Appendix A: Surface Water and Ground Water Interaction in the Darby

The purpose of this analysis is to identify watershed areas with the potential to receive a proportionately greater ground water contribution to stream flow than the watershed as a whole. The analysis is based upon a characterization of the physical properties of the underlying sub-surface material. The material that composes the watershed sub-surface varies downward along its vertical profile and laterally across the watershed surface. It is this spatial variation that partially explains the relative presence or absence of ground water in stream flow.

The volume of water that flows in a stream originates from multiple sources. Part of the total volume runs-off the land surface directly into the stream. Another part may be piped through storm drains or run through field tiles and ditches to the stream. Yet another part seeps through the sub-surface and into the stream through the banks and bottom of its channel. The relative portion of each of these parts is dependent upon many complex factors within the process by which water circulates on Earth, the hydrologic cycle. This analysis examines only one aspect of the hydrologic cycle, sub-surface flow, and is only an attempt to identify areas within the watershed that have the potential to provide a significant ground-water contribution to stream flow.

A.1.0 Sub-Surface Materials

The vertical profile of the watershed sub-surface is organized into layers. The topmost layer of the profile is the soil. Soil type, depth and management vary across the watershed, and control the amount of precipitation that infiltrates the ground and percolates through the vertical profile of the sub-surface. Under the layer of soil are deposits of gravel, sand, silt and clay that result from multiple glacial advances and retreats through Ohio during the Pleistocene Epoch, 10,000 to over 300,000 years ago. The method of deposition, composition of materials, and depth of these deposits vary across the watershed, and in part dictate the storage and transport capacity of the sub-surface for water. Below the glacial deposits is bedrock. Bedrock in the watershed is sedimentary, and dates to the Devonian and Silurian Periods, 360 to 440 million years ago. Like the glacial deposits above it, bedrock has the capacity to store and transport water. The porosity, degree of fracture, and connection to the surface are important factors in its ability to do so.

A.1.1 Soil

The dominant soil associations in the watershed are Kokomo-Crosby-Miamian, Miamian-Celina-Crosby, and Brookston-Crosby-Celina. Soil associations are areas that are composed of multiple soil types, but are grouped together based upon similar properties or behaviors that distinguish them from surrounding soil types and areas. Of importance to ground-water availability and movement is the soil's physical composition, compaction, and aggregation. These physical properties manifest in a particular drainage behavior that partially determines the amount of precipitation that will infiltrate the surface, percolate through the soil, and eventually reach the sub-surface water stores, or aquifers. Soil scientists qualitatively describe drainage behavior, and in the watershed the Kokomo-Crosby-Miamian association is classified as very poorly drained, Miamian-Celina-Crosby as well drained to moderately well drained, and Brookston-Crosby-Celina as very poorly drained. Associations that are poorly drained have lower infiltration rates, greater runoff or ponding, and typically less water available to recharge ground-water resources. The opposite is true for well drained soils. The following table provides the watershed breakdown of soil drainage behavior.

Watershed	Excessively drained	Well drained	Moderately well drained	Somewhat poorly drained	Poorly drained	Very poorly drained	Not Rated
Upper Big Darby Cr.	0.0%	13.7%	13.9%	40.3%	0.3%	31.3%	0.4%
Middle Big Darby Cr.	0.0%	6.0%	5.2%	42.9%	0.0%	44.7%	1.2%
Little Darby Cr.	0.0%	17.0%	8.9%	34.9%	0.3%	38.8%	0.1%
Lower Big Darby Cr.	0.2%	35.8%	7.2%	29.9%	0.0%	24.9%	1.9%
Grand Total	0.0%	18.6%	9.6%	36.6%	0.2%	34.2%	0.8%

As can be seen, there is some variation in soil drainage behavior from one sub-watershed to another. Based upon the presented data, it appears that the lower Big Darby soils are better drained than the upper Big Darby, and even more so than the middle Darby and Little Darby. It should be noted, however, that the natural ability of the soil to drain water is affected by surface land use and management practices. Urbanization and its associated increase in impermeable surface cover can impact the soil's efficacy in drainage. Agricultural and construction activities that alter the soil's natural structure can also improve or inhibit drainage. The presented statistics therefore represent the potential rather than the actual drainage behavior of the soil. The variability seen in soil drainage behavior between sub-watersheds may partially explain the differences in ground water contributions to stream flow.

A.1.2 Glacial Deposits

Glacial deposits of gravel, sand, silt and clay lie beneath the soil. The capacity of these deposits to serve as a ground-water resource is related to their level of sorting. Sorting is the process by which a given transport medium separates out certain particles on the basis of size, shape, or density. Well sorted materials are typically more hydraulically conductive then poorly sorted material, and therefore serve as a better ground-water resource. The types of glacial deposits found in the Big Darby watershed include end moraine, ground moraine, complex associations, and buried valley deposits.

End and ground moraine are typically poorly sorted, and have only low to moderate hydraulic conductivity. End and ground moraine material was either pushed along the front a glacier or carried atop it, and was deposited as the glacier melted and receded. End and ground moraine consists of an unorganized mix of rock, gravel, and soil, typically with a large silt and clay fraction, with few linear pathways for the transmission of water.

Complex associations vary from poorly to well sorted, and tend to have isolated areas of high hydraulic conductivity amongst larger, less conductive areas. Complex associations are composed end moraine, ground moraine, eskers, and other types of deposits. Eskers are formed in areas where inter-glacial streams cut through the ice, sorting the underlying deposits.

Buried valley deposits are well sorted, and are the most hydraulically conductive of the glacial deposits found in the watershed. Buried valley deposits are composed of sand and gravel carried from the glacier and deposited in historic valleys by glacial melt-water. Depending upon the rate the glacier is melting and the slope of the local land, glacial melt water can create turbulent rivers capable of transporting massive amounts of material.

A.1.3 Bedrock

Ancient bedrock lies below the glacial deposits. Bedrock in the watershed is sedimentary, meaning it was formed by the deposition of particles that were subsequently cemented or bonded together. Examples of sedimentary rock in the watershed are limestone, dolomite, and shale. These rocks are relatively impermeable, but through time the rocks become cracked, or fractured, by tectonic forces and the freeze and thaw of water. Further, passages through limestone are formed as it is slowly dissolved by water. These physical and chemical processes serve to increase the hydraulic conductivity of the bedrock, and increase its potential to serve as an aquifer.

As a general principle, limestone makes for a better aquifer than dolomite, and dolomite is better than shale. In the watershed, however, there is dolomite that produces a high water yield, measured in gallons per minute, and limestone that is characterized by a very low yield. This is because the value of bedrock as a water resource is dependent upon more than just its chemical composition. The degree of fracture, depth, and connection with the surface can play equal if not greater roles.

Throughout the majority of the watershed, streams flow through deep glacial deposits and have little contact with the bedrock. As such, most of the ground water contributed to stream flow originates from the glacial deposits. However, in isolated areas the glacial deposits area shallow enough that there is some connection between the underlying bedrock aquifers and the streams. In such areas, the magnitude of the ground water contribution to the stream maybe primarily dependent upon the hydraulic properties of the rock rather than those of the overlying deposits.

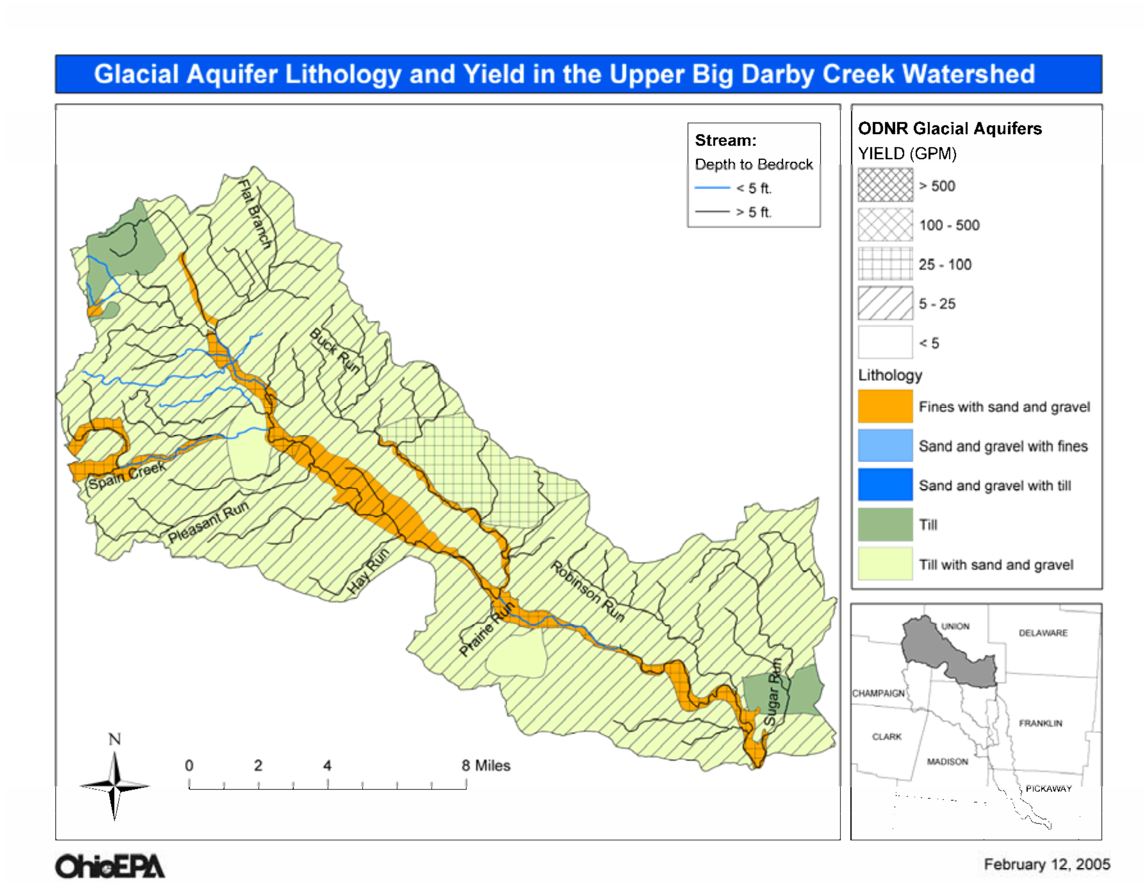
A.2.0 Glacial and Bedrock Water Resources of the Darby Watershed

The following text and figures discuss and portray the glacial and bedrock water resources of each Big Darby watershed, and the effect they may have upon the contribution of ground water to stream flow. The glacial aquifer figures that follow illustrate the lithology and estimated yield of the deposits. Lithology refers to the physical character and composition of the deposits. The lithology of the deposits is classified in order of increasing hydraulic conductivity as till, till with sand and gravel, fines with sand and gravel, sand and gravel with till, and sand and gravel with fines.

Estimated yield is a measure of the aquifer's value to provide water for a well. Yield is used on the following maps as a surrogate for hydraulic conductivity, because data regarding hydraulic conductivity was not available with the spatial specificity that yield was. Hydraulic conductivity is a better measure of the connectivity between ground and surface water, but yield can be useful if its limitations within this context are considered. Hydraulic conductivity is an intrinsic property of the glacial deposits. Conversely, yield is an extensive property and can increase with increasing depth of the glacial deposit of bedrock. The depth of an aquifer is of secondary importance to surface water; it is the relative ease by which water can move horizontally through aquifer that is of primary importance. Therefore, for the purpose of this analysis spatial variability in yield is only singnificant when it results from a change in the local lithology of the glacial deposits.

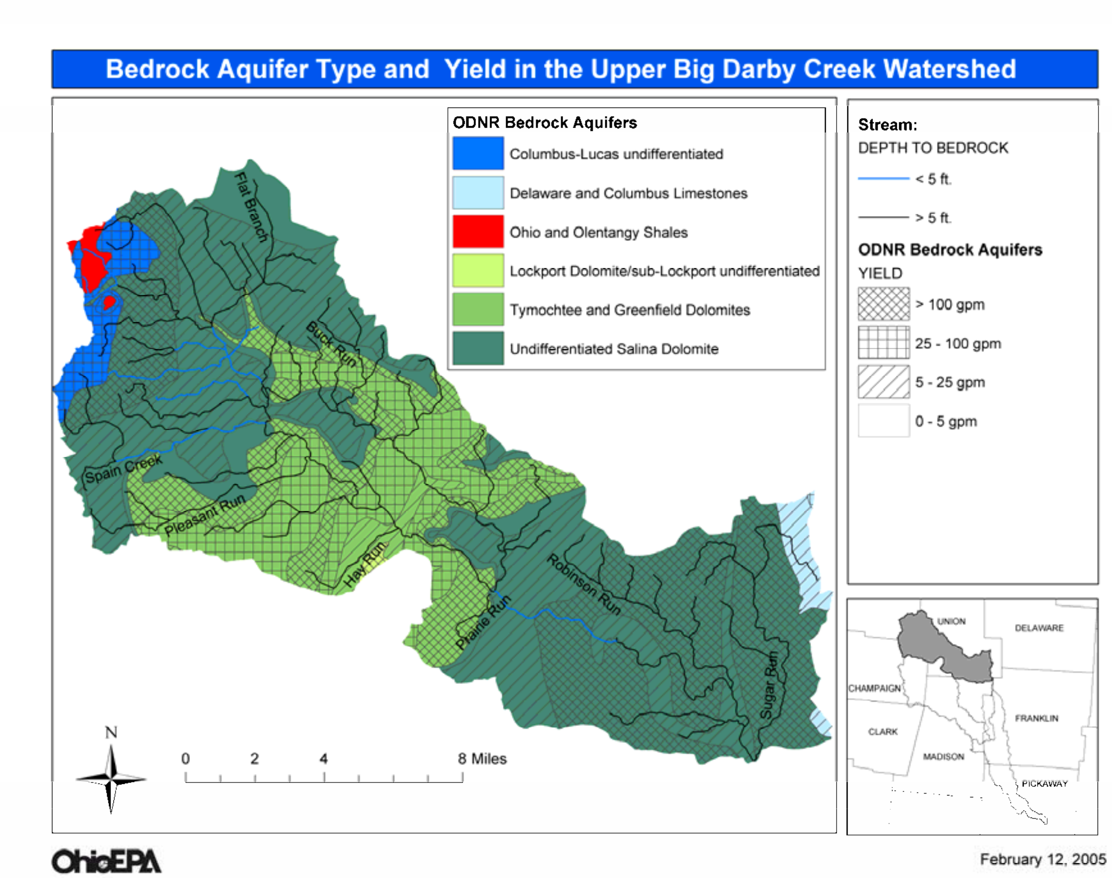
A.2.1 Upper Big Darby Creek Watershed

The upper Big Darby Creek watershed is dominated by till with sand and gravel. Some isolated lenses of till exist throughout, and there are fines with sand and gravel along the Big Darby Creek mainstem, Buck Run, and Spain Creek. Deposits on the northeast side of the sub-watershed are end moraine, while the southwest side is a mix of complex associations and ground moraine. The surficial fines with sand and gravel that are found along the Big Darby Creek mainstem are actually alluvial deposits rather than glacial deposits. This means that they were deposited by the stream after the Pleistocene ice-age. The glacial lithology of the upper Big Darby Creek is illustrated in the following figure.



As can be seen in the preceding figure, glacial aquifer yield in this sub-watershed is generally moderate. The dominant lithology, till with sand and gravel, yields between five and 25 gallons per minute (GPM). The area of higher yield to the north of Buck Run is associated with an increase in depth of the till with sand and gravel deposits, and therefore is of little consequence to stream flow. The area of higher yield along Spain Creek, however, is associated with the change in lithology to fines with sand and gravel. Unlike the fines with sand and gravel found along the Big Darby Creek mainstem, the Spain Creek area is in a buried valley setting that extends far into the adjoining watersheds. Spain Creek is in an uppermost extent of the Mad River Buried Valley Aquifer, and ground water yield from the buried valley may be greater than the surrounding moraine. One could reasonably expect a greater ground water contribution to stream flow in Spain Creek.

The blue streams in the following figure represent areas where the stream is likely in contact with bedrock. This conclusion is based upon a depth to bedrock of less than five feet, which is a conservative allowance for bank height. In areas where the stream is in contact with the bedrock, the hydraulic properties of the rock become important for it may be a source of ground water to the stream. The following figure illustrates the bedrock aquifer types and yields in the upper Big Darby watershed.

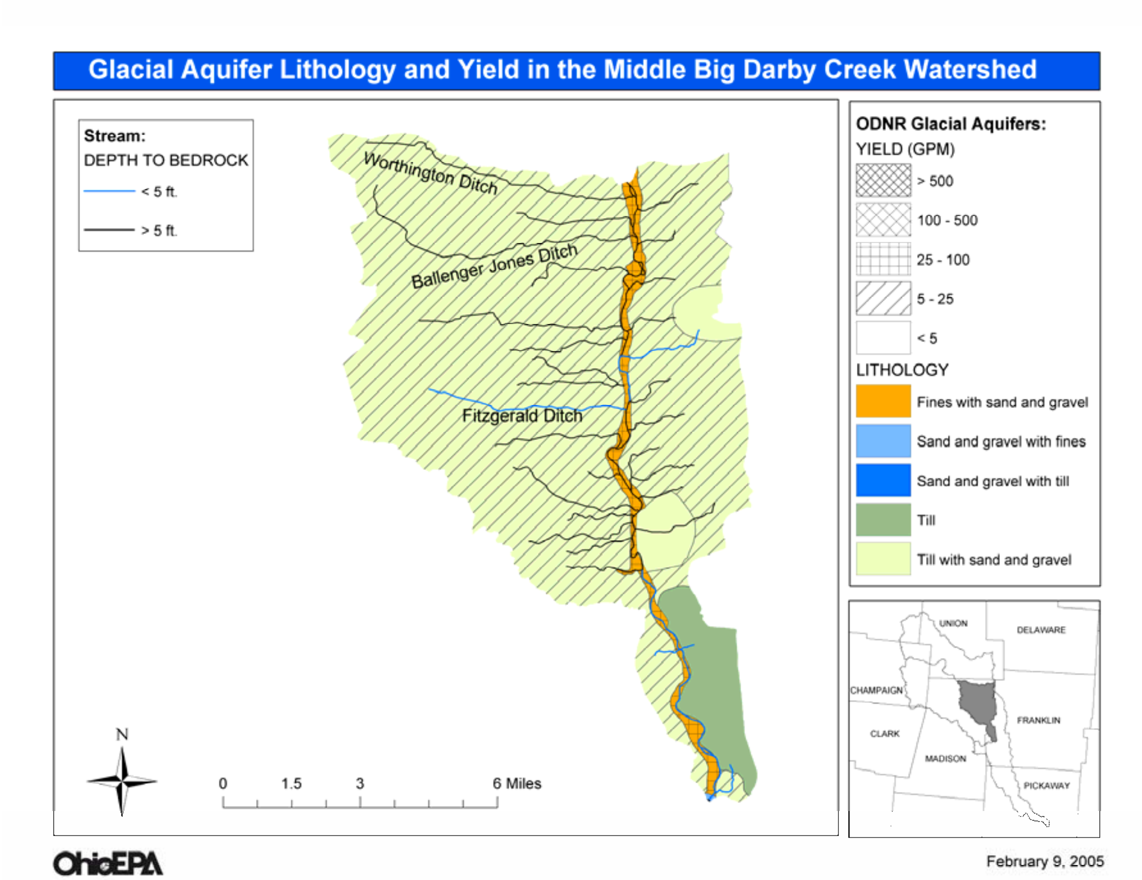


In the northwest area of the watershed several streams come in contact with some moderate and high yielding bedrock aquifers. This may result in higher ground water contributions to these streams than would result from only the overlying glacial deposits.

Where bedrock transitions from one type to another, there is often greater fracture and thus greater potential to move and store water. Note the blue stream segments on the northwest periphery of the watershed that run through Ohio and Olentangy Shale. These segments are part of the Little Darby Creek (Logan County). As the map indicates, shale is a low yield aquifer, but the surrounding Columbus-Lucas undifferentiated group is moderate yielding. While neither of these aquifer types are high yielding, there is potential for a greater ground water contribution to the stream because of the convergence of multiple rock types in the area.

A.2.2 Middle Big Darby Creek Watershed

Glacial aquifer lithology of the middle Big Darby Creek watershed is dominated by till with sand and gravel. Like the upper Big Darby Creek watershed, alluvial fines with sand and gravel are found along the mainstem. Additionally, a large lens of relatively impermeable till is found near the southern boundary of the watershed. The glacial deposits are dominantly ground moraine; complex associations exist throughout but are secondary in prevalence. Ground water yields of the glacial till with sand and gravel is low to moderate, and the alluvial fines with sand and gravel have moderate yields. The glacial aquifer lithology and yield for the middle Big Darby Creek watershed is illustrated in the following figure.

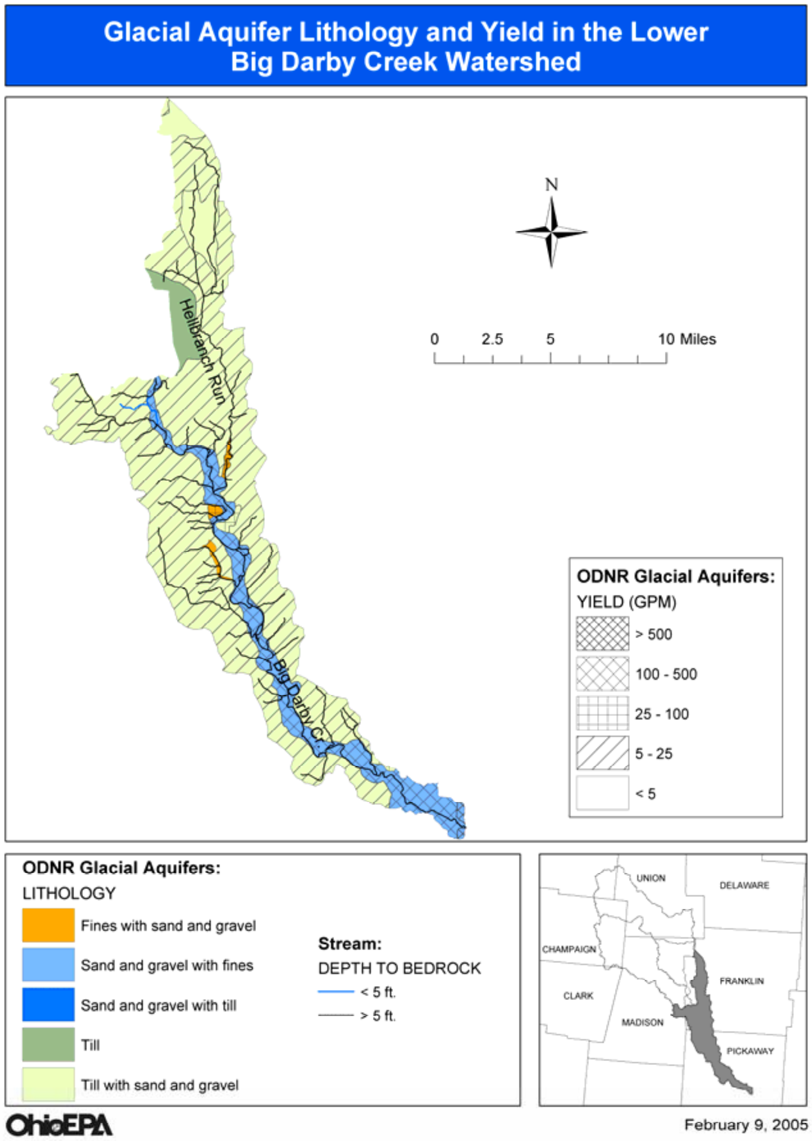


As can be seen in the following and preceding figures there is the potential for contact between the stream and aquifer on Fitzgerald Ditch and on the mainstem near the outlet of the watershed. Bedrock beneath Fitzgerald Ditch is Tymochtee, Greenfield, and Salina dolomite of moderate to high yield, which may result in a greater ground water contribution to this stream compared to other nearby tributaries. Bedrock beneath the mainstem segment is low-yielding limestone, and offers little potential for a significant contribution.

A.2.3 Lower Big Darby Creek Watershed

Lithology of the glacial deposits in the lower Big Darby Creek watershed is dominated by till with sand and gravel deposited as a complex association or ground moraine. Sand and gravel with fines in a buried valley setting is secondary but significant. A small lens of till exists in the Hellbranch Run area of the watershed.

The till with sand and gravel is mostly low-yielding, but the sand and gravel of the buried valley is high to very high yielding. This buried valley setting represents the area of greatest potential for a large ground water contribution in the entire watershed. The high conductivity of the sand and gravel, combined with the greater permeability of the watershed soil (discussed above), results in a greater potential for percolation to the aquifer and lateral transport to the stream. Based upon these two factors, ground water is likely a large component of stream flow during dry periods. Glacial aquifer lithology and yields for the lower Big Darby Creek watershed are illustrated in the following figure.



As can be seen in the figure, there is little connection between the streams and bedrock in the lower watershed. The disconnect is because of the greater average depth of the glacial deposits that characterize this watershed.

A.2.4 Little Darby Creek Watershed

Lithology of the glacial deposits in the Little Darby Creek watershed is dominated by till with sand and gravel. The till with sand and gravel deposits in this watershed were deposited as ground moraine or complex associations and are low to moderate-yielding. The headwaters of the Little Darby Creek runs through fines with sand and gravel, sand and gravel with till, and sand and gravel with fines in a buried valley setting. Like Spain

Creek in the upper Big Darby Creek watershed, this is part of the much larger Mad River Buried Valley Aquifer that extends into an adjoining watershed. The sand, gravel, and fines in this area are more conductive than the surrounding deposits, and a comparatively greater ground water contribution to stream flow can be expected.

Alluvial fines with sand and gravel exist in the middle reaches of the Little Darby Creek mainstem, and are characterized by moderate yields. As the Little Darby Creek approaches the Big Darby Creek confluence, the sub-surface deposits transition from alluvial to buried valley and the lithology becomes more coarse and conductive. The glacial deposits in this area are sand and gravel with fines, and the ground water contribution to stream flow is likely greater. Glacial aquifer lithology and yield for the Little Darby Creek watershed are illustrated in the following figure.