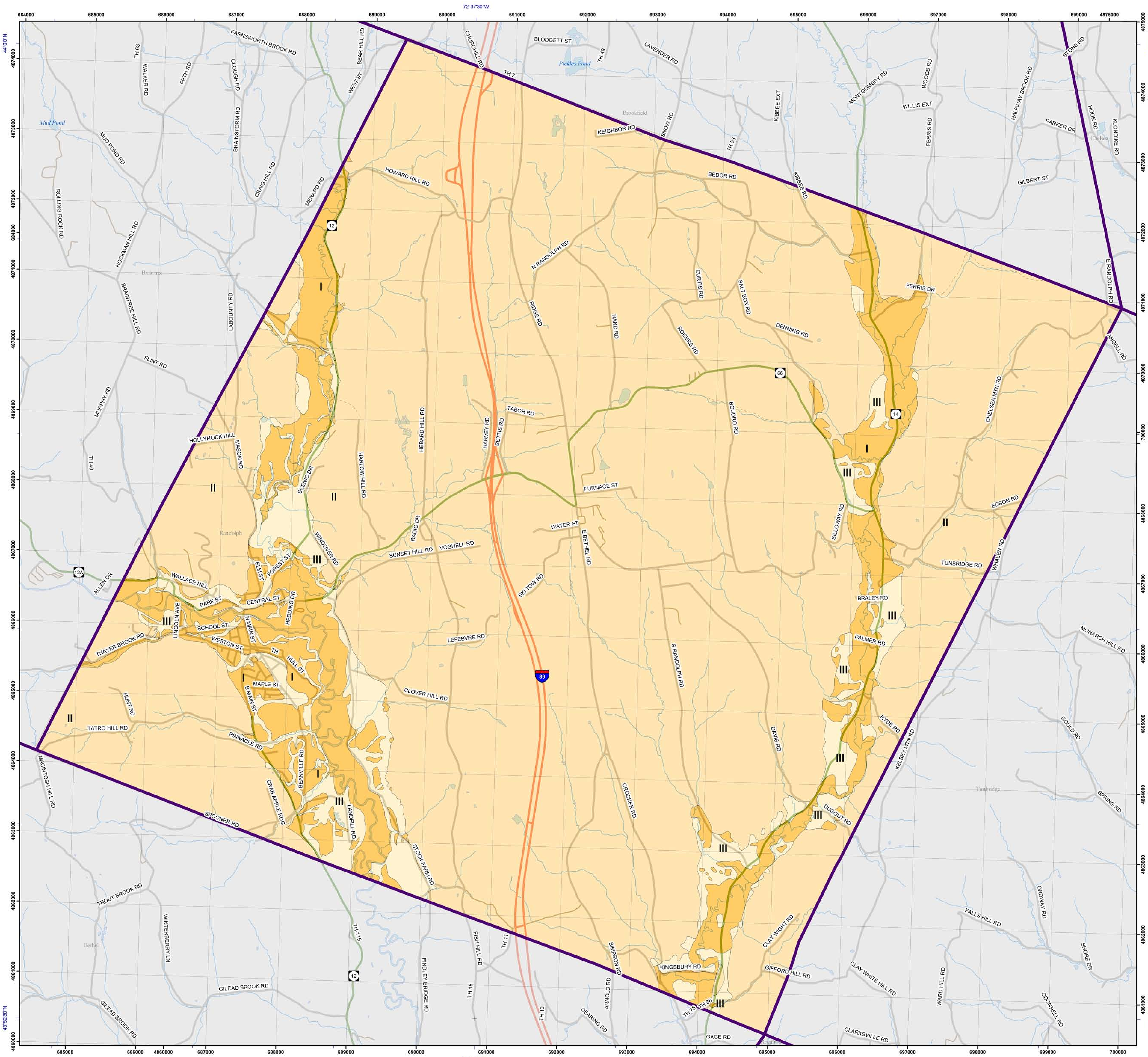
Open File Report VG11-2
Plate 3




## LEGEND

### Recharge Potential to Surficial Aquifers

**I** — Higher: Porous and permeable materials (Qd, Qic, Qal)comprising substantial unconfined aquifers. Includes materials (Qaf, Qal, Qed, Qst, Qft) that host relatively thin perched aquifers which flow laterally (above lake bottom deposits) and discharge into streams.

**II** — Moderate: Includes large areas of thin to thick till cover in upland areas (Qt) that provide moderate recharge to springs, seeps, and low-yield domestic wells set in till.

**III** — Low: Areas underlain by low-permeability lake bottom deposits (Qlb). Exceptions occur in limited areas (not separated on the map) where these deposits consist of fine sand overlying ice-contact sediments (Qic).

Town Boundary

Stream

Roads

## EXPLANATION

SHALLOW AQUIFERS
A shallow aquifer is a volume of porous and permeable sediment, either sand or gravel or a mixture of sand and gravel, which is exposed at the ground surface. Hydrologists refer to this as an unconfined aquifer because the aquifer is not sealed, capped or confined by an impermeable layer. Shallow aquifers are recharged by direct downward infiltration of surface water from precipitation, snow melt and possibly through the bottoms of stream channels.

BURIED AQUIFERS
Buried aquifers in surficial materials are confined by less permeable sediment. Recharge to the buried aquifers may be from adjacent and/or underlying surficial or bedrock materials.

RECHARGE POTENTIAL
Recharge potential is ranked from 1 being the highest to III being the lowest. The criteria for the rankings are based on the overburden thickness and the stratigraphy of the overburden as determined from analysis of the well logs. Recharge potential is dependent on the type of surficial material, assuming that water will flow more easily through coarse-grained, permeable sediment. However, in Randolph, many of the thickest and most permeable sediments overlie relatively impermeable lake bottom sediments.
The recharge potentials are qualitative and no absolute values on rates of recharge through each of the surficial material types can be provided.

Location of Study Area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Date: March 2011


0 0.5 1 2 3 Miles
0 0.5 1 2 3 4 5 Kilometers
SCALE 1:24,000

MN N
Magnetic declination
15.5 degrees west, 1968

# Recharge Potential to Surficial Aquifers, Town of Randolph, Vermont


by
Stephen Wright
2011



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Vermont Geological Survey

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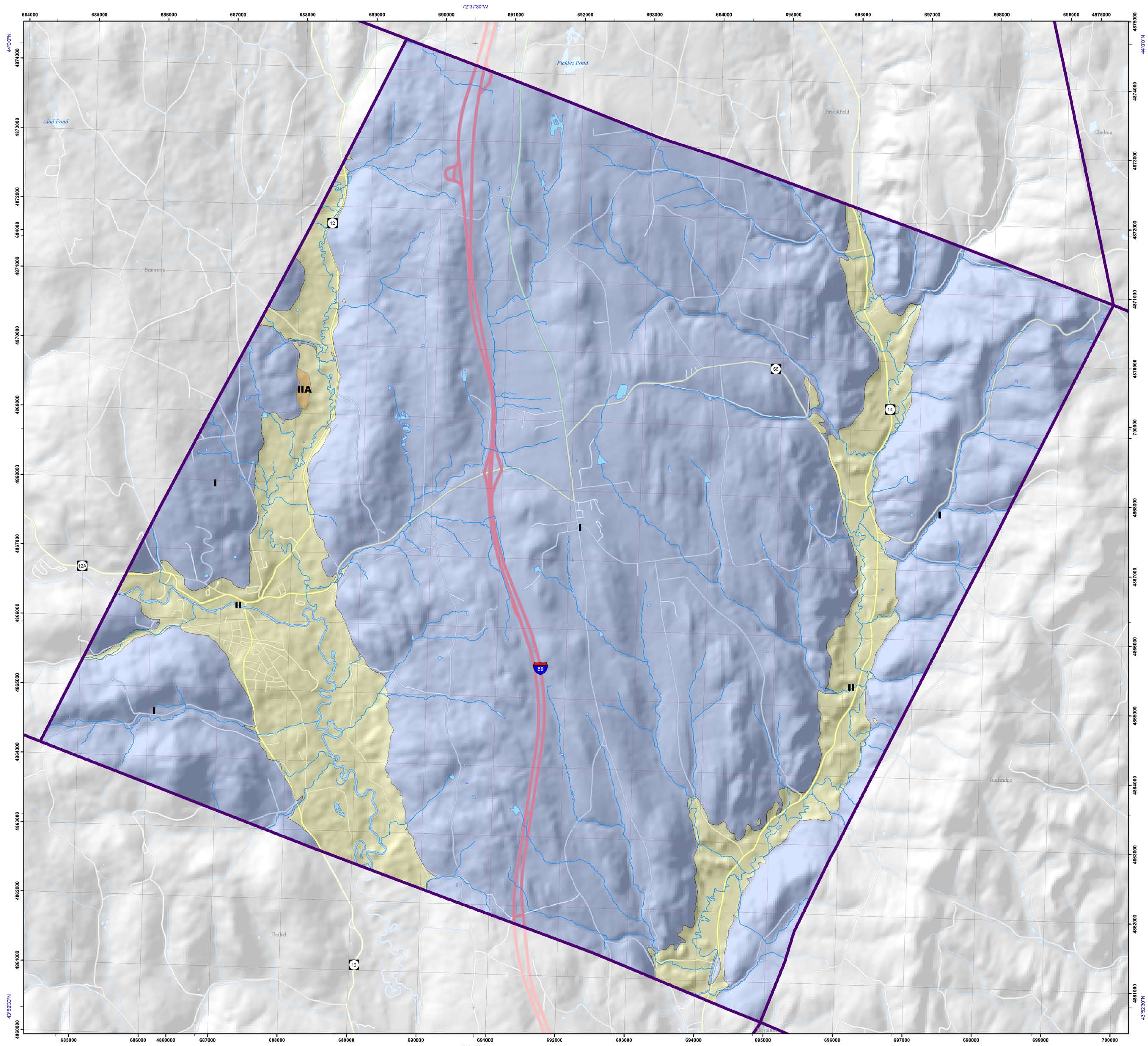
Open File Report VG11-2
Plate 4




## Legend

Recharge Potential to Bedrock Aquifer

| | |
|---|---|
| I | Higher: These are most commonly areas where the thin till veneer or bedrock outcrops enable some recharge into fractures (joints, open foliation planes) in the underlying rock. Soils developed on the till generally provide good infiltration of surface water. Percolation to the underlying bedrock surface through the till is generally slow, but the short distances involved still ensure relatively short travel times from the surface to the bedrock surface followed by travel along the bedrock surface to the nearest open fracture. Also includes areas of permeable and porous stream-deposited sediment, e.g. deltaic deposits (Qd) and the upper reaches of alluvial fans (Qaf) that overlie thin till or bedrock and areas of thick till accumulations where recharge potential may be limited. |
| II | Lower: Relatively impermeable lake bottom deposits (Qlb) which impede infiltration of water to the underlying bedrock aquifer. Includes younger fan terrace deposits (Qft) and alluvium (Qst, Qal) that overlie lake bottom sediments. |
| IIA | Higher or Lower: Wetland deposits (Qwl) which can provide higher recharge if located in upland areas underlain by thin till or bedrock. These same deposits offer lower recharge potential if located in lake bottom sediments (e.g. abandoned stream channels). |
| | Town Boundary |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Date: March 2011

0 0.5 1 2 3 Miles

0 0.5 1 2 3 4 5 Kilometers

SCALE 1:24,000

MN N

Magnetic declination 15.5 degrees west, 1968

# Recharge Potential to Bedrock Aquifer, Town of Randolph, Vermont


by
Stephen Wright


2011


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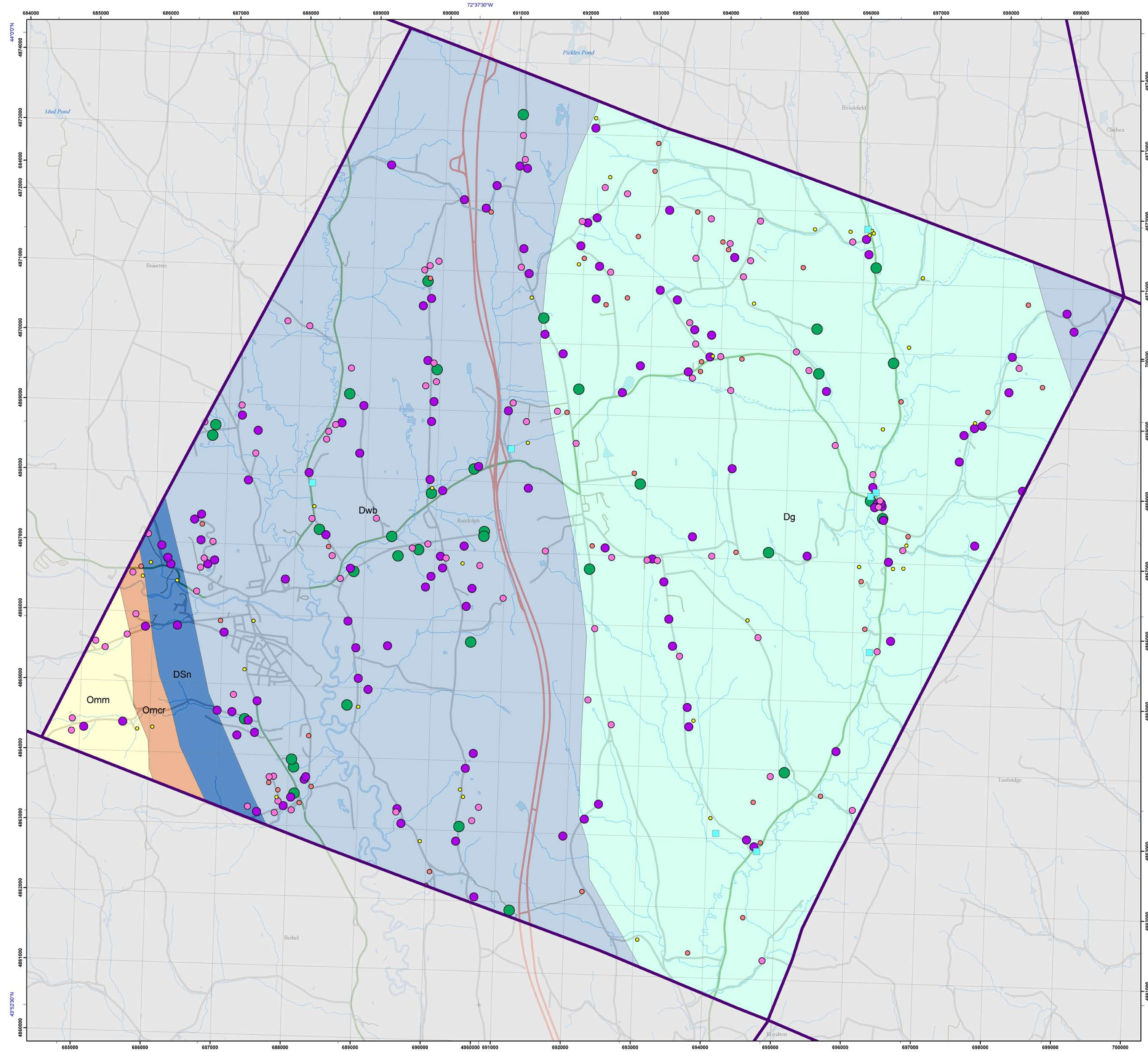
Plate 5




The Hydrogeologic Unit Map shows located bedrock wells in Randolph and gives mean well yield and depth by bedrock formation. 334 out of 612 water well records for Randolph were linked to either an E-911 address or a GPS location. 315/334 or 94% of the located wells in Randolph have reported yields >1 gpm.

## Legend

**Bedrock/Hydrogeologic Unit***

Dg - Devonian Gile Mountain Formation
Rock type: phyllite, schist, calcareous schist, and sandy marble
# of Wells: 155
Mean yield (GPM): 16 gpm
Mean Depth (FT): 274'

Dwb - Devonian Waits River Formation (Barton River)
Rock type: sandy marble and phyllite
# of Wells: 156
Mean yield (GPM): 23 gpm
Mean Depth (FT): 218'

DSn - Silurian to Devonian Northfield Formation
Rock type: slate, phyllite and silty marble
# of Wells: 9
Mean yield (GPM): 15 gpm
Mean Depth (FT): 265'

Omcr - Ordovician Cram Hill Formation
Rock type: phyllite, felsic and mafic meta-volcanics
# of Wells: 6
Mean yield (GPM): 11 gpm
Mean Depth (FT): 335'

Omm - Ordovician Moretown Formation
Rock type: quartzite, "pinstriped" granofels, and schist
# of Wells: 8
Mean yield (GPM): 9 gpm
Mean Depth (FT): 237'

* Bedrock units are from: Doll, C.G., Cady, W.M., Thompson, J.B., Jr., and Billings, M.P., 1961, Centennial geologic map of Vermont: Vermont Geological Survey, scale 1:250,000.

Yield in gallons per minute of bedrock wells with E911 or GPS location

0.0 - 2.0 GPM
2.1 - 5.0 GPM
5.1 - 10.0 GPM
10.1 - 40.0 GPM
40.1 - 150.0 GPM

Gravel Wells with E911 or GPS Location
# of Wells: 8
Mean Yield (GPM): 29 gpm
Mean Depth (FT): 103'

Town Boundary

Roads

Stream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# Bedrock Hydrogeologic Unit, Town of Randolph, Vermont


by
Stephen Wright and Marjorie Gale
2011


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