Assessment of Effects of Stump Lake Water Elevation on Ground-Water Elevation, Flow, and Chemistry in Tolna Coulee

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SWC Project No. 416-1
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Site 1: East Section Line site, located at 151-061-19AAD (USBLM) in Tolna Coulee.

Site 2: East Johnson Crossing site, located at 151-061-19ACA (USBLM) in Tolna Coulee.

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ABSTRACT

Eight holes were bored in Tolna Coulee near Stump Lake during the summer of 2006 to provide additional data (to that already published) describing the lithology of the Coulee. Monitoring wells were placed at four locations for the purpose of ongoing evaluation of ground-water elevations and changes in water chemistry. Water levels were measured at four times and water samples for water chemistry evaluation were collected at three times during the Fall of 2006. Current combined evidence from the ND State Water Commission, ND Geological Survey and Northern Plains Environmental studies, and bore-hole lithologies in this report indicate that continuous and connected sand deposits for the length of the Coulee in Section 19 are unlikely. The predominant near-surface material in the Coulee is a fine clayey silt, having a low (approx. 0.02 feet per day) hydraulic conductivity. Piezometric gradients indicate that ground-water flow is toward Stump Lake from the location of highest land-surface elevation in the Coulee. Under current climatic conditions, Stump Lake water would need to approach the highest elevation of the land surface in the Coulee for ground-water flow reversal occur. Water chemistry in the Coulee ground-water is primarily of the calcium bicarbonate type, with some fluctuating changes in sulfate concentrations caused by evaporation and leaching cycles. Stump Lake waters are strongly sodium sulfatic. Influx of Stump Lake water to ground water in Tolna Coulee would likely be identified by increasing specific conductance and total dissolved solids, and by elevated sulfate. The final degree of difference cannot be identified because changes of chemistry in Stump Lake are still transient and are changing quickly. The best indicator of Stump Lake water impact on local ground-water would be trends of increasing sodium percentage, expressed as an increasing sodium adsorption ratio (SAR). Ongoing measurements of ground-water levels and water chemistry will be conducted at the Tolna Coulee well sites.

INTRODUCTION: STUMP LAKE EFFECTS ON GROUND-WATER IN TOLNA COULEE

Since 2004 water flowing from Devils Lake to Stump Lake through the Jerusalem Channel has been causing Stump Lake water elevations to increase at a mean rate of 0.0309 feet per day. As of mid-September 2006, the elevation at the Stump Lake gage was about 1,444 feet above mean sea level (amsl), about 3.5 feet below the approximate (fluctuating) elevation of 1,447.5 feet in Devils Lake. At current rates of flow, approximate equilibrium between the two lakes should be reached in early 2007, although changing shoreline contours and increasing surface area on the filling lake may delay this. The outlet from Stump Lake to the Sheyenne River is Tolna Coulee which connects the Devils Lake - Stump Lake subbasin and Sheyenne River subbasin of the Red River basin. The divide is located at an elevation of approximately 1,559 feet *amsl* near the center (the SE quarter of the NE quarter) of Section 19 (T151N-R62W). The high elevation point has been locally called the "soft plug."

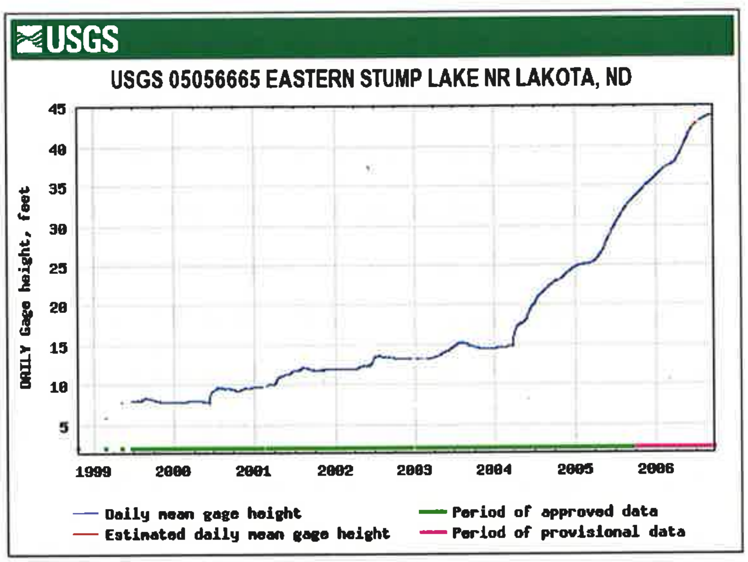

Figure 1. Stump Lake gage height above the 1400 feet *amsl* elevation datum.

Both interest and concern have been raised over the potential for ground-water movement from Stump Lake through Tolna Coulee. Issues include: Potential changes in ground-water and surface-water quality at lower elevations in the Coulee from ground-water seepage of highly saline waters in Stump Lake as elevations increase; and potential erosion of the dividing lands comprising the highest elevations.

Flow from Stump Lake through Tolna-Coulee ground water requires that hydraulic gradients enable flow in the southwestward direction from the Lake. It also requires that water-bearing porous materials be sufficiently conductive and continuous to allow for substantial flow. The purpose of this project is to monitor the directions of the piezometric gradient within the Coulee near Stump Lake, and water-quality changes in Tolna Coulee near the Stump Lake outlet.

METHODS

To achieve these objectives, five holes (locations on Figure 6) were drilled in Tolna Coulee during August and September of 2006. Four of the holes were drilled to a depth of about 20 feet using a Giddings probe with a 3-inch auger. Three wells were placed in Giddings bore holes on August 23, 2006. Wells were constructed of 1.25-inch polyvinyl-chloride (PVC) casing, with 5-foot #12 well screen. Well-screens were placed to the bottom of the deepest and most permeable materials within the bored interval. Sand pack (#10 sand) was placed around the well-screen to about 2 feet above the top of the screen. The annulus was then sealed to the surface with bentonite chips. Two bore-holes were drilled on August 31 (2006) using a forward rotary drill. The forward-rotary holes were drilled to approximately 40 feet. A single well was constructed of 2-inch PVC and placed in the first bore hole. Completion was the same as for the 1.25 inch wells, except that a 10-foot #12 well-screen was used. All wells were bailed or pumped until clean, and were secured with protective casing (PC). Wells were surveyed on September 12, 2006 according to the1929 Datum and also calibrated to the approximate 1983 Datum using U.S. Survey Feet Equipment-Trimble 4400 receivers with TSCI points 37591 to 37605. Initial piezometric measurements were made for each well on September 6, 2006. Initial water samples were collected on September 6, 2006. Samples were analyzed for general chemistry and trace elements. Long-term periodic measurements of water chemistry and water levels are planned.

WATER-BEARING FORMATIONS IN TOLNA COULEE

The general lithology of the Coulee indicates a complex history. Three recent studies have discussed water-bearing materials within and near the Coulee. These are: (1) A study of lithology, and deposition times and processes forming alluvial deposits within the Coulee conducted by Ed Murphy, Ann Fritz, and Farley Fleming of the North Dakota Geological Survey (NDGS) in 1997 (Murphy and others 1997) ; (2) a study of soils within the Coulee near the East Crossing conducted by Northern Plains Environmental (NPE) in 2002 (Lunde, 2002); and (3) a study of aquifers near the Coulee, conducted by Jon Patch and Rex Honeyman (2005) of the North Dakota State Water Commission (SWC).

General area aquifer maps indicate that the Spiritwood aquifer and the shallower Warwick aquifer intersect near the Coulee, or underlie the Coulee (Figure 2).

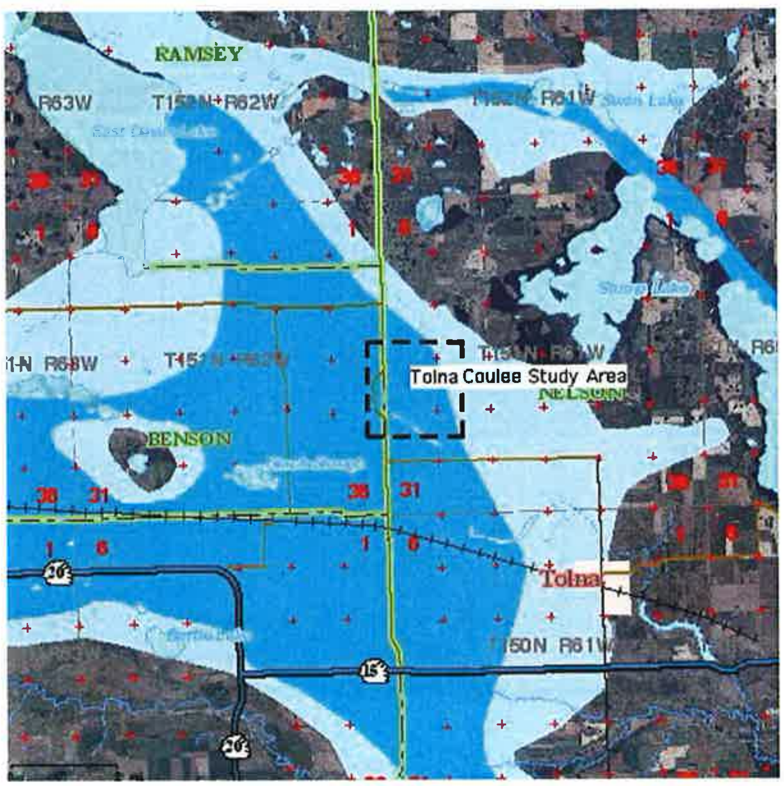

Figure 2. Map of shallow glacial aquifers near in the area of Tolna Coulee (From the North Dakota State Water Commission web database).

More detailed and recent local studies, however, indicate that the relatively thick sand and gravel deposits forming these aquifers are not found in the near-surface environment of the Coulee. Patch and Honeyman (2005) analyzed cross sections for transects on both then north (Transect C-C') and south (Transect D-D') borders of Section 19 (Figures 3, 4 and 5).

Spiritwood aquifer near Warwick and Sheyenne River

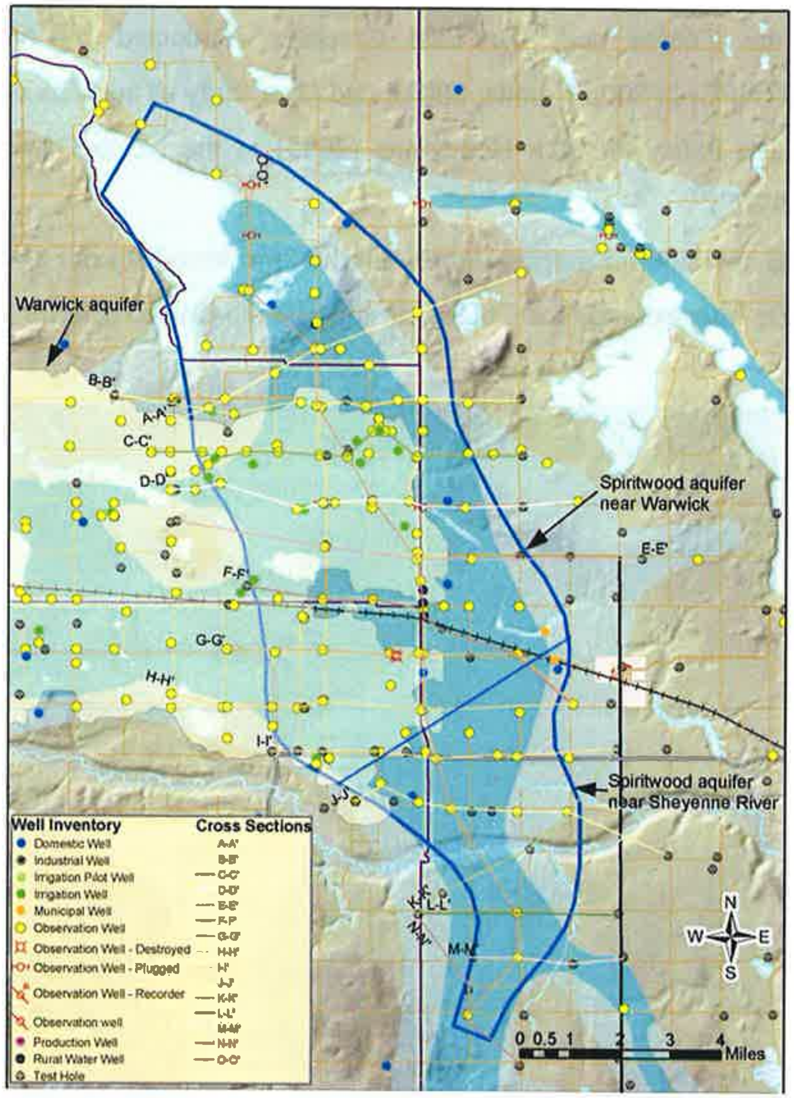

Figure 3. Map showing well locations on transects near Tolna Coulee (Figure 3 in Patch and Honeyman, 2005). Transect C-C' traverses the north border of Section 19 (Township 151 N, Range 61 West) and Transect D-D' traverses the south border of Section 19.

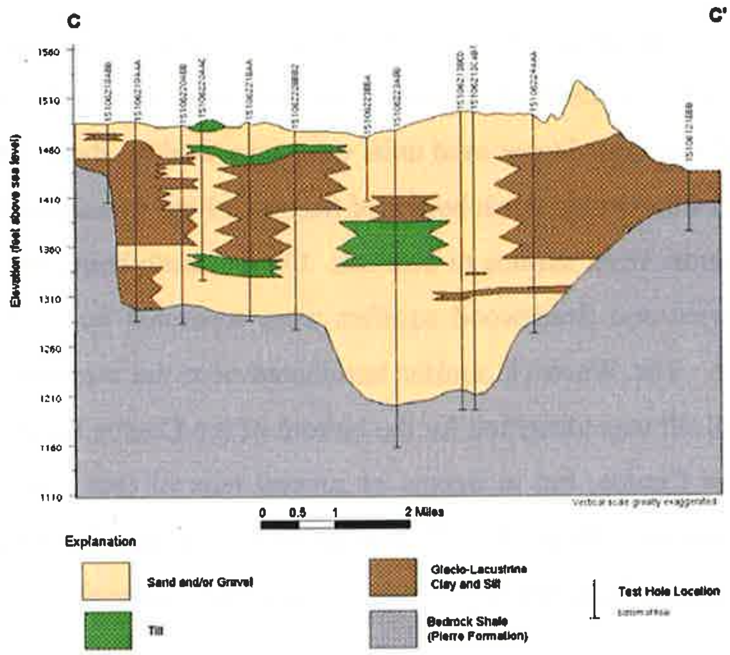

Figure 4. Map illustrating lithology of transect C-C' *(From Figure 6 in Patch and Honeyman, 2005)*

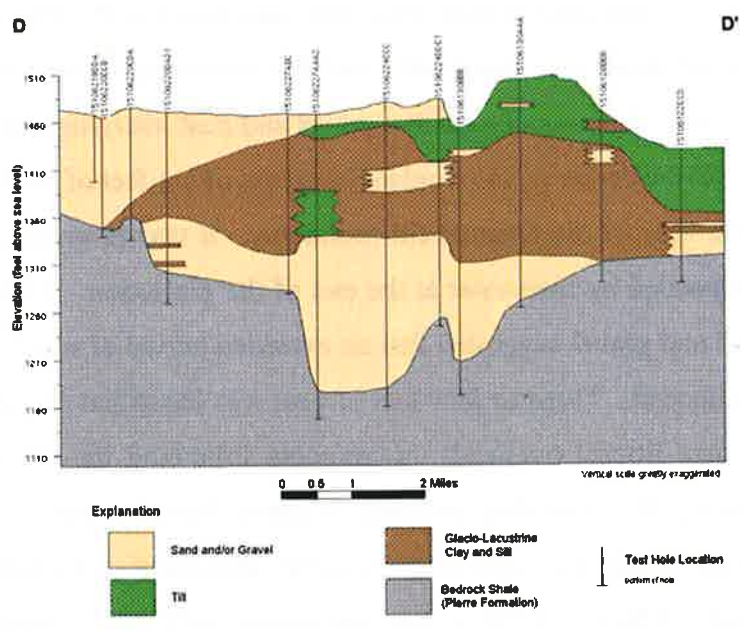

Figure 5. Map illustrating lithology of transect D-D' *(From Figure 7 in Patch and Honeyman, 2005.*

The north transect (C-C') identified about 200 feet of sand and gravel from the combined Warwick and underlying Spiritwood aquifers about a half-mile northwest of the northwest corner of Section 19 (Figures 3 and 4). However, at the northwest corner of Section 19 shallower and deeper sand units were separated by about 100 feet of glacio-lacustrine clay and silt. On the north border of Section 19 the fine deposits comprised the entire vertical column, from surface to bedrock. On the south boundary and west of the Coulee, the Warwick and Spiritwood aquifers were separated by the glacio-lacustrine clay and silt layer. The Warwick aquifer terminated near the western boundary of the Coulee, and glacial till was identified for the bottom of the Coulee itself. Local sand and gravel underlie the Coulee, but at depths of several tens of feet. These indicate that surficial layers near the bottom of the Coulee are likely composed predominantly of fine silts and clays derived from till and fluvially reworked materials of glacio-lacustrine origin.

Surficial materials were examined by Murphy, Fritz and Flemming, (1997). They examined the faces of two excavated trenches and three boreholes in the northwest quarter of Section 19. They described "channel-fill deposits in the Tolna Coulee" from "15 to 25 feet thick," consisting of peat, clay, silt, sand and gravel. The surface five feet was described as composed of "clayey silt," and the remaining column was described as consisting of interbedded lenses of sand and gravel and peat overlying till, and sometimes sand and gravel. At the center of the Coulee, in excess of six feet of sand and gravel was encountered at the base of the channel-fill sediments. It was proposed that this coarse unit was likely deposited by meltwater at the end of the glaciation. A layer of flat rocks overlying the sand and gravel suggested that an extended period of weathering took place resulting in a lag deposit. Three to four feet of peat was identified above the rock layer, indicating a stagnant littoral (wetland) environment following the glacio-fluvial event. Murphy and others (1997) recorded evidence of seven fluvial events, but indicated that only the top foot was likely deposited after European settlement of the area.

Nord Lunde of Northern Plains Environmental (NPE 2002), under contract with the Devils Lake Basin Joint Water Resources Board, analyzed seven borings across the center of the Coulee in northeast Section 19. Holes were bored to depths of ten to fifteen feet using a Giddings probe. The predominant soil was identified as a Borup silt loam

(USDA: Typic Calciaquoll). The surficial layer was a silt loam, interbedded on most sites with clay and sand and gravel deposits, each a few inches thick. Lunde stated that there is an average of about 80 inches of sediments deposited on his investigation site, which is underlain by alluvial clay and till. Both NDGS and NPE studies attributed a substantial part of the alluvial sediment to slope wash from major lateral drainage channels feeding into the Coulee.

NEW BORE-HOLE LITHOLOGIES

Observation Wells

Well locations are shown on Figure 6. Lithologies and well-construction information, including screened intervals, are in Appendix A.

Figure 6. Locations of Tolna Coulee observation wells in Township 151, Range 61, Section 19.

The first well (labeled East Section Line) was located at 151-061-19AAD [U.S. Bureau of Land Management (USBLM) nomenclature], or alternately in the southeast quarter of the northeast quarter of the northeast quarter of Section 19, Township 151 North, Range 61 West. It was located within the road easement of the northeast section line of Section 19, about 100 feet north of the cattails and rushes in the Coulee (see Site 1, introductory photos). The well-screen was placed in a gray silty sand. The lower boundary of the sand overlies a dense silty clay beginning at 12 feet and still present at the maximum boring depth (17 feet).

The second well (labeled East Johnson Crossing), was placed at 151-061-19ACA (USBLM), or alternately in the northeast quarter of the southwest quarter of the northeast quarter of Section 19, Township 151 North, Range 61 West. The well was placed on the southwest border of a field crossing near a wetland which extended westward (see Site 2, introductory photos). Eastward of the well for a few hundred feet is a somewhat elevated landform, locally called the "soft plug," which forms the highest land surface elevation between Stump Lake and Tolna Coulee, and effectively the divide between the Devils Lake-Stump Lake and the Sheyenne River subbasins. A transect of borings to depths of 10 to 15 feet was previously conducted by NPE (Lunde, 2002).

The East Johnson Crossing lithology to 22 feet consists of a silty material varying in clay content. Gravel in the top one and a half feet is likely from construction of the crossing. There is sufficient clay to make the silt very sticky, but without a great deal of cohesion. The top five feet were very dark and high in organic matter content. Deeper silts were unoxidized. Silty materials with clay are likely indicative of local low-energy fluvial deposition (depositon in slow-moving or static water). The silty composition may have an erosive source in what appears to be silt-stone locally directly overlying the Pierre Shale. The silt stone, in fact, seems to have a clay component somewhat similar to the silt on this site. Presence of peat bands (about 30%) at the 17 to 22 foot depth interval indicates a littoral environment prior to siltation, and slight gravel inclusions in the lower peat layer indicate the possibility of a high-energy fluvial event (fast-moving water) just prior to the littoral period. This well has the highest elevation of the four. No substantial independent sand or gravel layers were present. Coarse materials were found in layers so thin as to be difficult to separate from the predominant silt.

This well site was very close to the transect performed by NPE. The predominant sticky black to gray silt in the top 12 feet corresponds to the silt loam identified by NPE (2002). The lithology of the East Johnson Crossing well site, while slightly different in terminology, is very similar to that of the transect described by NPE.

Because there was no shallow sand layer on this site (within the top 20 feet) the well-screen was placed within the 7 to 12 foot interval of the silt layer. A slug test was conducted on September 27 to estimate the hydraulic conductivity (K) of the material. The unconfined method of Bouwer and Rice (1976) was used to estimate K. Because of limited borehole depth, the depth of the impermeable layer (required in the computation method) was unknown. But most sites drilled in the area have a dense olive-colored till or weathered bedrock underlying surficial deposits within 40 feet of land surface. Computations were made for ranges of lower boundaries varying from the bottom of the well-screen to 100 feet. Results varied within a narrow range of about 0.016 to 0.02 feet per day. The well-recovery profile is shown in Appendix B.

The third well (labeled West Johnson Crossing) is located at 151-061-19BDB (USBLM), or alternately in the northwest quarter of the southeast quarter of the northwest quarter of Section 19, Township 151 North, Range 61 West. The well was placed about 40 feet northeast of a field crossing near a wetland, and about 20 feet north of the wetland. Similar to the East Section-Line site, the top 12 feet were fine sandy, with some silt. Deeper layers (12 to 21 feet) exhibited a marked increase in clay content, with intermixed layers of peat and fine sand. A distinctive feature of this site was the presence of a shallower dark green peat layer, intermixed with gravel, at 5.5 to 7.5 feet. The sand, which extended from 3.5 to 12 feet, was unoxidized. This well site is near and similar in lithology to the sites described by Murphy and others (1997). Notably, the alluvium is somewhat deeper and the peat layer deeper and more pronounced than on the East Johnson Crossing site. Deeper alluvium may be due to the larger drainageway entering the Coulee northwest of the site.

The fourth well (labeled Southwest Corner) was located at 151-061-19CCC (USBLM), or alternately in the southwest quarter of the southwest quarter of the southwest quarter of Section 19, Township 151 North, Range 61 West. The well was located in tall grass about 60 feet from the edge of the cattails. This site was composed of oxidized sand from 4 to 9 feet, and unoxidized sand from 9 to 20 feet. It was underlain by a brittle silt with some clay content, possibly a silt stone. Other borings in the area indicate that this may be a silt stone that directly overlies the Pierre shale.

Drilled Bore Holes

Four additional bore holes were examined in southwest Section 19. The first two were bored at 151-061-19CBC (USBLM nomenclature), or alternately about half-way between the south and north borders of the southwest quarter section. Both holes were located in slough grass about 50 feet east of the cattails along the Coulee. Bore hole 151-061-19CBC (Appendix A) was drilled using a forward rotary drill rig. Bore-hole 151-061-19CBC2 was drilled using a Giddings probe.

Both bore-holes indicate a stiff to very-stiff grayish to greenish-brown (olive) silt with high clay content in the upper 25 feet (17 feet was the limit of the Giddings boring). The Giddings samples revealed strong iron stains (mottling) beginning at about 4 feet from the surface. A characteristic of this material was that no sign of a current water-table (as indicated by material lubrication, plasticity and liquidity, and extractable water with squeezing) was detected at 17 feet using the Giddings probe. This seems unusual for a site in slough grass only a few feet from sedges and a few tens of feet from cattails, and indicates an extremely low permeability material. However, it must be added that the hole was bored during a drought in which the portion of the Coulee west of the borehole, which is normally wetland, was dry at the surface. The forward rotary drilling indicated that these materials increased in stiffness at about 14 feet and graded to shale bedrock at about 25 feet. Lack of grittiness in the overlying materials indicate that it may be silt-stone in various states of weathering. This will be discussed further.

Hand-Augered Bore Holes

Two additional shallow holes were hand-augered to six feet in the center of the Coulee adjacent to the bore holes at 151-061-19CBC and 151-061-19CCC (Southwest Corner). These bore holes were located on sites normally covered by surface water, and access was enabled only by drought conditions in 2006. Both consisted of black high-organic silty clays.

The auger hole adjacent to 19CBC was located in sedge about 60 feet west of the drill site (forward rotary) near the section-line fence. The top foot was peat. From one to six feet the material was very a dark (black) silty clay similar in composition to adjacent "stiff" silty clays identified in nearby bore-holes, but less compacted, more lubricated by moisture and high organic-matter content, and very sticky because of moisture. The water table was at 6 feet. The Coulee-bottom material was similar to the top twelve feet of the East Johnson Crossing site near the "soft plug," but had higher clay content.

The auger hole adjacent to the well at 19CCC was located about 90 feet west of the drill site (forward rotary) on bare slough bottom (dry) west of the cattails. The top foot consisted of peat. One to three feet was a mixture of peat and silt. Three to five feet was silty clay similar in composition to the center auger-hole at 19CBC and very moist and sticky. The water table was encountered near the bottom of the five-foot sample.

Discussion

The shallow lithology of the East Johnson Crossing well is easily identified with the NPE transect, consisting of a surficial sticky silt (silt loam) overlying clay at about 12 feet. The well site, with very sparse sand varves, would correspond to the finer samples of the NPE transect.

Similarly, the lithology of the West Johnson Crossing well is very similar to the NDGS borings and trenches, with deeper alluvium, more pronounced peat in deeper layers, and greater predominance of sand and gravel lenses in the surficial materials than found at the East Johnson Crossing.

Somewhat less complex lithologies were identified at the northeast and southwest boundaries of Section 19, with continuous sands to 12 feet overlying a dense silty clay at the East Section Line well site, and about 20 feet overlying a dense clayey silt at the Southwest Corner Site.

Shallow (6-foot) borings within the Coulee in southwest Section 19 are very similar in texture and composition (sticky black silt), although somewhat finer, to those identified at the West Johnson Crossing Site, and are likely present in the surficial material for most of the Coulee at its center.

Somewhat puzzling is the presence of what appears to be Pierre Shale overlain by indurated silt or silt stone at only 25 feet, within 60 feet of the Coulee center, in the borehole (151-061-19CBC) midway between the mid-section line and southwestern corner of the southwest quarter of Section 19 (Appendix A). This is very shallow compared with shale identified at 245 feet at 151-061-30BBA, only a quarter mile directly south. The elevated shale boundary may possibly be explained by the lithology of a north-south bore-hole transect (B-B') shown on Figure 6 of Murphy and others (1997), and shown in Appendix C of this report. The published transect lithologies indicate a steep incline in the bedrock surface beginning below 1,200 feet in 150-061-06 to above 1,425 feet in Section 21 (a mile east of Section 19). This would be the approximate elevation of the shale identified in the test hole at 151-061-19CBC. It may indicate that the bedrock high, identified a mile east of the Coulee, extends westward to the Coulee in southwest Section 19.

In summary, the combined (but limited) evidence indicates an environment that was highly scoured (bedrock proximity), and a complex near-surface lithology reflecting a variable water-energy environment. The main surface material in the center of the Coulee is an alluvial high-organic sticky silt loam with apparent increasing clay content from north to south, and with peat layers in some areas. The silt-loam surficial layer has a K of about 0.02 feet-per-day, and has a common thickness of six to 12 feet. Within and beneath the silt loam, and within the littoral zone bordering the Coulee are bands of peat, sand and gravel at some sites, and integral sand deposits at others, varying in thickness from approx. 12 feet to 25 feet. There are also areas very near the Coulee center and within the littoral zone where silty clay is encountered immediately at land surface with no coarse alluvium. This likely indicates a history of strong local scouring. Current combined evidence from the SWC, NDGS and NPE studies, and bore-hole lithologies in this report indicate that continuous and connected sand deposits for the length of the Coulee in Section 19 are unlikely. The Warwick aquifer is on the western border of the Coulee and likely provided erosive material for modern deposits, but is not identifiable within the Coulee itself. Isolated sections and lenses of the Spiritwood aquifer appear to underlie the Coulee, but by all current evidence are separated from the surface by a substantial thickness of glacio-lacustrine clay and silt, or in some cases till. The placement, thickness, and disposition of modern sand and gravel deposits thus appear to be governed mainly by local erosive events and the energy distribution of scouring streams during events of active discharge within the Coulee.

TOLNA COULEE HYDROLOGY

Area Hydrology

The surface and ground-water hydrology of Tolna Coulee in Section 19 is governed by local topography. The Coulee, as shown on Figure 7, is incised as much 100 feet below the surface of adjoining uplands and receives surface drainage water from those uplands through large drainageways and also directly from runoff on steep slopes of the Coulee.

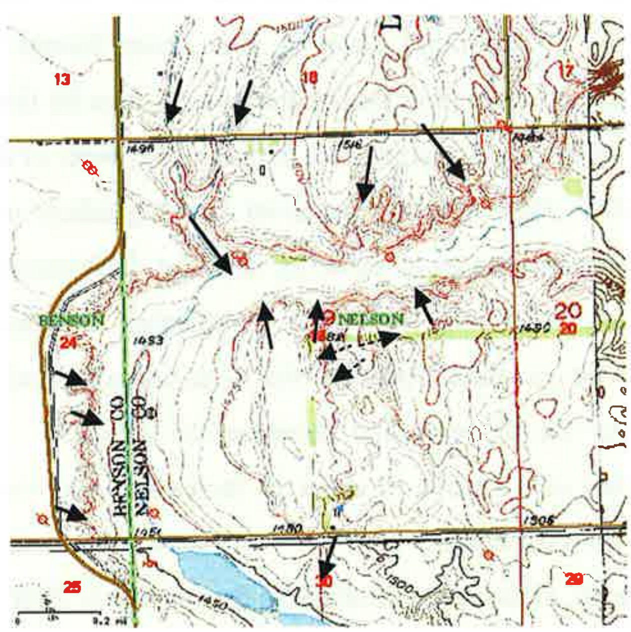

Figure 7. Topographic map of the Tolna Coulee near Section 19, with illustration of some of the major drainage patterns. The base map source is a 7.5 minute U.S. Geological Survey map as accessed using the *North Dakota State Water Commission web mapservice.*

In addition, water tables formed from local recharge on adjoining lands are naturally elevated in relation to Coulee ground water, thus providing a natural gradient for ground-water discharge toward the Coulee. The erosive source of alluvium within the Coulee suggested by Murphy and others (1997) and further attested by the similarity of texture in alluvial materials to nearby till and bedrock further confirm this hydrologic regime, since water erosion presupposes substantial runoff. The natural disposition of this hydrologic system, therefore, is to cause ongoing recharge and subsequent elevated water tables within the Coulee. These, in turn, would form a natural hydraulic gradient conducting ground water from the points of highest elevation within the Coulee floor (in northeast Section 19) to points of lower elevation, both northeastward (toward Stump Lake), and southwestward, and then eventually southeastward within the Coulee.

Initial Piezometric Data

Land surface and piezometric elevations, land slopes and hydraulic gradients are on Figure 8 and Table 1. The hydraulic gradients between wells are similar to land slopes, indicating that topography and local recharge and evaporation are governing the water-table elevations. For ground water to flow from Stump Lake through Tolna Coulee, the piezometric gradient must be positive (water must be flowing downhill). The hydraulic gradients are of similar magnitude, with the exception of the Southwest Corner which is about double. However, this apparent larger gradient may be an artifact of computation, since calculations were made by dividing differences in elevation by the linear distance between wells using state-plane coordinates. The actual flow path within the Coulee will likely be curvilinear between the West Crossing and the Southwest wells, which would increase the distance and decrease the gradient. A somewhat higher gradient, however, may also be due to apparent increasing clay content in the silt (and clay) surface layer within the coulee.

Of the four wells, measurements taken on September 6, 2006 (shown on Figure 8) indicate that the highest water elevation is in the East Johnson Crossing well near the "soft plug." From this approximate location, water flows both eastward toward Stump Lake and southwestward toward the West Johnson Crossing and the Southwest Corner well. Ground-water flow from Stump Lake through the Coulee is thus currently infeasible. Piezometric elevations at all wells with the exception of the Southwest Corner well are above the current level of both Stump Lake, and Devils Lake. Rising water levels in Stump Lake will cause a flattened gradient (and slower flow velocities) between the East Johnson Crossing and East Section Line wells and Stump Lake, which should result in locally higher water tables due to slower outflow of local recharge water. Thus, if current climatic influence remains constant we would expect to maintain the piezometeric gradient toward the lake from the East Johnson Crossing well up until the site itself is reached by Stump Lake water.

Table 1. Land-surface elevations, lake elevations, and piezometric elevations for September 6 through November 6, 2006.

Site Location	El. Land Surface (feet amsl)	El. Water Table (feet amsl) 9/6/06	El. Water Table (feet amsl) 9/27/06	El. Water Table (feet amsl)) 11/6/06	Distance (feet amsl)	Hydraulic Gradient (9/6)	Land Slope (ft./ft.)
Section Line	1455.94	1452.85	1453.96	1454.3	0	-	
East Crossing	1459.35	1457.51	1458.19	1458.55	2090	-0.0022	-0.0016
West Crossing	1459.05	1455.29	1457.69	1458.33	3755.1	0.0013	0.00018
Southwest Corner	1448.57	1442.92	1444.87	1447.7	7162.3	0.0036	0.0031

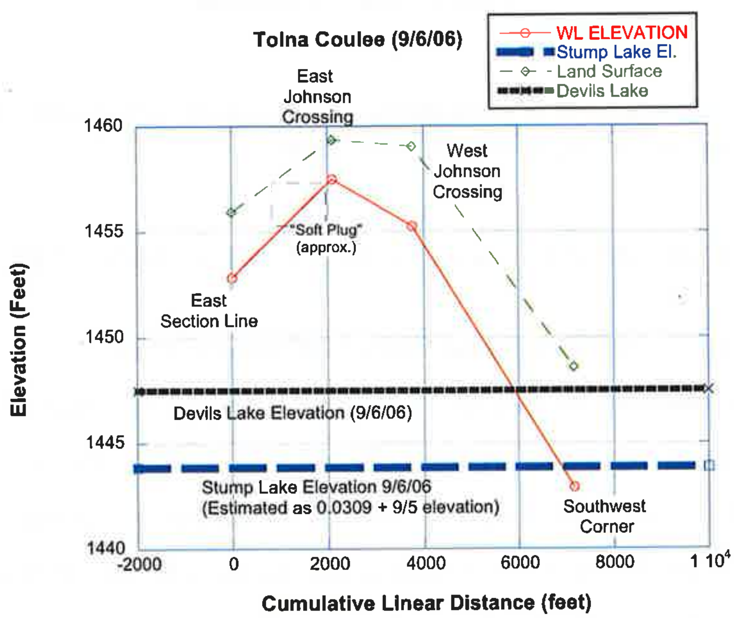

Figure 8. Land-surface elevations, lake elevations, and piezometric elevations for September 6, 2006.

Additional piezometric measurements were made on September 27, October 23, and November 6 of 2006. Intervening rains had increased the water levels substantially since the previous measurement on September 28, as compared in Table 1 and Figure 9. The directions of flow as indicated by the piezometric gradients were the same through November 6 and had gained in elevation over current Stump Lake levels in all wells. Between October 23 and November 6 elevation changes were negligible.

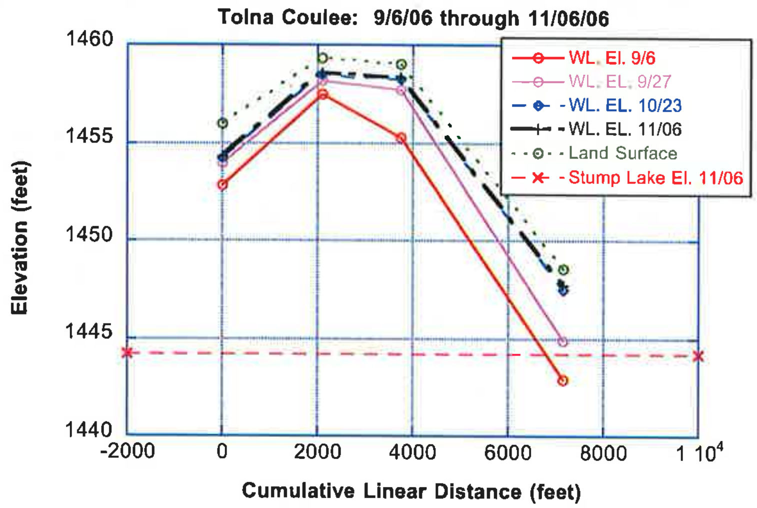

Figure 9. Comparison of piezometric elevations in Tolna Coulee wells for September 6 through November 6, 2006.

STUMP LAKE AND TOLNA COULEE WATER CHEMISTRY

Initial Water Chemistry for Tolna Coulee Surface Water and Wells

Two water chemistry sample sets have been collected in waters of Tolna Coulee:

(1) A partial (anion only) data set was collected from surface waters in Tolna Coulee by Tim Larson of the SWC on June 28, 2006. The sample set included surface-water bodies in Sections 19, 20, and 30, including the western border of Stump Lake. In addition to anion composition, specific conductance (SC) and pH were measured on field and laboratory samples. Results are shown on Table 2. Site 1 is on the west end of Stump Lake; Site 2 is on the east side of a wetland located on the west boundary of the "soft plug," Site 3 is on the west side of the same wetland; and Site 4 is on the north side

of a wetland located in NW Section 30 (T 151N, R61W). Locations are shown on Figure 10.

Surface water in Tolna Coulee is very low in SC compared with Stump Lake, and its anionic composition is primarily bicarbonatic, compared with sulfatic water in Stump Lake. Changes in surface water composition should be easily discernible by comparison of these parameters. The difference in pH in the same wetland complex (Sites 2 and 3) is difficult to explain without further information and bears caution. Surface waters in Tolna Coulee are exposed portions of the water table and should reflect local ground-water chemistry.

Table 2. Surface-water chemistry for 6/28/06 samples.

Site	Location	Field SC (μS/cm)	Lab SC (μS/cm)	Field pH	Lab pH	Si mg/L	Fl mg/L	HCO_3 mg/L	CO_3 mg/L	SO_4 mg/L	Cl mg/L	NO_3 mg/L
1	15106120AB	-	6920	8.21	8.42	14.6	0.28	510	18	2840	492	<0.02
2	15106119A	534	556	8.39	8.39	19.2	0.165	312	9	26.8	6.8	<0.02
3	15106119B	442	461	7.27	7.14	12.4	0.168	242	<1	42.9	1.76	0.06
4	15106130BB	506	518	7.6	7.89	32.2	0.22	325	<1	8.24	1.5	<0.02

Figure 10. Locations of surface-water samples for general chemistry, June 28, 2006.

(2) Well-water samples were collected in the Tolna Coulee wells on September 7, 2006, and again on October 23. A water sample was also collected from the western boundary of Stump Lake in Section 20. Complete general chemistry and important parameters [pH, SC, sodium adsorption ratio (SAR)] for well water is shown on Table 3, and selected trace elements are on Table 4. A piper diagram showing ion distribution is on Figure 11.

Table 3. General chemistry for Stump Lake (6/28/06 and 10/23/06) and from Tolna Çoulee observation wells on 9/7/06 and 10/23/06.

Location	Date	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO3 mg/L	CO3 mg/L	SO4 mg/L	Cl mg/L	F mg/L	NO3 mg/L	TDS mg/L	PerNa %	SAR	SC µS/cm	pH
15106119AAD	9/7/06	196	56.5	7.6	1.3	428	<1	360	9.73	0.184	0.35	781	2.2	0.12	1176	8.63
15106119AAD	10/23/06	187	52.4	7.1	<1	413	<1	355	9.13	0.177	0.18	744	2.2	0.12	1136	
15106119ACA	9/7/06	86.5	26.1	10.3	3.02	400	<1	22.1	8.38	0.221	0.09	405	6.4	0.25	621	8.5
15106119ACA	10/23/06	86.7	24.2	6.6	1.99	387	<1	20.9	7.62	0.237	0.18	383	4.3	0.16	593	
15106119BDB	9/7/06	191	56.6	30.7	6.61	912	<1	15.1	17.2	0.2	0.09	837	8.6	0.5	1277	8.21
15106119BDB	10/23/06	201	52	27	5.76	919	<1	9.92	18.7	0.141	0.18	837	7.5	0.44	1277	
15106119CCC	9/7/06	100	31.9	34	3.51	505	<1	42.9	3.3	0.213	0.4	516	16.2	0.76	792	8.74
15106119CCC	10/23/06	125	37.1	17.1	3.06	568	<1	37.8	3.68	0.208	<0.09	555	7.4	0.34	855	
15106120AB Stump Lake	6/28/06					510	18	2840	492	0.28		5190			4000	8.21
15106120AAB Stump Lake	10/23/06	126	246	1160	76.4	529	21	2990	545	0.22	0.89	4230	65.4	13.8	6310	

Table 4. Trace elements and selected parameters for Tolna Çoulee observation wells on 9/7/06.

Location	Date	Fe mg/L	Mn mg/L	F mg/L	B µg/L	SiO2 mg/L
151-06119AAD	9/7/06	0.067	0.135	0.184	<50	
151-06119AAD	10/23/06	0.037	0.901	0.177		
151-06119ACA	9/7/06	0.042	1.57	0.221	<50	
151-06119ACA	10/23/06	0.247	1.96	0.237		
151-06119BDB	9/7/06	3.9	3.2	0.2	130	
151-06119BDB	10/23/06	4.84	3.43	0.141		
151-06119CCC	9/7/06	1.04	0.515	0.213	61	
151-06119CCC	10/23/06	2.47	0.615	0.208		
151-06120AAB	10/23/06	0.048	0.051	0.22		
151-06120AB	6/28/06			0.28		14.6

There are three identifiable types of water in Table 3 and Figure 11:

1. Water from the East Crossing (151-061-19ACA), West Crossing (151-061-19BDB), and SW Corner (151-061-19CCC) well sites was of the calcium bicarbonate type (Table 3, Figure 11). Sodium Adsorption Ratio (SAR) values are all low (< 1). Water samples are also characterized by iron and manganese concentrations one to two orders of magnitude larger than the other measured sites (Table 4). These sites are shown in black script and symbols on Tables 3 and 4 and Figure 11.

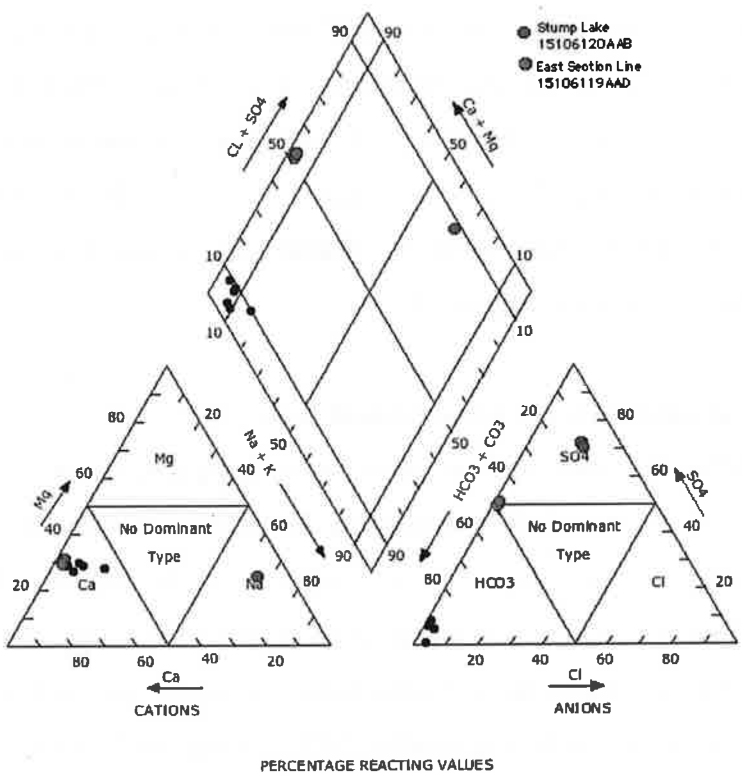

Figure 11. Piper plot of general water chemistry in Stump Lake and in all Tolna Coulee wells collected on 9/7/06 and 10/23/06.

2. Water from the East Section-Line Site (151-061-19AAD) was of the calcium sulfatic type (Table 3, Figure 11). While bicarbonate concentrations were similar to other Tolna Coulee well sites (described above in Group 1), sulfate was an order of magnitude higher. Higher sulfate as calcium sulfate likely results from leaching of gypsum in soils (such as Calciaquolls) bordering wetlands, where periods of evaporative precipitation are intermixed with periodic flushing. This is consistent with the location of the wells, about a hundred feet from cattails in the center of Tolna Coulee. Similar to Group 1, the SAR

is low. Iron and Manganese, however, are substantially lower than the Group 1 wells, likely indicative of more oxidized conditions. This site is shown in green script and symbols on Tables 3 and 4 and Figure 11.

3. Stump Lake water is characterized by very high Specific Conductance (>4,000 μs/cm) compared with maximum 1,277 μs/cm on all other sites. The SC is changing, however, with the influx of Devils Lake water, having been > 6,000 μs/cm in June. It is difficult to predict what terminal concentrations may be, given the complex interaction of influent Devils Lake water with bottom sediments of Stump Lake, which contain evaporative deposits from long-term dry conditions. Stump Lake water is distinctive, being strongly expressed as the sodium sulfatic type. Even more distinctive than high sulfate, which can occur under leaching from soils having gypsum deposits, is the high sodium, characterized by high SAR values (approx. 14). In addition, manganese and iron are lower than in samples from Group 1. Stump Lake water is shown red script and symbols on Tables 3 and 4 and Figure 11.

Identifying Stump Lake Influx to Local Ground Water

Of the differences indicated, influx of Stump Lake water to ground water in Tolna Coulee would likely be identified by increasing SC and total dissolved solids (TDS), and by elevated sulfate. The final degree of difference cannot be identified because changes of chemistry in Stump Lake are still transient and quickly changing. They are expected, however, to remain well above local ground-water concentrations. Sulfate concentrations may be ambiguous in that soils classified by NPE (Lunde, 2002) for the "soft plug" area are known to be prone to gypsum accumulations which may cycle back to ground-water during leaching events. There were no substantial changes in well-water chemistry between September and October samplings in 2006. However, in a wetter year some fluctuations in sulfate concentrations may be expected. Similarly, higher manganese and iron in Tolna Coulee well water are likely caused by reducing conditions, indicated by the high organic matter content, gley color and presence of peat in the East and West Crossing well lithologies. Introduction of new water may change oxidation state causing their precipitation. Because of possible changes in redox, trace element concentrations may prove to be unreliable indicators of Stump Lake water influx. The most reliable indicator is sodium, which is distinctive to Stump Lake water. A substantial change in SAR would likely provide the best indicator of Stump Lake water influx to local ground water.

Recommendations

Piezometric evidence indicates that a change in hydrologic conditions that would enable high TDS flow from Stump Lake through Tolna Coulee's ground water would have to be drastic; something approaching a natural topping of the "soft plug" by Stump Lake. Monitoring required to track such a slow-moving system need not be frequent, and one measurement and water sample per year would likely suffice. However, to be conservative and to better understand the natural fluctuations in Tolna Coulee ground water, I recommend that piezometric measurements and water samples be collected three times per year (Spring, Summer and Fall as access allows) for three years following equilibration of Stump Lake with Devils Lake. After that time one sample per year should be collected in Fall, or at the time of best access to the wells until such a time as the Jerusalem Channel ceases to flow. If large increases in Stump Lake elevation continue, or if water samples indicate unexpected changes, sample frequencies may be increased as necessary to evaluate ground-water impact from the changes.

SUMMARY

Water quality changes in Tolna Coulee from influx of Stump Lake water depend on advection and diffusion. Of these advection should be the largest. Advective flow of highly saline water from Stump Lake through Tolna Coulee past the high elevation point (the "soft plug") is not currently feasible. Piezometric gradients and the direction of flow are toward Stump Lake. The direction of flow from the high-elevation point should not change as Stump Lake approaches the Devils Lake elevation. Neither should it change as the combined Devils Lake and Stump Lake elevations rise and approach the high elevation point of the Coulee. In addition, there is no evidence of a continuous highly conductive (sand or gravel) material for the length of the Coulee in Section 19. The surficial material, which appears to occupy the center of the Coulee for most and possibly all of its extent, consists of six to 12 feet of a clayey silt having a low K (about 0.02 feet per day). Advective movement of water would thus likely be slow, even with favorable hydraulic gradients.

East of the high elevation point changes in water quality may be expected as Devils Lake and Stump Lake advance, but would not be expected to affect the East Section-Line well before they reach an elevation of at least 1452.5 feet. Diffusion may advance this effect somewhat, but potential effects of diffusion have not yet been examined. However, they are expected to be small.

Water samples taken June, September and October of 2006 indicate ground-water within Tolna Coulee is predominantly of the calcium bicarbonate type, with some gradation of increasing sulfate, depending on local evaporative conditions and climatic events. The water of Stump Lake is strongly of the sodium sulfatic type, which much higher (>3x) specific conductance and TDS than well water in the Coulee. While the degree of these gross indicators may change with time, sodium concentrations should serve as the main indicator of the likely influx of Stump Lake water, should influx occur.

Under current and immediately forseeable hydrologic conditions, Stump Lake influx into or through Tolna Coulee ground water is not considered likely.

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Bouwer, Herman, and R.C. Rice. 1976. A slug test for determining hydraulic conductivity of unconfined aquifers with completely or partially penetrating wells. Water Resources Research. 12:423-428.

Lunde, Nordan. May 15, 2002. Soil Survey Report: Tolna Outlet Section 19, T151N R61W Nelson County, North Dakota. Northern Plains Environmental Project #200127.

Patch, Jon, and Rex P. Honeyman. 2005. Water Supply Investigation for the City of Devils Lake, Spiritwood Aquifer near Warwick and the Sheyenne River, Ramsey, Benson, Eddy and Nelson Counties, North Dakota. 153 pp.

Murphy, Edward C., Ann Fritz, and Farley Flemming. 1997. The Jerusalem and Tolna Outlets in the Devils Lake Basin, North Dakota. Report of Investigation No. 100. North Dakota Geological Survey. 36 pp.

APPENDIX A: WELL AND BORE-HOLE LITHOLOGIES FOR TOLNA COULEE

151-061-19AAD (East Section Line)
NDSWC 15392

Date Completed:	09/08/2006	Purpose:	Observation Well
L.S. Elevation (ft):	1456	Well Type:	1.25 in. - PVC
Depth Drilled (ft):	17	Aquifer:	Sand Sediments
Screen Int. (ft.):	7-12	Data Source:	

Completion Info: 1/3 bag # 10 sand, 0.5 bag bentonite chips, water table appr. 3-4 ft. Drilled using probe
Surveyed by SWC 9/12/06

Remarks: Located west of section line trail, about 12 feet west of trail, appr. 50 feet north of the coulee crossing (cattails)

Lithologic Log

Depth (ft)	Unit	Description
0-1.5	LOAM	black, est. 15-25% clay, abrasive, some co. sand, pre silt, abundant organic matter
1.5-3	LOAM	est. 15% clay, pred. silt, some sand, gray, unoxidized
3-12	SAND	silty, gray
12-17	CLAY	dense, silty, gray, est. >40% clay

151-061-19ACA (East Johnson Crossing)
NDSWC 15394

Date Completed: 09/08/2006 Purpose: Observation Well
L.S. Elevation (ft): 1459 Well Type: 1.25 in. - PVC
Depth Drilled (ft): 22 Aquifer: Sand Sediments
Screen Int. (ft.): 7-12 Data Source:

Completion Info: 0.5 bags #10 sand, 2.3 bags bentonite chips, Drilled using probe
Surveyed by SWC 9/12/06

Remarks: Located south of Roger Johnson's east crossing next to wetland, southwest border of area known locally as the "soft plug"

Lithologic Log

Depth (ft)	Unit	Description
0-1	SAND	brown, some fine gravel
1-1.5	SAND	gray, with gravel
1.5-3	SILT	with abundant organic matter, black
3-5	SILT	w/ abundant organic matter, black
5.5-8	SILT	gray, 15% clay (est.)
8-10	SILT	gray, est. 10% clay
10-12	SILT	15-20% clay (est.), some co. sand
12-16	SILT	gray, 10% clay (est.)
16-17	SILT	brown, 10% clay (est.) some sand
17-20	SILT	10 % clay, est., some sand, gray, appr. 30% peat
20-22	SILT	gray, with peat and fine gravel

151-061-19BDB (West Johnson Crossing)
NDSWC 15393

Date Completed: 09/08/2006 Purpose: Observation Well
L.S. Elevation (ft): 1459 Well Type: 1.25 in. - PVC
Depth Drilled (ft): 21 Aquifer: Sand Sediments
Screen Int. (ft.): 6-11 Data Source:

Completion Info: 2/3 bag #10 sand, 0.5 bag bentonite chips, drilled using probe
Surveyed by SWC 9/12/06

Remarks: Located next to West crossing of wetland on Roger Johnson's land

Lithologic Log

Depth (ft)	Unit	Description
0-2	LOAM	silt loam, black, some vf sand, < 10% clay (est.)
2-2.5	LOAM	same, gray, some gravel
2.5-3.5	SAND	fi., some silt, < 5% clay (est.)
3.5-4.5	SAND	silty, fi., gray, with detrital shale
4.5-5.5	SAND	silty, fi., gray
5.5-7.5	SAND	vf., gravelly, gray, with dark green peat
7.5-8.5	SAND	silty, fi., gray, < 10 % clay (est.)
8.5-12	SAND	fi., silty, dark gray, < 10% clay
12-21	SILT	black, 15-20% clay (est.), + fine sand (gritty) and peat layers.

151-061-19CBC
NDSWC 15401

Date Completed: 09/08/2006 Purpose: Test Hole
L.S. Elevation (ft): 1450
Depth Drilled (ft): 40
Data Source:

Completion Info: no well placed - clay and weathered bedrock

Remarks:

Lithologic Log

Depth (ft)	Unit	Description
0-3	TOPSOIL	black
3-4	SAND	co. and fi. with gravel
4-14	CLAY	est. 40% with silt, stiff, grayish brown with mottles
14-21	CLAY	est. 40%, silty, brown, mottled, very stiff
21-25	CLAY	est. 40%, dark gray, very stiff
25-40	SHALE	bedrock, dark gray, very stiff, somewhat brittle, est .40% clay

151-061-19CBC2
NDSWC 15395

Date Completed: 09/09/2006 Purpose: Test Hole
L.S. Elevation (ft): 1450
Depth Drilled (ft): 16
Data Source:

Completion Info:

Remarks:

Lithologic Log

Depth (ft)	Unit	Description
0-4	CLAY	silty, light greenish gray, est. 30% clay
4-16	CLAY	est. 30% clay, silty, same as above, many mottles

151-061-19CCC (Southwest Corner)
NDSWC 15400

Date Completed: 09/08/2006 Purpose: Observation Well
L.S. Elevation (ft): 1449 Well Type: 2 in. - PVC
Depth Drilled (ft): 35 Aquifer: Sand Sediments
Screen Int. (ft.): 8-18 Data Source:

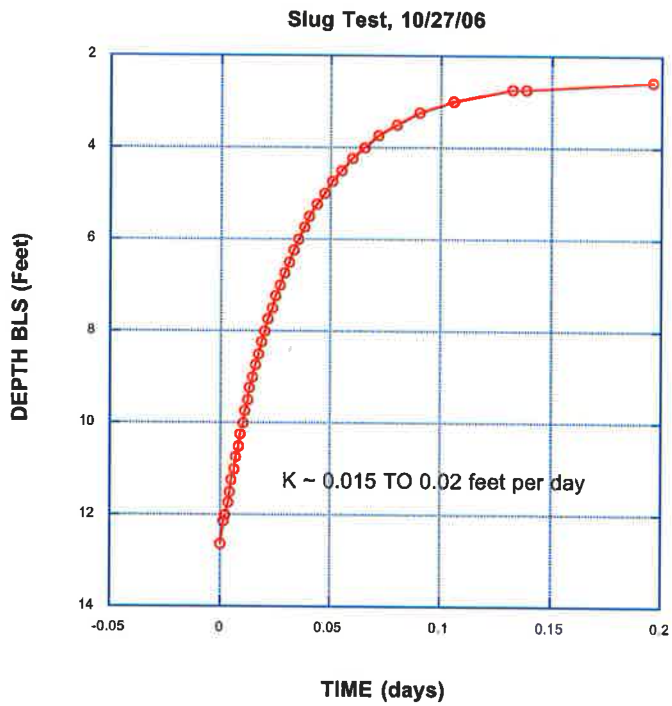
Completion Info: 3 bags # 10 sand, 5 bags bentonite chips
Surveyed by SWC 9/12/06

Remarks: located about 300 ' northwest of the road in tall grass along the coulee

Lithologic Log

Depth (ft)	Unit	Description
0-1	TOPSOIL	black
1-4	TILL	yellow
4-9	SAND	fi. and med., oxidized
9-16	SAND	fi. and med., gray, unoxidized
16-20	SAND	fi. and co., gray
20-35	SILT	abundant clay, light gray, increasing brittleness and clay with depth, possible silt stone

APPENDIX B: WELL RECOVERY FOR THE EAST JOHNSON CROSSING WELL SITE



APPENDIX C: BEDROCK LOCATIONS FROM THE NDGS (1997) REPORT

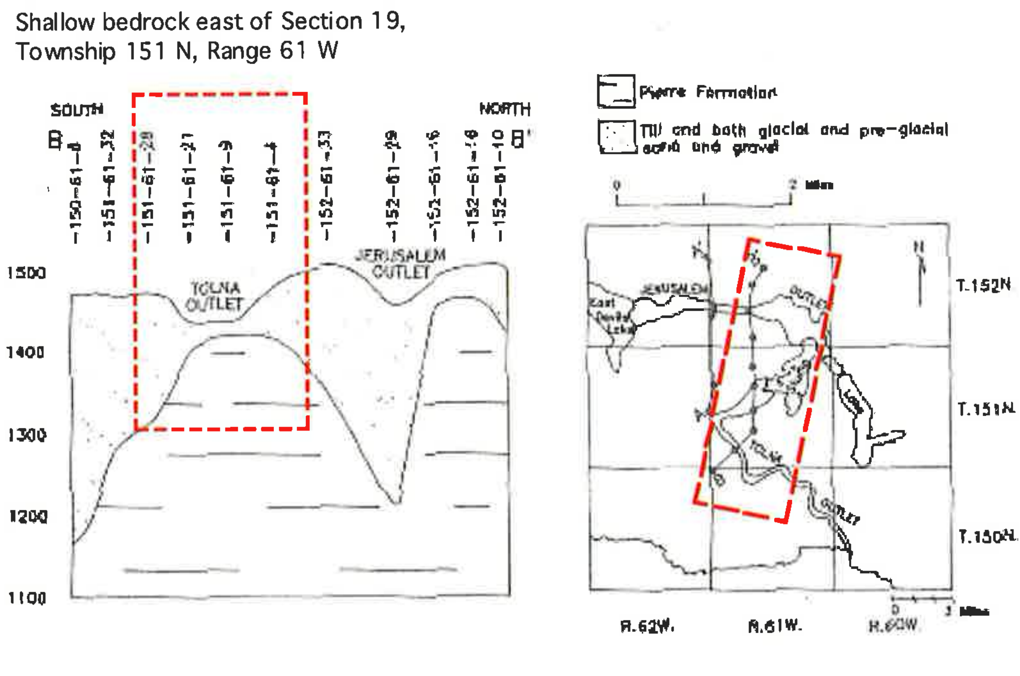


Figure 6. Generalized cross-sections in the East Devils Lake-Stump Lake area. Well locations are given by township, range, and section number.

Figure C -1. Illustration of shallow bedrock east of Section 19, from the discussion of shallow bedrock identified in boreholes at 151-061-19CBC in Tolna Coulee. Adapted from Figure 6 of Murphy and others (1997).