CONCEPTUAL WATER BALANCE MODEL AND FATE ASSESSMENT

Produced Water Spill
McKenzie County, North Dakota

Prepared for:
Greenberg Traurig
1200 17th Street
Suite 2400
Denver, CO 80202
(303) 572-6551

Wright Water Engineers, Inc.

October 2015

151-066.000

CONCEPTUAL WATER BALANCE MODEL AND FATE ASSESSMENT

Produced Water Spill McKenzie County, North Dakota

Prepared for

Greenberg Traurig
1200 17th Street
Suite 2400
Denver, CO 80202
(303) 572-6551

Prepared by

Wright Water Engineers, Inc.
2490 W. 26th Ave, Ste 100A
Denver, Colorado 80211
(303) 480-1700

October 2015

151-066.000

TABLE OF CONTENTS

Page

FIGURES

TABLES

ATTACHMENTS

MAPS

CONCEPTUAL WATER BALANCE MODEL AND FATE ASSESSMENT
Produced Water Spill
McKenzie County, North Dakota

1.0 INTRODUCTION AND BACKGROUND

On or about the afternoon or early evening of July 3, 2014, a leak developed in a brine gathering system pipeline, owned and operated by Crestwood Midstream Partners, LP (Crestwood). The release of approximately 26,000 barrels or 1.1 million gallons (MG) occurred near a pipe coupling located approximately 1 mile south of Bear Den Bay (Lake Sakakawea) adjacent to Turnuey Ridge Road near the McKenzie/Dunn County line (See Figure 1-1.) Conditions were such during the holiday weekend that this leak did not become apparent until anomalous flow data were identified on July 7, 2014. A site inspection of the pipeline length late in the day defined the spill location as 47°47’04"N and 102°38’40"W or in the SE¼ of the NE¼ of Section 24, Township 150 North, Range 94 West of the 5th P.M.

The pipe failure allowed fluids within the pipeline to pool at the surface adjacent to the pipe where they flowed according to the surface topography, primarily in a southwestward direction along the north side of Turnuey Ridge Road. The total distance of the flow path from the spill entry point to Lake Sakakawea including numerous beaver dams (some intact and active, some intact and silted in, and some previously breached) is 7,400 feet. The 7,400-foot length is comprised of 2,250 feet of overland flow, 2,650 feet of channel flow, and 2,500 feet of flow through ponds.

Some fluids also moved northeasterly approximately 450 feet from the spill point but were constrained by the road and higher elevations. Map 1 shows the drainage area above the lower beaver pond (point of fluid withdrawal), the general location of significant sample sites, and the fluid flow path. Map 2 provides a closer perspective on the spill area and includes sample location nomenclature.

The subject pipeline carried produced[1] water from oil and gas operations in the area. Typical of brine gathering systems, this pipeline did not flow continuously and therefore was not under

[1]Pipeline fluids are described in this report as produced water but may also have contained flowback water.

constant pressure. Upon identification of the leak, conveyance of fluids was halted so that appropriate mitigation of the brine release could occur.

The North Dakota Department of Health (Environmental Health Section) has developed "Guidelines for the Assessment and Cleanup of Saltwater Releases" (2014, currently in draft) for the mitigation of saline water spills. This document emphasizes a primary focus on salt (sodium and chloride) as the constituent of concern, stating "There are no known biological or chemical additives that can remove or consume salt. Salts can only be redistributed by means of excavation or mobilizing them so they can be moved to noncritical areas." The document further states that when in-situ remediation is the selected mitigation, the plan "should be designed to allow salt impacts to migrate below the root zone of local vegetation and provide a sufficient nutrient base to allow for the reestablishment of vegetation."

Another document, "A Guide for Remediation of Salt/Hydrocarbon Impacted Soil" distributed by the North Dakota Industrial Commission Department of Mineral Resources, echoes the same general guidance.

The following dates and timeline of events are provided for a better understanding of the sequence of events associated with the spill;

- July 3-7 — Episodic discharge of produced water to the surface from the pipeline at the discharge location. During this time, there was reportedly some rain near the spill location.
- July 7-8 — Identification of the release and initial response to locate the discharge location.
- July 7-11 — Development and implementation of a plan to collect spilled fluids and flush fresh water along the flow path to a collection and fluid withdrawal location (Dam 1).
- July 11-16 — Period of fresh water flushing with coordinated withdrawal at Dam 1 through a pumping station, pipeline and temporary storage.

- July 9-Present — Soil and water monitoring at various locations along the flow path with frequency of sampling diminishing over time.
- July 11-Nov. 8 — Episodic withdrawal of fluids from Dam 1 until freezing temperatures made the systems inoperable.

1.1 Purpose and Scope/Nature of Conceptual Model

This conceptual water balance model (actually, 2 separate models, as presented in Section 5.0) and fate assessment report is provided as a means to address issues associated with likely distribution of the spilled fluids from the July 2014 event, and to serve as a basis for developing appropriate next steps to complete restoration activities. Considerable site monitoring (soil and water), mitigation (soil removal/replacement and soil amendments), and field observations have occurred during the 15 months since this incident occurred. Map 2 provides an overview of the spill area complete with the sampling location nomenclature developed by Crestwood and their consultant Keitu Engineering & Consultants, Inc. (Keitu). With the benefit of these observations and collected data, this document has been prepared by Wright Water Engineers, Inc. (WWE) to provide a conceptual model for the fate of the fluids that were spilled as they relate to surface water and groundwater. Onsite data during or shortly after the spill related to, for example, rates of flow, precipitation, and antecedent (beginning) soil infiltration capacity are not available. Consequently, the conceptual models presented herein are qualitative to semi-quantitative in nature, and their purpose is to develop a working theory of the fate of the spill fluid, focusing on whether some of this fluid remains in the soils in the study area for purposes of remediation and helping to define next steps.

This document is organized to provide background on the existing geographic, geologic, hydrologic, and hydrogeologic conditions and the role these play in the fate of the spilled fluids. Section 5.0 of this report brings this background information together with the observations to date to provide a conceptual water balance model for the distribution of the fluids introduced into the environment from the spill event. Section 6.0 interprets the results of Section 5.0 and summarizes the fate assessment.

While this water balance focuses on the fate of the fluids, qualitative inferences have been made relative to the distribution of the salt, as well, as discussed in Section 6.0.

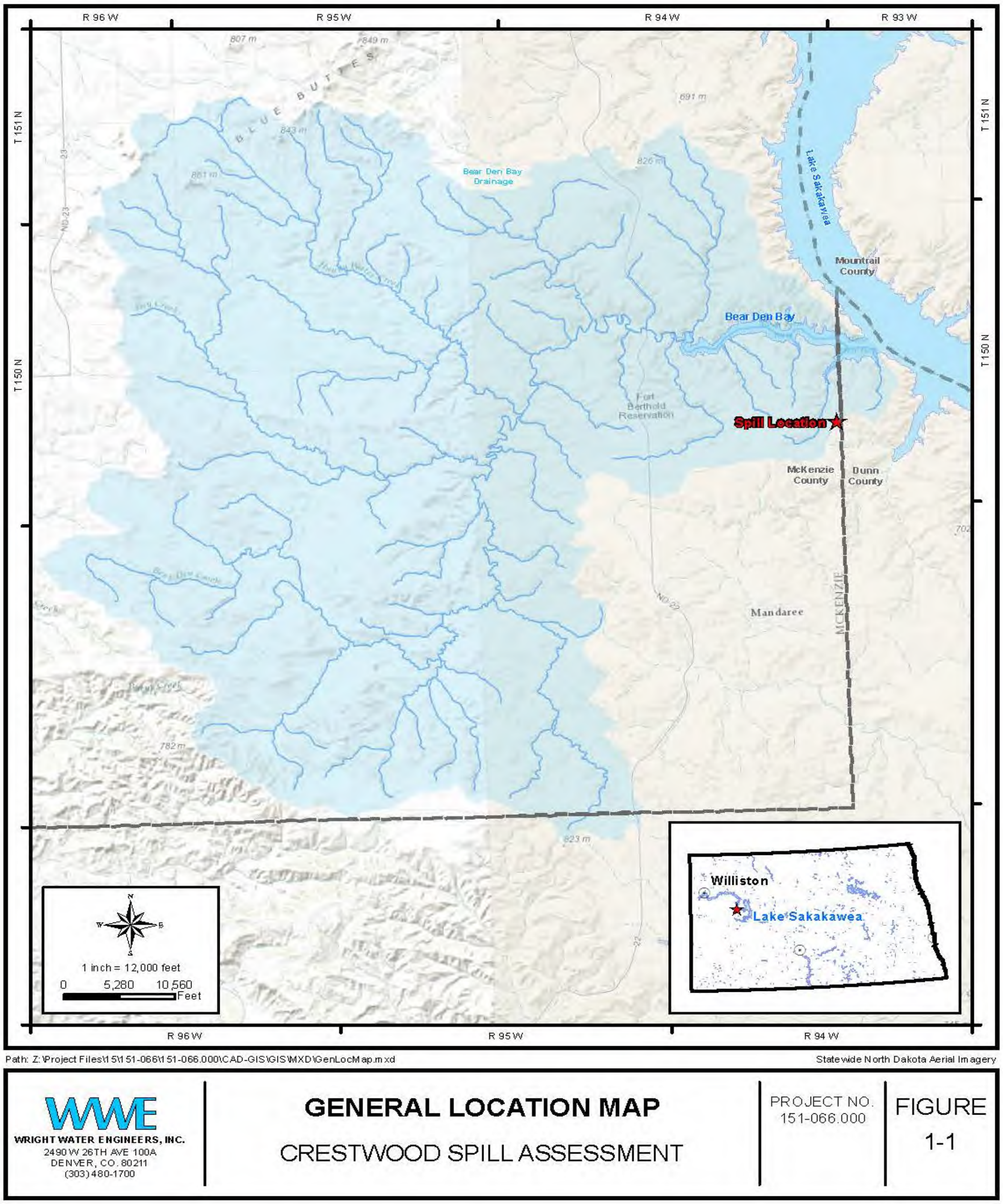


Figure 1-1: General Location Map

1.2 Documents and Data Reviewed

Numerous documents and data have been reviewed by WWE to prepare this report. While not exhaustive, a list of the most significant documents and data reviewed is provided below:

Childs, E.C. 1969. *An Introduction to the Physical Basis of SOIL WATER PHENOMENA.* John Wiley & Sons Ltd: Great Britain

Crestwood and KEITU. 2014. ND 1a Gathering System Brine Spill July 2014 Released Volume to Surface Water Estimate. North Dakota

Dunne, Thomas, and Luna B. Leopold. 1978. *Water in Environmental Planning.* W.H Freeman and Company: New York.

Fetter, C.W. (1980) *Applied Hydrogeology: Second Edition.* Columbus, OH: Merrill.

Freeze, R. Allan and John A. Cherry. (1979) *Groundwater.* Englewood Cliffs, NJ: Prentice Hall.

Hillel, Daniel. 1980. *Applications of Soil Physics.* Academic Press, Inc: New York

Keitu Engineering & Consultants, Inc., Phase 1a Brine Gathering System Incident – Remediation Status Report, 2015.

National Weather Service, Weather Gage (KEENE 3 S, ND US (GHCND: USC00324571)).

Natural Resources Conservation Service: Conservation Engineering Division. (June 1989) *Urban Hydrology for Small Watersheds: TR-55*. *Second Edition*. United States Department of Agriculture. Technical Release 55.

North Dakota Department of Health, Environmental Health Section (2014). Guidelines for the Assessment and Cleanup of Saltwater Releases.

North Dakota Geological Survey, Geology of Dunn County, North Dakota. 2001. North Dakota Geological Survey Bulletin 68 – Part I and North Dakota State Water Commission County Groundwater Studies 25 – Part I.

North Dakota Geological Survey, Ground-Water Data for Dunn County, North Dakota. 1976. North Dakota Geological Survey Bulletin 68 – Part II and North Dakota State Water Commission County Groundwater Studies 25 – Part II.

North Dakota Geological Survey, Ground-Water Resources of Dunn County, North Dakota. 1979. North Dakota Geological Survey Bulletin 68 – Part III and North Dakota State Water Commission County Groundwater Studies 25 – Part III.

North Dakota Geological Survey, Geology of McKenzie County, North Dakota. 1985. North Dakota Geological Survey Bulletin 80 – Part I and North Dakota State Water Commission County Groundwater Studies 37 – Part I.

North Dakota Geological Survey, Ground-Water Data for McKenzie County, North Dakota. 1985. North Dakota Geological Survey Bulletin 80 – Part II and North Dakota State Water Commission County Groundwater Studies 37 – Part II.

North Dakota Geological Survey, Ground-Water Resources of McKenzie County, North Dakota. 1985. North Dakota Geological Survey Bulletin 80 – Part III and North Dakota State Water Commission County Groundwater Studies 37 – Part III.

North Dakota Geological Survey, Physical Data for Land-Use Planning – Divide, McKenzie, and Williams Counties, North Dakota. 1977. Report of Investigations 62.

North Dakota Industrial Commission Department of Mineral Resources. A Guide for Remediation of Salt/Hydrocarbon Impacted Soil.

North Dakota State Water Commission, Master Plan for Garrison Dam/Lake Sakakawea, Nov. 2007.

North Dakota State Water Commission, Water Well Permit Records.

Soil and Water Quality Laboratory Result. 2014 & 2015. Minnesota Valley Testing Laboratory, Inc.

Street, Robert J. (2007) *Groundwater and Wells: Third Edition.* New Brighton, MN: Johnson Screens.

U.S. Department of Agriculture, Soil Survey of McKenzie County, North Dakota.

U.S. Department of Agriculture - Natural Resource Conservation Service, Part 630 Hydrology National Engineering Handbook, Chapter 7 Hydrologic Soil Groups, 210-VI-NEH, May 2007.

U.S. Department of Agriculture - Natural Resource Conservation Service, Web Soil Survey, McKenzie County.

U.S. Department of Agriculture - Soil Conservation Service, Soil Taxonomy: A Basic System of Soil Classification for Making and Interpreting Soil Surveys. Washington, DC. 1975.

U.S. Department of Commerce – National Oceanic and Atmospheric Administration, Mean Monthly, Seasonal and Annual Pan Evaporation for the United States, NWS Technical Report 34.

U.S. Environmental Protection Agency, Ambient Water Quality Criteria for Chloride, EPA 440/5-88-001, Feb. 1988.

U.S. Environmental Protection Agency, Standards of Quality for Waters of the State, North Dakota, 2001.
http://water.epa.gov/scitech/swguidance/standards/upload/ndwqs.pdf.

U.S. Geological Survey, Stream Gage Bear Den Creek near Mandaree, North Dakota.

Viessman Jr., Warren, John W. Knapp, Gary L. Lewis, and Terence E. Harbaugh. 1977. *Introduction to Hydrology*. Second Edition IEP-Dun-Donnelley. Harper & Row: New York.

Wang, X., S. Shang, Z. Qu, T. Liu, A. M. Melesse, and W. Yang. 2010. Simulated Wetland Conservation-restoration Effects on Water Quantity and Quality at Watershed Scale. *Journal of Environmental Management*, Vol. 91.

1.3 Field Visit

In addition to reviewing the documents and data sources listed above, WWE conducted a field visit on August 14, 2015 (Attachment A contains photographs obtained on this field trip).

1.4 Spill Response and Follow-Up

Immediately following the recognition of the pipeline failure, and in keeping with guidelines for mitigation of saline water spills, approximately 1 MG of fresh water was flushed down the ravine hillside and into the drainage channel over approximately 5 days. The flushing flow eventually reached the most downstream (lower) beaver pond (aka Dam 1) where the water was pumped to temporary storage tanks near the release area and hauled away for disposal. Pumping from Dam 1 continued for roughly 4 months after the flushing was completed. In total, approximately 5.4 MG were removed from Dam 1 from the time of first flushing (July 11, 2014) to November 8, 2014, when freezing temperatures made it impractical to continue.

Monitoring of soils and water began immediately after spill identification and was frequent during the first few months following the event. Monitoring has continued to date with sampling now occurring on a quarterly basis.

A June 2015 report by Keitu outlines a monitoring and remediation plan for the spill area. This report provides specific sampling and monitoring objectives as well as goals for returning the soils to a vegetative productive state.

1.5 Limitations

Wright Water Engineers, Inc. has endeavored to provide professional services for this project in accordance with engineering practices accepted in this area at this time. The opinions expressed in this report represent professional judgments that were prepared based on information either obtained by or provided to us from various sources. WWE reserves the right to modify any conclusions deemed appropriate upon receipt and review of new or additional information.

2.0 GEOGRAPHIC SETTING

The subject spill occurred along Turnuey Ridge Road near the McKenzie/Dunn County line. From the spill location, fluids moved southwest along the road into a ravine that drains into Bear Den Bay, a tributary of the third-largest man-made lake in the United States, Lake Sakakawea with a normal pool volume of 23.8 million acre-feet (AF). Lake Sakakawea is a drinking water source for the Fort Berthold Indian reservation, occupied by the Arikara, Hidatsa, and Mandan tribes, in North Dakota. Bear Den Bay's drainage area is approximately 140 square miles and the unnamed drainage area upstream of Dam 1 is approximately 750 acres, with a total drainage area (at the mouth of the unnamed tributary) of about 840 acres.

The remainder of this section describes the general geographic setting of the spill area relative to elevation, vegetation, climate, and land use.

2.1 Key Elevations

The elevation at the spill location is approximately 2,230 feet. Approximate elevations at strategic locations along the flow path (see Map 2) include the top of ravine (2,220 feet), Coulee Start (2,020 feet), Dam 1 (1,900 feet), and Lake Sakakawea (1,840 feet). Thus, the total elevation change along the flow path is about 390 feet. This occurs over a distance of about 7,400 feet, for an overall slope of about 5.3%. Key facts associated with this flow path such as lengths, slopes, and volumes are provided on Map 2, on a reach-by-reach basis.

2.2 Vegetation

The spill area consists of a rugged landscape (Badlands topography) with dramatic and steep-sided hills that drop into ravines carrying runoff to Lake Sakakawea. The majority of the vegetation within the spill area is classified as upland grasslands according to the Garrison Dam/Lake Sakakawea Master Plan (North Dakota State Water Commission, 2007) and includes native annual grasses, perennial weeds, forbs, and wildflowers. Within the protected portions of the drainage channel, the larger vegetation includes juniper and green ash along with a variety of shrubs. More discussion of vegetation is found in Section 4.0.

2.3 Climate

As discussed in more detail in Section 4.0, the general climate of western North Dakota is semi-arid and known for having cold winters and hot to mild summers. The average monthly temperature of McKenzie County in January is 13°F and the average temperature in July is 72°F. The average yearly precipitation is 14 inches, with the heaviest rainfall occurring in May, June, and July. Large thunderstorms in the summer months dominate the weather patterns. Precipitation leading up to and during the spill is discussed in Section 5.0. The average snowfall is 35 inches per year (USDA, Soil Survey of McKenzie County, North Dakota).

2.4 Land Use and Soils

The spill area consists of moderately to severely sloped uplands dissected by coulees leading to Lake Sakakawea. Soils consist of coarse to moderately textured soils formed from weathered sedimentary formations comprised of sandstone, siltstone, mudstone, claystone, and lignite. The two main soil groups found in the unnamed drainage to Bear Den Bay are the Cabba-Badland-Arikara complex and the Arikara-Shambo-Cabba loams. The Arikara, Cabba, Shambo and Badland soil groups are described as well drained soils with a hydrologic grouping from B to D, meaning that they range from having a moderately low to moderately high runoff potential when thoroughly wet (USDA-NRCS, 2007). Other key soil properties are presented in Section 5.0.

In the upper reaches of the drainage, where the spill was moving as overland flow (rather than as channelized flow) there is considerable “micro-topography” with ups and downs, depressions, and slumps that create small storage areas and, in general, irregularities that promoted spill infiltration. The roots from the good vegetative cover enhanced infiltration. The substantial infiltration that occurred along the flow path is demonstrated by the large area of vegetation that was killed by the salt loading, as demonstrated by soil chemistry data along the flow path. There is additional discussion of soils in Section 5.0 and infiltration in Section 3.0. There is no public access to the Bear Den Bay area so it is classified as a low-density recreation area. Recreational land use includes hunting and fishing.

3.0 GEOLOGIC AND HYDROGEOLOGIC SETTING

The geologic and hydrogeologic conditions associated with the spill area are described in the three-part published documents by the North Dakota Geological Survey (NDGS) and North Dakota State Water Commission (NDSWC) covering the Geology (Part I), Ground-Water Data (Part II) and Ground-Water Resources (Part III) for both McKenzie and Dunn counties, North Dakota. The McKenzie County report series falls under Bulletin 80 from the NDGS and County Groundwater Studies 37 from the NDSWC. The Dunn County report series is Bulletin 68 from the NDGS and County Groundwater Studies 25 from the NDSWC. Considerable geologic and hydrogeologic information is available from these three-part county reports including formation names, stratigraphy, lithology, structure, aquifer names, depth to groundwater, flow direction, etc. More details about geology, hydrogeology, and groundwater are provided in the remainder of this section.

3.1 Geology

The spill area is located along the eastern boundary of McKenzie County in the Missouri Plateau Section of the Great Plains Province. This portion of McKenzie County was within the limits of continental glaciation which left behind thin and patchy areas of till exposed at the surface. Consolidated bedrock formations exposed in the area are of Tertiary age. Recent sediment consists of alluvium or colluvium, which is generally confined to lowland areas of current or Pleistocene drainages. Pleistocene sediments consist of till on the upland areas and water-sorted sediment in and along glacial drainages.

Plate 1 of Part I in both county reports provides information about exposed geologic formations in the spill area. A copy of Bulletin 80, Part I, Plate 1 (McKenzie County) is provided in Attachment B. The geologic maps for both counties depict the Sentinel Butte Formation as the bedrock unit underlying the entire spill area, with some overlying remnant glacial deposits in the higher elevations. Beneath the Sentinel Butte Formation is the Tongue River Formation, which is not exposed at the surface or mapped in this area. Although available mapping shows no alluvium in the unnamed drainage into which the brine fluids were spilled, as discussed in Section 3.1.2, alluvium is clearly present and infiltrated some of the spill volume. Additional details about the stratigraphy and lithology of the underlying geology of the spill area are provided below.

Of particular geologic note is that the fine-grained nature of the Sentinel Butte Formation makes it susceptible to landslides particularly in the more deeply incised drainages such as the one in the spill area. A published map (Snsh SW-1) by the NDGS reveals that much of the drainage (including the entire valley bottom along the spilled fluids flow path) is mapped as landslide deposits (see Attachment C). A site visit by WWE in August 2015 confirmed the widespread extent of these landslide features. A photograph of a representative landslide can be found in Attachment A. As noted in Section 2.4, the numerous local slumps/sloughs in the spill flow path promoted temporary surface ponding and infiltration.

3.1.1 Stratigraphy

As stated above, surficial geologic mapping of McKenzie and Dunn counties reveals some remnant glacial deposits overlying the Tertiary-aged Sentinel Butte Formation in the spill area. The McKenzie County map (Attachment B) identifies the uppermost deposits in the spill area as glacial materials of the Coleharbor Group. The underlying Sentinel Butte Formation, in turn, overlies the Tongue River Formation in the spill area. The Tongue River Formation is considered to be the shallowest regional aquifer used as a reliable water supply source. Table 3-1 provides a stratigraphic column for the geologic formations in McKenzie County. Note that not all stratigraphic intervals are present throughout the county.

3.1.2 Lithology

The Coleharbor Group is comprised of materials ranging in size from silts and clays to pebbles, cobbles, and boulders. These deposits are quite variable in thickness within the area but seldom exceed 30 feet. Although not specifically mapped, unconsolidated alluvial and colluvial materials exist beneath and adjacent to the channel in the unnamed drainage. These materials are comprised of sediments from the underlying and exposed bedrock formation within the drainage that were carried by precipitation or gravity (i.e., landslide, etc.) toward the channel bottom and reworked by ongoing fluvial activity.

Underlying the unconsolidated materials is the Sentinel Butte Formation with thicknesses up to 620 feet. This formation consists of alternating beds of sandstone, siltstone, mudstone, claystone, and lignite beds. Ironstone nodule zones in the siltstone and mudstone and petrified wood in the lignite and carbonaceous shale are characteristic of this formation.

Table 3-1: Partial Stratigraphic Column for McKenzie County

(Figure 4 in Bulletin 80, Part 1)

ERA	SYSTEM	SEQUENCE	FORMATION OR GROUP		THICKNESS	DOMINANT LITHOLOGY
Cenozoic	TERTIARY	TEJAS		Alluvium Colluvium	0-60	Silt, Sand, and Gravel
				Coleharbor	0-300	Till, Sand, Gravel, Silt, and Clay
				Wiota	0-30	Sand and Gravel
		ZUNI		Golden Valley	0-180	Silt, Clay, and Sand
			Fort Union Group	Sentinel Butte	0-620	Silt, Clay, Sand, and Lignite
				Tongue River	250-600	Silt, Clay, Sand, and Lignite
				Slope	600-650	Silt, Clay, Sand, and Lignite
				Cannonball		Mudstone and Sandstone
				Ludlow		Silt, Clay, Sand, and Lignite
Mesozoic	CRETACEOUS			Hell Creek	200-250	Clay, Sandstone, and Mudstone
			Montana Group	Fox Hills	200-250	Sandstone and Shale
				Pierre	2000-2300	Shale
			Colorado Group	Niobrara	200-230	Shale, Calcareous
				Carlile	300-350	Shale
				Greenhorn	200-230	Shale, Calcareous
				Belle Fourche	220-250	Shale
			Dakota Group	Mowry	90-130	Shale
				Newcastle	0-150	Sandstone
				Skull Creek	180-270	Shale
				Inyan Kara	400-525	Sandstone and Mudstone
	JURASSIC			Swift	440-570	Mudstone and Sandstone
				Rierdon	90-140	Shale and Sandstone
				Piper	380-450	Limestone, Shale, and Anhydrite
	TRIASSIC					
		ABSAROKA		Spearfish	380-450	Siltstone and Salt
Paleozoic	PERMIAN			Minnekahta	25-40	Limestone
				Opeche	200-420	Shale, Siltstone, and Salt
	PENNSYLVANIAN		Minnelusa	Broom Creek	200-220	Sandstone and Dolomite
				Amsden	300-350	Dolomite, Sandstone, and Shale
				Tyler	80-180	Mudstone and Sandstone

Beneath the Sentinel Butte Formation is the underlying Tongue River Formation, which consists of fine- to intermediate-grained sandstone, siltstone, claystone, and lignite with a thickness of between 250 and 600 feet. The contact between the Sentinel Butte and Tongue River formations is not mapped in the spill area or unnamed drainage (see Attachment B) along which the spilled fluids traveled.

3.1.3 Structure

The spill area is structurally located to the south of the center of the Williston Basin. As a result, the sedimentary strata of the area generally dips gently to the north. However, the north-south oriented Nesson Anticline is a major geologic structure within the Williston Basin located west of the spill area between Range 95 and 96 West. While not specifically represented in the three-part county report, this structure may influence the dip of the deeper geologic formation toward the northeast in the vicinity of the spill area in McKenzie County.

3.2 Hydrogeology

According to Bulletin 80, Part III, groundwater in McKenzie County is primarily used for domestic and livestock purposes as derived from three aquifer systems of Late Cretaceous and Tertiary age. These include, from deepest to shallowest, the Fox Hills and basal Hell Creek aquifer, the Ludlow aquifer, and Tongue River aquifer.

According to Bulletin 80, Part III, recharge to the deepest aquifers is from subsurface inflow from adjacent areas to the south and from underlying beds. Discharge by outflow is generally to the north and upward leakage into the overlying aquifer systems. The water generally is lower in dissolved solids than water from the overlying aquifers of Tertiary age. Many wells developed in this aquifer system in the valley of the Little Missouri River and adjacent to Lake Sakakawea are confined and flow at the land surface. Wells tapping this aquifer system yield about 100 gallons per minute (gpm).

Sandstone units within the Tertiary-aged Ludlow and Tongue River aquifers have smaller conductivity values than those in the deeper units. The Ludlow aquifer is likely recharged from the underlying deposits and discharges by seepage to the Little Missouri River. The Tongue River aquifer system is recharged by precipitation and seepage from surface water and discharges north outside of McKenzie County. Shallow wells in the overlying deposits of the Sentinel Butte Formation generally have higher heads than wells in the Tongue River aquifer system, indicating that groundwater is either moving downward or perched in low permeability intervals that do not allow much, if any, vertical movement. The latter is considered the most likely given that head in the Tongue River aquifer system is generally lower than in the underlying aquifer system, indicating there is upward recharge from the underlying strata. Wells tapping the Ludlow and Tongue River aquifer systems yield about 25 gpm.

Bulletin 80, Part III does not discuss unconsolidated alluvial groundwater resources in the eastern portion of McKenzie County or in general along the small streams and drainages of the county serving as water supplies for shallow wells or infiltration galleries, although field observations indicate that alluvium (and colluvium) is present in the unnamed drainage.

3.2.1 Depth to Groundwater

Figure 17 of Bulletin 80, Part III shows that the potentiometric surface of the Tongue River aquifer in the vicinity of the spill is approximately at elevation 1,920 feet, or about 300 feet below the spill point elevation. This information is recreated below as Figure 3-1. A site visit to the unnamed drainage found no evidence of the contact between the Sentinel Butte and Tongue River formations and no significant spring discharges. This suggests the fine-grained units within the Sentinel Butte Formation are confining the groundwater within the Tongue River aquifer so that there is little to no hydrologic communication between the surface water in the unnamed drainage and this underlying aquifer.

Review of North Dakota well permit records finds that there are a handful of water supply wells located within approximately 5 miles of the spill location (mapping of these wells and associated data is available in WWE files). Data from these wells vary considerably relative to age, well depth, depth to groundwater, and completeness of subsurface lithologic information. In general, there appears to be only limited use of groundwater from the Sentinel Butte Formation based on reported well yields. This formation is known to be a source of water to wells within the reservation for stock and individual domestic use, however, records of such use could not be found in the North Dakota permit records. Larger producing wells in the permit records appear to be from deeper bedrock formations (presumably the Tongue River Formation). WWE initially evaluated whether the water level in Lake Sakakawea could affect the depth to groundwater beneath the spill area, but was not able to locate sufficient records/data to evaluate this potential.

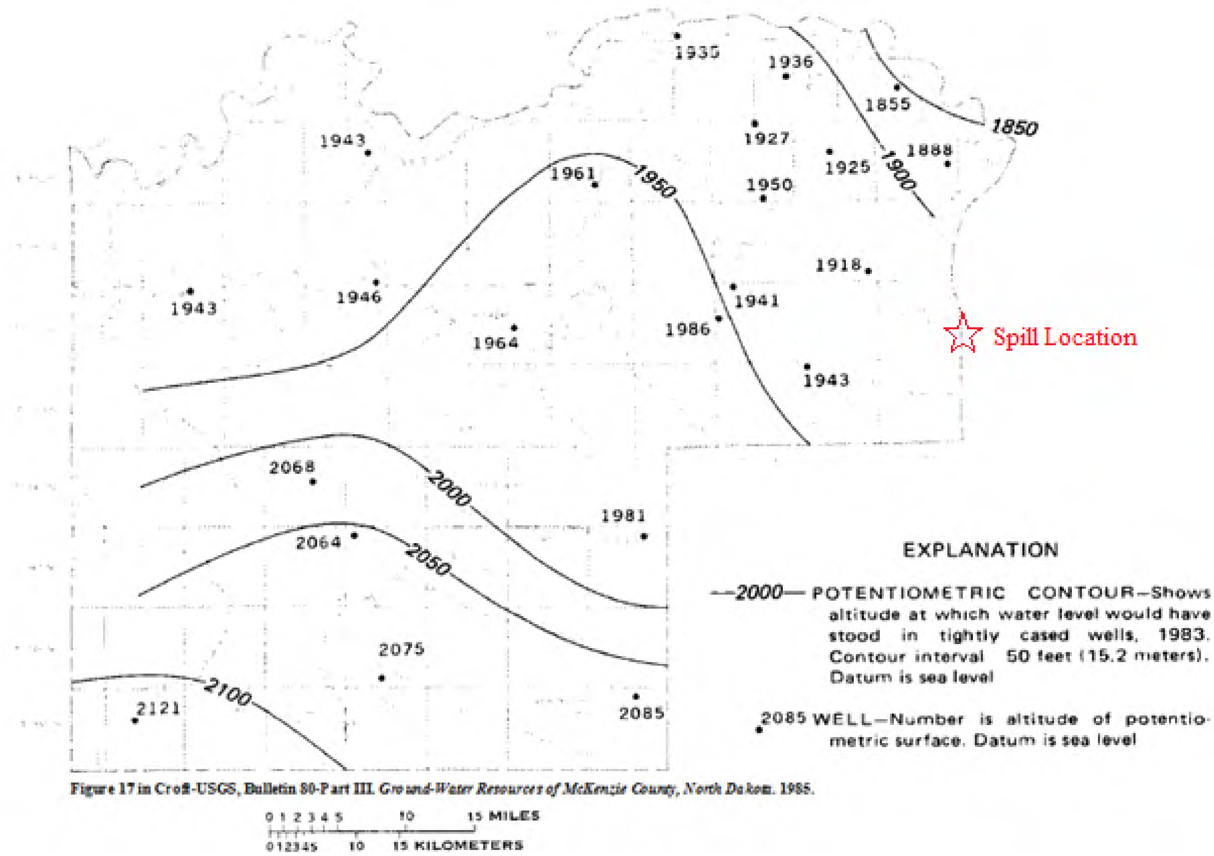


Figure 3-1: Potentiometric Surface of the Tongue River Aquifer System, 1983

3.2.2 Groundwater Flow

The general groundwater flow direction within the Tongue River aquifer is considered to be from the south toward the north with an average gradient of about 10 feet per mile according to Bulletin 80, Part III. Potentiometric contours on Figure 3-1 suggest a southwest to northeast flow direction in the spill area.

3.2.3 Groundwater Quality

Water from the Tongue River aquifer system is generally soft and of sodium bicarbonate type. Much of the water in this aquifer is yellowish brown due to dissolved organic compounds. As a result, this water source is generally used for domestic and stock purposes and not for municipal or irrigation purposes. The median dissolved solids concentration is about 1,850 milligrams per liter (mg/L) with 5 percent of the anions represented by chloride. Chloride concentrations in the aquifer are larger than in samples from the glacial drift and alluvial aquifers and from many of the samples obtained from the overlying Sentinel Butte Formation. This elevated chloride concentration relative to the overlying Sentinel Butte Formation indicates upward recharge from the underlying deposits. Surface water quality data are presented in Section 4.0.

4.0 HYDROLOGIC SETTING

This section briefly reviews key aspects of surface water hydrology for the spill area watershed. The information and data presented in this section are utilized in Section 5.0, where the conceptual water balance model and fate assessment are presented.

4.1 Basic Watershed Characteristics

The size of the watershed is about 750 acres from Dam 1 (the lower beaver pond) to the basin headwaters (see Map 2 for locations of key features). The total watershed area from the mouth (confluence of the channel and Bear Den Bay) is about 840 acres. The total distance of the flow path from the spill entry point to Lake Sakakawea including numerous beaver dams (some intact and active, some intact and silted in, and some previously breached) is 7,400 feet. This 7,400-foot length is comprised of 2,250 feet of overland flow, 2,650 feet of channel flow, and 2,500 feet of flow through ponds.

The longitudinal slope of the watershed is about 5.3 %, while the range of side slopes from the edges of the watershed to the stream channel varies from roughly 11% to 28%, with most in the range of 17% to 24%. The watershed slopes from south to north and discharges into Lake Sakakawea. Section 3.0 describes watershed landforms, geology, and hydrogeology. As noted in Section 3.0, the watershed has numerous landslides, irregular typography, significant areas of localized storage of overland flow and good vegetative cover. This channel geometry is shown in the photographs in Attachment A.

From the headwaters of the watershed to approximately sampling location S6 (Coulee Start), the surface runoff is predominantly overland flow or shallow concentrated flow during large snowmelt events and heavy storms. From Coulee Start downstream, there is a defined stream channel, interspersed with beaver ponds. The typical defined channel width is often about 3 feet, side slopes range from vertical to mild when approaching the ponds, and the typical depth of top of bank is about 2 feet. However, there are also reaches where the channel is shallower, and has very mild side slopes; these reaches promoted infiltration of the spill flows. As shown in Attachment A (which provides photographs of the channel at various locations), substrate in the channel can be described as a mixture of soils, bedrock, and petrified wood from the Sentinel Butte Formation.

The channel contains shrubs and grasses in most reaches above the beaver ponds and is exposed downstream of the ponds. When looking at the watershed as a whole, vegetation generally consists of grasses, shrubs, elms, and ash trees, which is typical for locations in North Dakota with an average elevation of about 2,000 feet (the average elevation of this watershed is about 2,040 feet). When WWE observed the channel on August 14, there was a small base flow of roughly 5 gpm over its length, with some variation depending on “losing” or “gaining” reach. Crestwood staff reported to WWE that the channel typically has a small base flow of about 10 gpm, and WWE’s water balance calculations account for this.

The Keene weather station is about 6 miles southwest of the spill site, with coordinates of 47° 53’ 47.75” N and 102° 55’ 14.87” W. The record of data at this station is from August 1950 to July 2015 with 92% data coverage per daily data points, which is considered good. There are no known weather stations associated with organizations such as CoCoRaHS that are closer to the spill site than the Keene station.

Table 4-1: Monthly Total Precipitation at Keene, North Dakota provides monthly precipitation data for the closest National Oceanic and Atmospheric Administration (NOAA)/National Weather Service (NWS) meteorological station, Keene 3 S, ND US (GHCND:USC00324571) for the time period of record, 1950 to 2015.

Table 4-1: Monthly Total Precipitation at Keene, North Dakota

	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
2014	0.29	0.39	0.36	1.29	2.02	2.97	1.48	3.07	1.80	0.78	0.59	0.11	15.16
2015	0.56	0.52	0.54	0.63	1.17	1.62	1.76	-	-	-	-	-	-
Average (1950-2015)	0.39	0.37	0.54	1.17	2.25	3.11	2.22	1.54	1.36	1.00	0.53	0.42	14.91

Note that July 2014 was drier than the long-term average, as were May and June 2014. These relatively dry conditions may have increased the potential infiltration of spill flows as they moved down the watershed, as discussed in Section 5.0, although the reported precipitation in the area at the time of the spill would have been an offsetting factor, as discussed below.

Table 4-2 provides daily precipitation data from June 15 through November 8, 2014 which includes the period that was initially evaluated by the conceptual water balance model discussed in Section 5.0.

Table 4-2: Daily Precipitation Totals from June 15 to Nov 8, 2014 at Keene, North Dakota

Date	Precipitation (inches)
6/15/2014	0.00
6/16/2014	0.00
6/17/2014	0.00
6/18/2014	0.55
6/19/2014	0.00
6/20/2014	0.00
6/21/2014	0.00
6/22/2014	0.00
6/23/2014	0.08
6/24/2014	0.05
6/25/2014	0.00
6/26/2014	0.09
6/27/2014	0.05
6/28/2014	0.58
6/29/2014	0.32
6/30/2014	0.47
7/1/2014	0.37
7/2/2014	0.00
7/3/2014	0.00
7/4/2014	0.00
7/5/2014	0.00
7/6/2014	0.00
7/7/2014	0.13
7/8/2014	0.00
7/9/2014	0.00
7/10/2014	0.00
7/11/2014	0.00
7/12/2014	0.00
7/13/2014	0.00
7/14/2014	0.00
7/15/2014	0.00
7/16/2014	0.00
7/17/2014	0.00
7/18/2014	0.00
7/19/2014	0.00
7/20/2014	0.00
7/21/2014	0.03
7/22/2014	0.00

Date	Precipitation (inches)
7/23/2014	0.00
7/24/2014	0.30
7/25/2014	0.40
7/26/2014	0.00
7/27/2014	0.00
7/28/2014	0.00
7/29/2014	0.00
7/30/2014	0.00
7/31/2014	0.25
8/1/2014	0.00
8/2/2014	0.00
8/3/2014	0.08
8/4/2014	0.00
8/5/2014	0.31
8/6/2014	0.08
8/7/2014	0.00
8/8/2014	0.00
8/9/2014	0.00
8/10/2014	0.00
8/11/2014	0.00
8/12/2014	0.00
8/13/2014	0.00
8/14/2014	0.00
8/15/2014	0.00
8/16/2014	0.65
8/17/2014	0.00
8/18/2014	0.00
8/19/2014	0.00
8/20/2014	0.04
8/21/2014	0.00
8/22/2014	0.00
8/23/2014	0.67
8/24/2014	0.37
8/25/2014	0.16
8/26/2014	0.00
8/27/2014	0.00
8/28/2014	0.00
8/29/2014	0.04

Date	Precipitation (inches)
8/30/2014	0.00
8/31/2014	0.67
9/1/2014	0.25
9/2/2014	0.03
9/3/2014	0.00
9/4/2014	0.70
9/5/2014	0.00
9/6/2014	0.00
9/7/2014	0.00
9/8/2014	0.00
9/9/2014	0.00
9/10/2014	0.00
9/11/2014	0.00
9/12/2014	0.00
9/13/2014	0.00
9/14/2014	0.00
9/15/2014	0.00
9/16/2014	0.00
9/17/2014	0.00
9/18/2014	0.00
9/19/2014	0.00
9/20/2014	0.00
9/21/2014	0.00
9/22/2014	0.00
9/23/2014	0.00
9/24/2014	0.00
9/25/2014	0.00
9/26/2014	0.00
9/27/2014	0.00
9/28/2014	0.00
9/29/2014	0.00
9/30/2014	0.81
10/1/2014	0.18
10/2/2014	0.05
10/3/2014	0.00
10/4/2014	0.00
10/5/2014	0.10
10/6/2014	0.00

Date	Precipitation (inches)
10/7/2014	0.00
10/8/2014	0.00
10/9/2014	0.00
10/10/2014	0.00
10/11/2014	0.00
10/12/2014	0.00
10/13/2014	0.05
10/14/2014	0.00
10/15/2014	0.00
10/16/2014	0.00
10/17/2014	0.00
10/18/2014	0.00
10/19/2014	0.00
10/20/2014	0.00
10/21/2014	0.00
10/22/2014	0.00
10/23/2014	0.00
10/24/2014	0.00
10/25/2014	0.00
10/26/2014	0.00
10/27/2014	0.09
10/28/2014	0.26
10/29/2014	0.05
10/30/2014	0.00
10/31/2014	0.00
11/1/2014	0.00
11/2/2014	0.00
11/3/2014	0.00
11/4/2014	0.00
11/5/2014	0.00
11/6/2014	0.00
11/7/2014	0.00
11/8/2014	0.00

The Keene weather station reported rain every day from June 26 through July 1, although the total amount of 1.88 inches during this time in not anticipated to have produced large rates of runoff or increases in soil moisture. In fact, in the middle of summer in western North Dakota, the average daily evapotranspiration would have consumed most, if not all, of this 6-day average daily precipitation of 0.31 inches. In addition, it is important to note that there was no antecedent rainfall on the two days prior to the spill (July 3), at least at the Keene gage. With this said, however, operators working in the general area reported some rain over the July 4 weekend when the spill occurred, but no onsite precipitation data or verbal/written accounts of the timing or intensity of this rainfall or observed runoff rates are available. There were also reports of encountering wet soils when constructing the temporary access road to the lower beaver pond, but this could have been attributable to excavating into the soil, encountering a localized wet area, or other factors. The available precipitation data and anecdotal accounts do not suggest soil saturation (i.e., very wet conditions) throughout the watershed, but there may have been some wet weather (storm runoff) flow that promoted the downstream movement of the spill.

The average temperature recorded at the nearest NWS weather station to the spill site (near Keene, ND) is about 42 degrees Fahrenheit (°F). The coldest month is January, which averages 11.3°F and the warmest month is July with an average temperature of 69.5°F. The average temperatures of the months leading up to the July 3, 2014 spill were close to average for the area.

Table 4-3 provides temperature data from the Keene Station for 1950 to 2015.

Table 4-3: Average Monthly Temperature near Keene, ND (°F)

	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
2014	13.8	8.8	26.0	40.6	54.0	62.2	67.0	67.9	58.4	48.0	20.5	22.0
2015	18.8	12.7	36.8	46.1	53.0	67.0	70.5	-	-	-	-	-
Historical Average (1950-2015)	11.3	17.1	28.8	43.1	54.2	63.2	69.5	68.4	58.2	44.8	28.0	15.6

Pan evaporation data were obtained from the National Weather Service Technical Report No. 34. This report provides evaporation data for stations around the United States; Williston, North Dakota was selected as the closest station. During the period of July 3 through November 8, 2014, there was approximately 25 inches of pond (free water) evaporation.

Relative to evapotranspiration (plant water use) during the same time period, WWE assumed that the value would be approximately 24 inches, consistent with numerous water rights and hydrologic studies that WWE has performed, including assignments in North Dakota. As discussed in Section 5.0, WWE made the simplifying assumption that there was not significant evapotranspiration in the area affected by the spill, because the vegetation was either killed or severely damaged between July 3 and November 9, 2014. However, there was substantial infiltration in these areas, as discussed in Sections 3.0 and 5.0.

4.2 Regional Streamflow Data

The nearest USGS streamflow gage is located on Bear Den Creek near Mandaree, North Dakota, approximately 6 miles west of the spill site. The latitude of the stream gage is 47°47'14" N and the longitude is 102°46'05" W. The drainage basin for the Bear Den Creek gage is 74 square miles, or about 60 times larger than the watershed where the spill occurred (thus mandating a basin adjustment factor, as discussed in Section 5.0). The average annual streamflow at the Bear Den Creek gage is 5.7 cfs, or about 0.054 gpm per acre.

The yearly streamflow trend indicates that the highest flows occur in March and decrease throughout the spring and summer. Streamflow is usually very low in the winter months due to freezing temperatures.

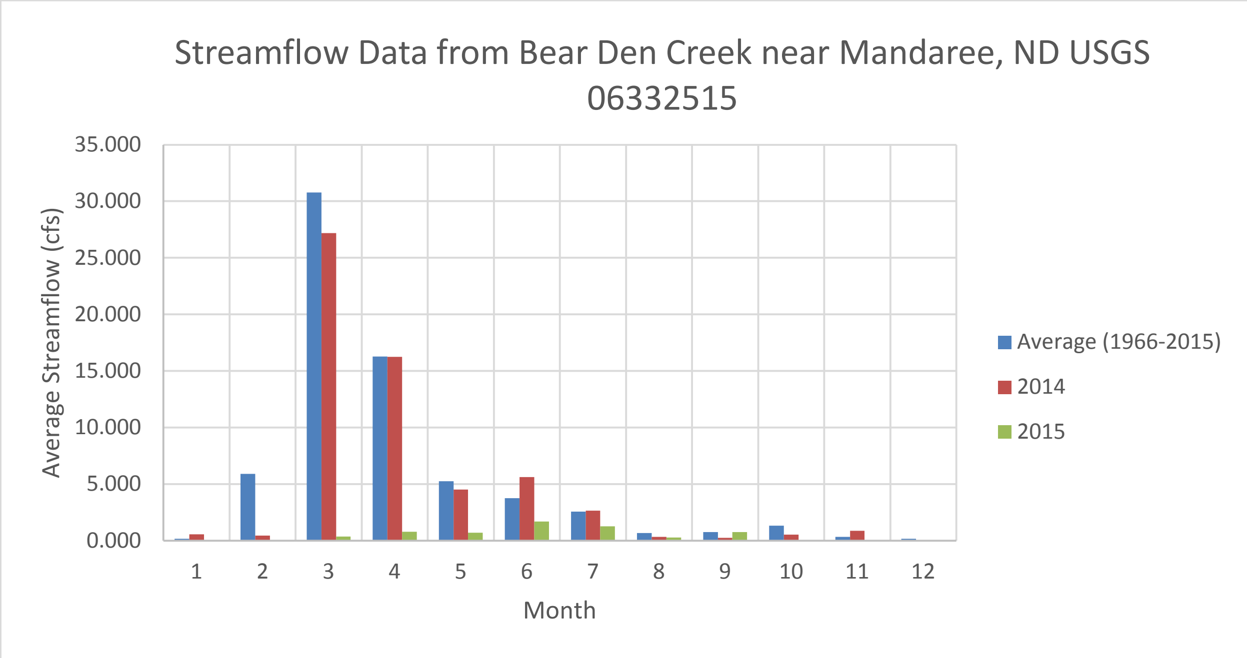


Figure 4-1: Streamflow Data from Bear Den Creek near Mandaree, North Dakota

The levels of streamflow recorded in 2014 were generally consistent with average historical flows. For example, July 2014 saw an average streamflow of 2.66 cubic feet per second (cfs), which was 3.5% higher than the historical average July streamflow of 2.57 cfs. June 2014 flows were higher than the long-term average, while May flows were lower.

Table 4-4: Monthly Bear Den Creek Streamflows – Average vs. 2014 and 2015 (cfs)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average (1966-2015)	0.17	5.90	30.76	16.28	5.25	3.77	2.57	0.68	0.77	1.33	0.33	0.16
2014	0.58	0.45	27.18	16.25	4.51	5.63	2.66	0.34	0.25	0.52	0.89	ice
2015	ice	ice	0.37	0.79	0.69	1.69	1.28	0.27	0.77	ice	ice	ice

4.3 Regional Water Quality Data

The main water quality constituent of concern in this evaluation is chloride, because at 87,600 mg/L, chloride levels were very high in the spill water (far in excess of chloride water quality criteria and standards); the chloride killed large areas of vegetation, chloride residuals remain in soils, and chloride is highly mobile in shallow groundwater. This report does not evaluate metals, because the large majority of the spill volumes infiltrated into fine-grained soils with high cation exchange capacity and ability to immobilize most metals. Chloride concentration data from the nearest USGS stream gage location on Bear Den Creek near Mandaree, North Dakota, (approximately 6 miles from the spill site) can be used to roughly project background chloride concentrations. Although the specific water quality history of the unnamed drainage where the spill occurred is not known because no known sampling had been done there, the water quality of Bear Den Creek is the closest approximation available. The average chloride concentration in Bear Den Creek is 7.0 mg/L. Since data collection began in 1966, the lowest level of chloride measured was 0.3 mg/L and the highest level was 180 mg/L. The closest sampling date to July 3, 2014 is June 9, 2014 with a chloride concentration of 32.4 mg/L. Chloride data from Lake Sakakawea for a nearby public water supply intake confirm that 7 mg/l for background is a reasonable value.

The four main sampling parameters in the Crestwood/Keitu sampling plan are chloride, calcium, nitrate, and pH. The average, maximum, and minimum values from sampling points from 1966 to 2015 for each these parameters are given in Table 4-5, below.

Table 4-5: Water Quality Data from USGS Stream Gage—Bear Den Creek near Mandaree, North Dakota (1966-2015)

	Chloride (mg/L)	Calcium (mg/L)	Nitrate (mg/L)	pH
Average	7.0	35.8	0.2	8.3
Minimum	0.3	5.49	0	7
Maximum	180	180	1.4	9.6

4.4 State Beneficial Use Classifications

The unnamed tributary to Lake Sakakawea is classified as a Class III stream. Streams of this class are generally suitable for agricultural and industrial use and have low average flows potentially with long periods of no flow. As provided by the United States (U.S) Environmental Protection Agency's website in their repository of current state, tribal and territorial standards for waters of the U.S. (http://water.epa.gov/scitech/swguidance/standards/upload/ndwqs.pdf), the maximum limit for chlorides in North Dakota Class III streams is 250 mg/L as a 30-day arithmetic average.

4.5 Storage Volumes

Storage volumes are available for the relevant water bodies, as follows.

4.5.1 Lake Sakakawea

Lake Sakakawea is the third largest man-made reservoir in the U.S, behind Lake Mead and Lake Powell. Lake Sakakawea can store 23.8 million acre-feet and covers 178 miles along the Missouri River. The U.S. Army Corps of Engineers oversees management of Lake Sakakawea and Garrison Dam, which includes hydropower, flood control, irrigation, and navigation. Lake Sakakawea receives runoff from the drainage area that includes the spill location. There is extensive published literature on this lake, including hydrology and water quality data.

4.5.2 Storage Volume in Beaver Ponds

WWE identified several beaver ponds in the drainage channel along the spilled fluid flow path from aerial imagery. The ponds within the segment between Beaver Dam 1 and Dam 1 impede, store and passively release runoff water within the surrounding basin.

Storage was determined by utilizing the most recent 2014 statewide aerial imagery from the North Dakota GIS Hub Data Portal, which provided sufficient information for this evaluation. Using beaver dam sampling locations from the Keitu report as a guide, WWE delineated the ponds in GIS and the aggregate surface area was calculated.

A field visit by WWE estimated the ponds to have an average depth of 1-2 feet, with deeper water in the largest pond (average depth of 2.5 feet) and shallow water (less than 1 foot) in many of the other ponds.

Total storage in the beaver ponds was calculated as approximately 0.4 MG, with approximately 0.8 acres of surface area and an approximate 1.5 foot depth—this estimate is thought to be conservative, and could be larger.

As noted in Section 4.0, NOAA's Technical Report 34 provides pan evaporation data at the Willington gauge in the North Dakota region of about 25 inches from July 3 until November 8.

5.0 CONCEPTUAL WATER BALANCE MODEL AND FATE ASSESSMENT

Two conceptual models were prepared to determine the nature and movement of the fluids through the watershed. First, as presented in Section 5.1, an initial water balance model for the timespan of July 3, 2014 (spill date) to November 8, 2014 (end of pumping) was prepared to establish the hydrologic inflow and outflow components to the overall conceptual model. Then, as shown in Section 5.2, the results of the initial water balance model were refined and calibrated to measured chloride concentrations within the unnamed drainage and calibrated to an estimate of spilled fluids that reached Lake Sakakawea. This model was reduced to the period from July 3, 2014 (spill date) to July 9, 2014 (date of first water samples) to assess conditions prior to fresh water flushing and pumping from Dam 1.

As discussed in Section 1.1, the two models should be viewed as qualitative to semi-quantitative in nature, given the lack of onsite data for parameters such as flow rates, precipitation, spill infiltration rates, and wet weather (storm) flows in the drainage during the spill. Some of the values presented in this section, such as the measured amount of water pumped out of the beaver ponds, are known with a high level of confidence and are precise, while others, such as the calculated quantity of "natural" flow in the drainage, are rough projections that are not precise.

5.1 Initial Conceptual Model for Timespan of July 3 – November 8, 2014

WWE initially prepared a water balance model and fate assessment for the watershed where the spill occurred that is based on the data provided earlier in this report, related to (for example) geology, soils, vegetation, climatology, and hydrogeology. Figure 5-1 summarizes hydrologic inflow and outflow values for the conceptual water balance model for the study area. As shown in Figure 5.1, the initial model focuses on water volumes rather than chloride concentrations.

The following inflows are included, as described on Figure 5-1:

- Spill water
- Flushing water (clean water)
- Streamflow (clean water)
- Storage (clean water in beaver ponds)

Outflows in the conceptual water balance model, as also described in Figure 5-1, include:

- Pumped water (mixture of spill and clean water)
- Evaporation (clean water)
- Evapotranspiration (clean water)
- Infiltration and storage in unconsolidated materials (channel alluvium and colluvium) and in bedrock. (mixture of spill and clean water)
- Discharge to Lake Sakakawea (mixture of spill and clean water)

The time span evaluated for these inflows and outflows is July 3, 2014 (when the spill occurred) through November 8, 2014 (when Crestwood stopped pumping water out of the lower beaver pond), a period of 129 days. Figure 5-1 shows that inflows/outflows during this time were approximately 7 MG.

Sections 5.1.1 and 5.1.2 provide brief explanations of how the quantities for the various inflows and outflows shown in Figure 5-1 were determined.

Figure 5-1 – Conceptual Water Balance for Unnamed Drainage – July 3 to November 8, 2014

Water Balance Components

Storage - Volume of all beaver ponds totaling approximately 0.4 million gallons (MG). Ponds were assumed to be full throughout the entire time period. Consequently, ponds are neither an inflow or outflow, but they did serve to dilute concentrations of contaminants in the produced water as it flowed down the drainage channel.

Spill Water- The spill of roughly 1.1 MG of produced water that occurred from July 3, 2014 to July 7, 2014. The water was discharged from a brine gathering pipeline and impacted about 6 acres and 5,700 linear feet of the drainage channel.

Flush Water - Roughly 1 MG of clean flush water was discharged into the drainage channel as part of Crestwood's immediate remediation effort. The water source was local groundwater.

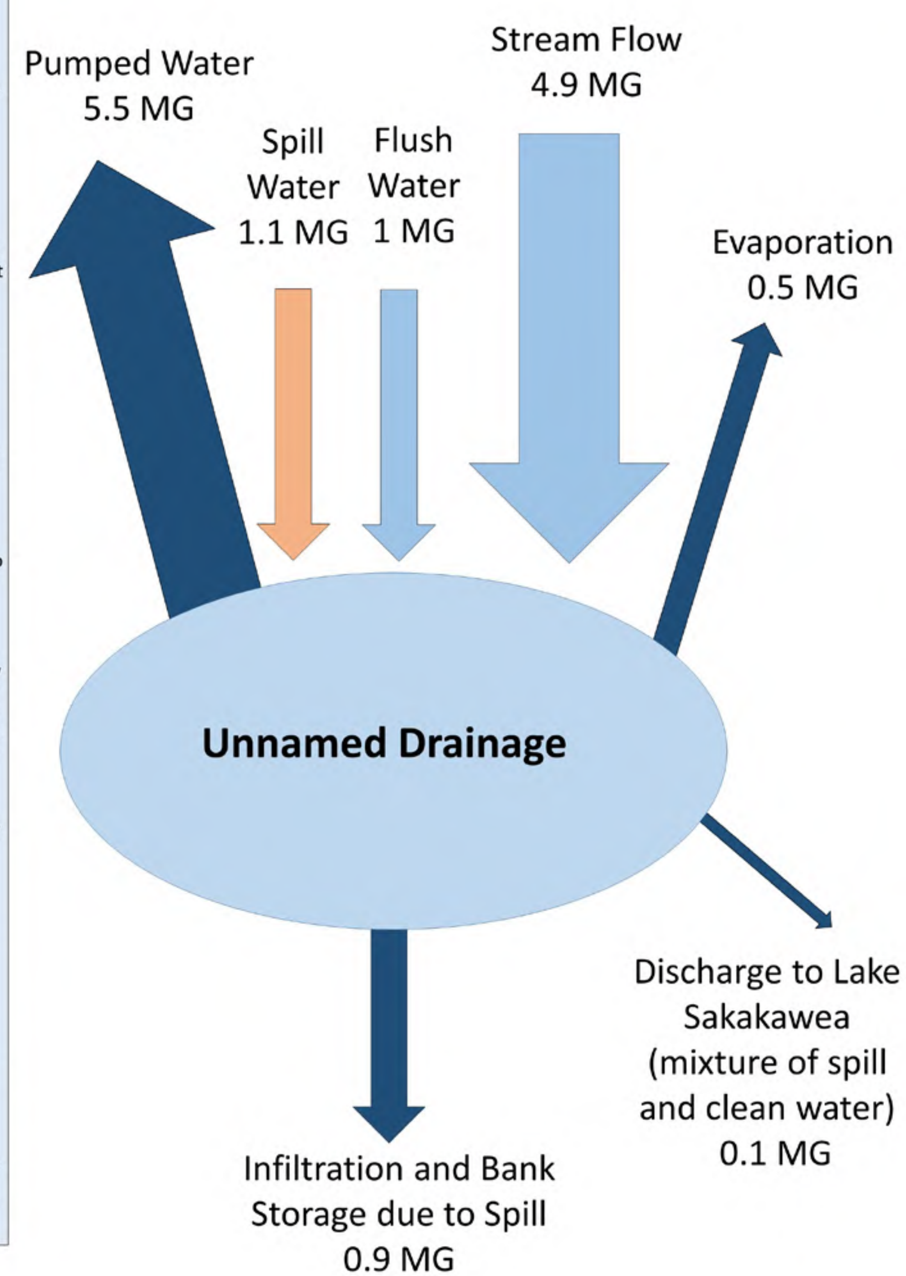
Pumped Water- Water was pumped from the lower beaver pond from July 11 to November 8, 2014. This beaver pond was drained (and pumped) 52 times. The water was pumped up a pipeline to tanks for disposal offsite. The total volume pumped was 5.4 MG. There was additional pumping along road of 0.1 MG that brought the pumped total to 5.5 MG.

Streamflow- Runoff from the 750 acre drainage area (upstream from lower beaver pond) of the unnamed channel was calculated from July 3 to November 8, 2014. The precipitation record in the region and the soil classifications for the watershed were used to calculate runoff through the unnamed channel, utilizing the NRCS TR-55 procedure. Roughly 4.9 MG of runoff occurred during this time.

Infiltration and Bank Storage due to Spill- Some flow on the surface infiltrated into the soil and was stored in unconsolidated deposits (alluvium and colluvium) or consolidated deposits (bedrock). Some other flow was stored in the channel banks. About 0.9 MG infiltrated or was held as bank storage from July 3 to November 8, 2014.

Evaporation/ Evapotranspiration- Evaporation was calculated by delineating the surface area of the beaver ponds and applying the regional evaporation rate, which resulted in 0.5 MG. Evapotranspiration was assumed to be negligible because vegetation was killed or severely impacted shortly after uptake of the high chloride concentration spill water.

Discharge to Lake Sakakawea- The remainder of the water balance was attributed to discharge into Bear Den Bay in Lake Sakakawea. The water discharged was a mixture of spill and clean water.



Conceptual Water Balance Projections

(MG= million gallons)

Inflows		Outflows	
Spill Water	1.1 MG	Pumped Water	5.5 MG
Flush Water	1.0 MG	Evaporation	0.5 MG
Streamflow	4.9 MG	Infiltration and Bank Storage due to Spill	0.9 MG
		Discharge to Lake Sakakawea (mixture of spill and clean water)	0.1 MG
TOTAL INFLOW	**7.0 MG**	**TOTAL OUTFLOW**	**7.0 MG**

A refined and calibrated version of this model is discussed in Section 5.2 and on Figure 5-2

5.1.1 Explanation of Inflow Quantities

5.1.1.1 Spill Water

The spill volume of 1.1 MG of produced water (also referred to as "brine" in the Keitu reports)—with elevated concentrations of total dissolved solids (particularly chloride)—was provided to WWE by Crestwood and Keitu. It is WWE's understanding that the basis for 1.1 MG is evaluation of the disparity between various recorded brine storage tank levels and fluid volumes injected into disposal wells. The spill occurred starting on about July 3 and was discovered late in the day on the 7. The pipeline was no longer carrying fluids on July 8.

5.1.1.2 Flush Water

The volume of flushing water of 1 MG was also provided to WWE by Crestwood and Keitu. It is WWE's understanding that the basis for this quantity is the number of tanker trucks and their volumes mobilized to the site for this purpose. Flushing occurred from July 11 to July 16, 2014. The flush water was discharged on the steep slope immediately adjacent to the road, at the Top of the Ravine location shown on Map 2.

5.1.1.3 Streamflow

The calculated value of 4.9 MG of streamflow in the 750-acre watershed from July 3 through November 8, 2014 was determined by WWE via a simplified hydrologic study of the watershed (see Section 4.0 for review of basic hydrologic characteristics of study area). WWE determined the watershed size by delineating the drainage area on U.S Geological Survey (USGS) topographic mapping. Watershed soils were determined by reviewing the Natural Resources Conservation Service (NRCS) web soil survey (websoilsurvey.sc.egoc.usda.gov) in McKenzie County, North Dakota (using NRCS nomenclature). This review indicated that the percentage of hydrologic soil groups in the watershed can be approximated as follows:

- Hydrologic Soil Group A: None
- Hydrologic Soil Group B: 20%
- Hydrologic Soil Group C: 60%
- Hydrologic Soil Group D: 20%

The composite NRCS runoff curve number (CN) value that applies to this watershed—soils of this type with "fair" ground cover—is 84.

As discussed in Section 4.1, WWE obtained daily precipitation data for the relevant time span from a National Weather Service station located near Keene, North Dakota, approximately 6 miles to the southwest. This is the closest certified weather station. WWE also looked for other weather stations in the general vicinity of the spill location on such websites as CoCoRaHS and Weather Underground. This search indicated that there are no closer weather stations to the spill site. Observations from people who were in the study area over the holiday weekend indicate that there was some precipitation, but no actual precipitation or runoff data are available. Given the reports of precipitation, there may have been some storm flow when the spill occurred.

After assembling this basic information, it was then feasible to calculate the approximate runoff volume for July 3 through November 8, 2014 via the widely utilized NRCS procedure "Urban Hydrology for Small Watersheds: TR-55." The model described in TR-55 begins with a rainfall amount uniformly imposed on the watershed for a specified time distribution. Mass rainfall is converted to mass runoff by using a CN. The CN is based on soils, plant cover, amount of impervious area (where applicable), interception, and surface storage. TR-55 yields a runoff volume for the time period of 4.9 MG. TR-55 is a simple procedure that provides reasonable conceptual-level projections for runoff volumes.

To check the TR-55 calculations for reasonableness, WWE obtained streamflow data for Bear Den Creek at Mandaree, North Dakota. This watershed is 74 square miles in size, versus about 1.25 square miles in size where the spill occurred; consequently, an area adjustment factor should be used (the larger the watershed, the lower the unit rate of runoff under normal conditions). The area adjustment factor is discussed in standard engineering references that address hydrology, such as *Introduction to Hydrology* (Viessman, Knapp, Lewis, and Harbaugh, 1977). WWE also relied on our experiences with calculating flows/yields in ungaged watersheds that are similar to this setting, with semi-arid conditions and about 14 inches per year of precipitation. The unit rate of runoff from Bear Den Creek from July 3 to November 8 was about 9 gallons per acre per day, versus about 52 gallons per acre per day for the unnamed tributary where the spill occurred, calculated per the TR-55 method. This area adjustment factor of about 6 is reasonable, given the difference in drainage area sizes. A smaller runoff volume would result in a smaller release to the Bay.

5.1.2 Explanation of Outflow Quantities

5.1.2.1 Pumped water

Crestwood set up a pump station that was operational on July 11, 2014 to pump water out of Dam 1 into a pipeline to temporary storage tanks and then to tanker trucks for offsite disposal. Pumping records (via number of tanker trucks) were maintained. These records indicate that a total of 5.4 MG were pumped out of Dam 1 (from the lowermost beaver pond) from July 11 through November 8, 2014. This volume includes any water that was pumped from the constructed basin a short distance downstream from the terminal beaver pond (a second pumping system had been set up to capture any water that bypassed the lower beaver pond to minimize the volume of release to Lake Sakakawea). In addition to the 5.4 MG of pumping, shortly after the spill was discovered, a pool of produced water was observed adjacent to the road; upstream of the Top of Ravine this water was pumped out and totaled roughly 0.1 MG. Thus, the total amount pumped, as shown on Figure 5-1, is 5.5 MG.

5.1.2.2 Pond Evaporation and Plant Evapotranspiration

The combined surface area of the major beaver ponds is approximately 0.8 acres. During the relevant time span, approximately 2 feet of evaporation would have occurred, resulting in an evaporation loss of approximately 0.5 MG. With regard to losses due to evapotranspiration, WWE made the simplifying assumption that during the relevant time span, any vegetation in the flow path from Coulee Start upstream to the spill location was either killed or damaged such that there was no (0) outflow from the study area due to evapotranspiration. This assumption is conservative, since this mechanism normally would remove water from the system and result in less produced water discharged downstream to Lake Sakakawea. See Section 4.0 for additional information on channel geometry.

5.1.2.3 Infiltration Followed by Storage in Unconsolidated Deposits and Bedrock and Channel Bank Storage

To calculate the quantity of water stored in soils, alluvium, colluvium, and the underlying bedrock, WWE assumed that infiltration into soils occurred in association with the following flow types in the noted reaches (see Map 2 for details):

- Overland flow from the spill locations to Coulee Start over 2,250 feet.
- Channelized flow with infiltration to the channel bottom and bank storage from Coulee Start to the Beaver Dam 1 and then from Dam 1 to Lake Sakakawea, a total distance of about 2,650 feet.
- Within the beaver ponds (2,500 feet length) there was some seepage out of the pond bottoms although the seepage was more than offset by natural flows in the watershed (including evaporation losses).

Regarding the start of the flow path, from the spill to Coulee Start, Map 2 shows the approximate surface areas available for infiltration in the flow path are as follows:

- Area A – 50,000 square feet
- Area B – 15,000 square feet
- Area C – 65,000 square feet
- Area E – 20,000 square feet

When these areas are combined, the total surface area of soils subject to infiltration is about 145,000 square feet, or roughly 3.3 acres. Based on background information provided to WWE, including soil chemistry data, WWE determined that the spill water would have infiltrated to an average depth of 5 feet (deeper in some areas and shallower in others). This translates into a total soil volume subject to infiltration of the spill water of 725,000 cubic feet. WWE assumed that 15% of the soil volume would be available to store the spilled produced water (the typical void space of silty to clayey loam is 30-40%, so this is conservative) for a total of 108,750 cubic feet of water storage capacity or about 0.8 MG of infiltrated spill water.

An important aspect of both the spill and fresh water flushing is that they occurred episodically in a pulse-like manner, over extended timespans (4-5 days in the case of the spill, for an average daily flow of 0.22 MG (over 5 days), and 6 days in the case of the flushing, for an average daily flow of 0.17 MG). This gradual introduction of water into the system (in contrast to entire volumes of the spill and flush water being compressed into, for example, a few hours) promoted infiltration. This can be likened to the most effective way to water a flower pot—pour some water into the pot, let the soil "recover" for a few minutes, then water it some more, repeating the process as needed.

WWE determined that 0.1 MG of additional spill water would infiltrate into the defined channel and beaver ponds downstream between Coulee Start and Lake Sakakawea. For the initial model, we did not account for infiltration in the beaver ponds (although this was accounted for in the refined model described in Section 5.2) and we calculated losses from the approximately 3,000 feet of channel length to be about 0.1 MG, with about 1/3 as bank storage and 2/3 are channel bottom storage. When combined with the 0.8 MG of infiltration in the overland flow reach this gave a total infiltration loss in the initial model of 0.9 MG.

WWE next determined how much of this 0.9 MG of water stored within the soil would remain in the soil versus infiltrate into bedrock. WWE assumed a bedrock vertical primary hydraulic conductivity of 1×10^{-6} cm/sec (about 0.003 feet per day for the limiting claystone bedrock) in the 129-day time span, meaning that the water would have migrated approximately 0.4 feet into the bedrock. Assuming a bedrock contact area of 145,000 ft^2, this translates into approximately 0.06 MG of water stored in the bedrock, leaving 0.84 MG in unconsolidated materials adjoining the flow path area. Even if the bedrock contact areas were doubled or tripled, the resulting values for bedrock storage of 0.12 and 0.18 MG are small.

As a reasonableness check, WWE evaluated whether it would be feasible to infiltrate 0.8 MG into areas A, B, C, and E shown on Map 2. Infiltration would have occurred over the 4-5 day spill period. The amount of daily infiltration required would be about 0.2 feet (about 3 inches), which would be met. In other words, there was enough surface infiltration capacity to introduce 0.8 MG into the unconsolidated and consolidated deposits, in the zone of overland flow (upstream of Coulee Start) over the 4-5 day spill period.

5.1.2.4 Release to Lake Sakakawea

The amount of the release to Lake Sakakawea over the 129-day period is a derived value; namely, knowing all inflows and outflows, this value was derived by subtracting the sum of outflows from the sum of inflows, yielding a value of 0.1 MG in the initial conceptual model. The water discharged was a mixture of spill and clean water with no means for assessing the relative proportion of each.

5.1.3 Assessment of Inflow versus Outflow Quantities in Initial Conceptual Model

Figure 5-1 demonstrates that inflows to the watershed from July 3 through November 8, 2014 totaled about 7 MG, while outflows also totaled about 7 MG—thus, at a conceptual level, there is a water balance for the watershed. It should be emphasized that this analysis is conceptual in nature, and all inflow and outflow values are approximations. Given the conceptual nature of this model, WWE decided to refine and calibrate the water balance described above with measured chloride concentrations from water samples obtained on July 9, 2014 and an assessment of diluted spill water that reached Lake Sakakawea. This revised model using chloride concentration data is discussed in Section 5.2.

5.2 Refined Conceptual Model Using Calibration Data

After completing the initial model (graphically represented in Figure 5-1), WWE looked to available chloride concentration data to refine and calibrate the second model. Calibration points were chosen from the Dam 1 and Creek to Bay locations, namely chloride concentration of 25,000 mg/L and 20,000 mg/L, respectively. In addition, WWE wanted to use a value for the diluted spill fluid that entered the bay as another calibration point. To establish a value for this third calibration point, WWE reviewed a procedure that Keitu developed on behalf of Crestwood. A discussion of this review and modifications are discussed in Section 5.2.1. Incorporation of all calibration points into the refined model is discussed in Section 5.2.2.

5.2.1 Keitu Assessment of Spill Fluid Release and WWE Refinement

Relative to the Keitu procedure, the following text was prepared by Crestwood and Keitu in a one page document titled "ND Phase 1a Gathering System Brine Spill July 2014 Released Volume to Surface Water Estimate" to summarize the nature of this investigation:

> ***Summary***
>
> *A November 2014 letter from the US EPA requested a volume estimate of oil production brine released to the nearest surface water, i.e. unnamed tributary into Bear Den Bay during the July 2014 Phase 1a Gathering System release. Keitu Engineers & Consultants, Inc. was engaged by Crestwood Midstream Partners LP to assist in preparing its response.*
>
> *Crestwood reported a 24,000 barrel release from their Phase 1a brine gathering system to regulatory authorities from a pipe leak on 8 July 2014. Total impacted area was approximately 6.1 acres spread over 7600 linear distance and an elevation drop of 380 feet. Approximately 5500 barrels (230,000 gallons) of "9-lb brine" reached the unnamed tributary stream via an adjacent ravine.*
>
> ***Methodology***
>
> *The estimate is based on the amount of brine necessary to give the chloride levels observed immediately after the spill was discovered. Stream boundaries and elevations had been shot by registered land surveyors brought to the site. Water volume was estimated using seven equal-distant basin elevations along the width of water way was averaged into 6 cubes at each of 45 points along the stream and/or bay. The volume of each segment was totaled to provide the final water volume.*
>
> *Water samples were taken at fourteen (14) separate locations and tested for multiple parameters including chlorides during the initial response. Analytical results at each point along the stream or bay were assigned to their respective location. Chloride concentrations for segments without analytical data were approximated from known concentrations from adjacent points. Two separate approaches were used. The first method used linear distance from each known value i.e. linear extrapolation. The second approach incorporated length, width, and depths i.e. volumetric weighted average. The volumetric method estimated the total chloride levels 6.1% higher than the prior method and was used for the final estimate. A sample of the brine from the Phase 1a gathering system was obtained shortly after system restart, as was used as the basis for the chloride content in the released brine. While measurable levels of chloride were observed in the springs and stream flows in the watershed, no correction for background chloride levels were made.*

Based on the methodology described above, Keitu estimated that 9 barrels (bbl) of diluted brine had actually entered Bear Den Bay. WWE has reviewed the methodology of Keitu and found it to be useful in many respects. The underlying concept of estimating how much of the spill was actually discharged into the Bay based on the amount of brine (produced water) necessary to give the chloride levels observed shortly after the spill discovery is reasonable and helpful. However, WWE has made the following refinements to Keitu's methodology (all stations and other locations below are shown on Map 2):

1. The volume of water between station S11 and the Creek to Bay location should be included. This translates into an additional 38 bbl of produced water in the bay.

2. The volume of water between the Creek to Bay location and the S12 sampling site should also be included. This results in a total of 143 bbl of additional produced water released to the bay. The 143 bbl value was determined by using calculus for the relevant volume of water, which has the shape of a triangular prism.

3. A chloride concentration of 24 mg/L was associated with sample point S16. Background chloride concentrations in the bay are about 7 mg/L. Consequently, WWE assumed that there would be an additional amount of spilled water in a water volume between S16 and a location 800 feet farther out into the bay, where the concentration would be back to 7 mg/L. This translates into an additional 60 bbl of produced water.

In addition to the 3 factors described above, it should be recognized that the Keitu methodology was based on chloride samples collected on July 9, or 6 days *after* the spill began. Spill concentrations may have been higher earlier in the event. Consequently, WWE developed an approach to potentially increase the concentrations. We did this by analyzing data from the Creek to Bay location. Specifically, on July 9, the chloride concentration at this location was 19,600 mg/L, while on July 13, the concentration had dropped to 12,600 mg/L. This represents a rate of decline of 1,750 mg/L per day. WWE "reversed" this quantity and assumed that it could be applied to *increase* concentrations from samples on July 9 to be representative of July 3 conditions. Specifically, for a starting concentration (on July 9) of 19,600 mg/L at the Creek to Bay station, if this concentration is increased by 1,750 mg/L for 6 days, the calculated July 3 concentration is 30,100 mg/L. The ratio of 30,100/19,600 mg/L is about 1.5. Consequently, WWE used this procedure to determine that the diluted spill volume estimated for sampling conditions on July 9 could be increased by 50% to account for higher concentrations.

In summary, Keitu estimated that 9 bbl of the spill was discharged to the Bay. However, when the 3 additional factors described above are included to refine Keitu's analysis, the quantity of produced water discharged to the bay should be increased, as follows:

Keitu starting # bbl	=	9
# bbl from S11 to Creek to Bay	=	38
# bbl from Creek to Bay to S12	=	143
# bbl from S16 to background in Bay	=	60
Total # bbl, based on data from July 9, 2014	=	250

If the multiplier of 1.5 is applied to the 250 bbl, to account for potentially higher concentrations earlier in the event, 250 bbl increases to 375 bbl (rounded to 400 bbl). In other words, this analysis provides a range of from 250 to 400 bbl. It is important to recognize that the upper end of this range (400 bbl) potentially overestimates the number of bbl, for 3 reasons:

1. WWE's methodology already accounts for an 800 foot-long volume of water in the bay where the chloride concentration is assumed to transition from 24 mg/L to 7 mg/L (resulting in a 60 bbl addition).
2. Travel velocities for the chloride discharge into the bay were calculated (in an idealized manner, utilizing "plug flow" conditions) and found to be very small. As an example, at sample point S16, the velocity was calculated to be 0.2 feet per day. While velocity calculations assume "plug flow," the spill water would probably have been well mixed with ambient Lake Sakakawea water at Station S16.
3. The spill duration was from July 3 to July 7, so there was only about a 2-day gap from the tail end of the spill to the July 9 sample date (as opposite to about 6 to 7 days from July 3 to July 9).

5.2.2 Calibrated Conceptual Model

Armed with the analysis described in Section 5.2.1 and chloride concentration data from July 9, 2014 at Dam 1 and Creek to Bay, WWE recognized that it would be feasible to refine our initial water balance model described in Section 5.1. In the refined analysis, WWE accounted for both water volumetric and chloride mass balances. WWE calibrated utilizing the facts that: 1) the beaver ponds had a measured chloride concentration on July 9 of 25,000 mg/L; 2) the Creek to Bay location had a July 9 concentration of about 20,000 mg/L; and 3) the number of barrels of diluted spilled fluid that entered the bay was as much as roughly 400 bbl. In other words, WWE attempted, with our refined model, to reassess the reasonableness of the inflow and outflow values of the initial conceptual model. Key adjustments made to the original conceptual model include:

- Switch to a focus on the contaminants (i.e., chloride) within the spilled fluids using available early chloride concentration data.

- Switch from the 129-day period (July 3 to November 8, 2014) to evaluating the time period from July 3 through July 9 (7-day model) because it represents the period of the spill through the early chloride concentration data. Shortly, afterward, flushing and pumping began which complicate the analysis.

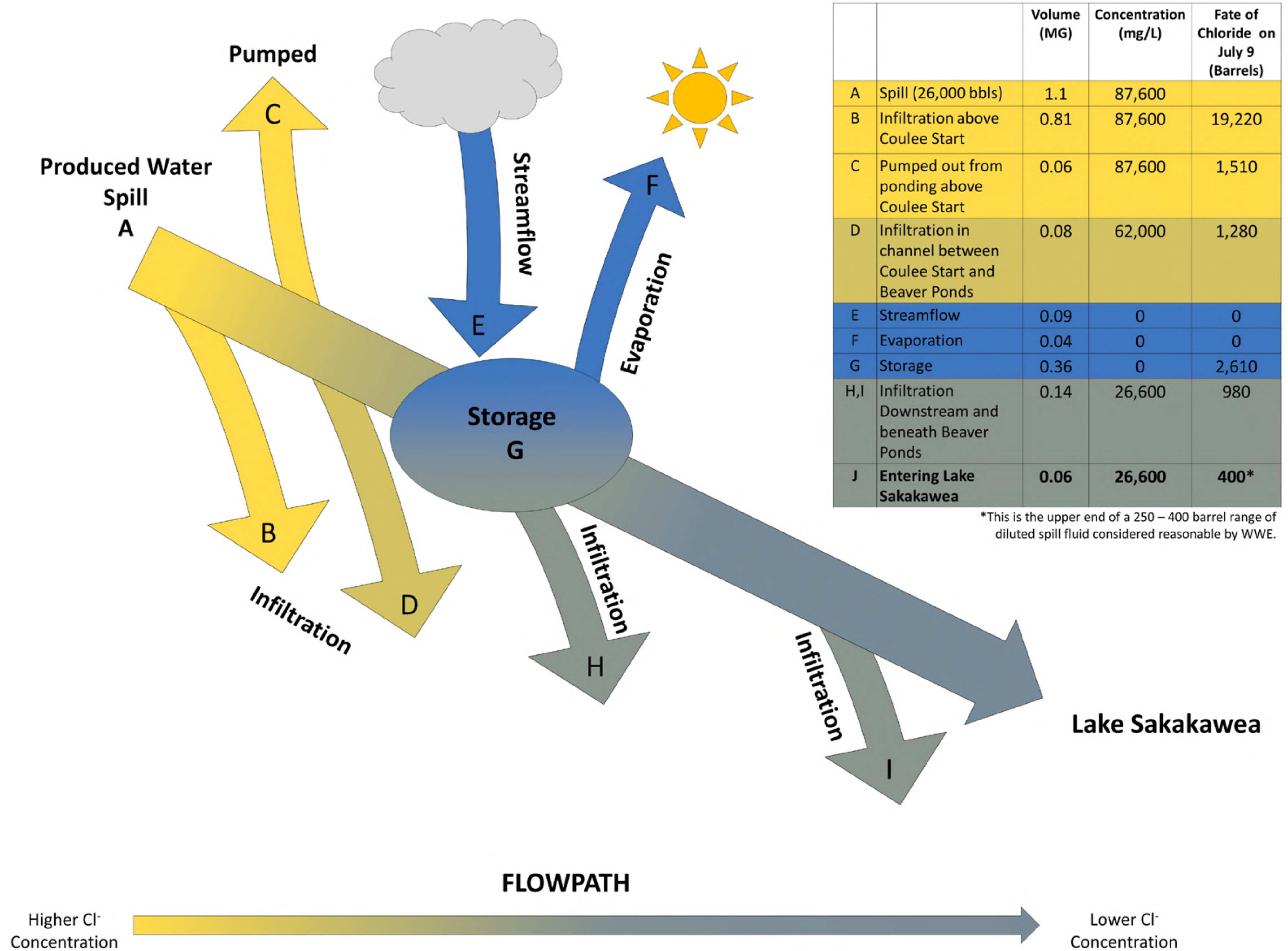
- Because pumping at Dam 1 did not begin until July 11, the only pumping of produced water was associated with the removal of about 65,000 gallons from a small ponded area adjacent to the road, shortly after the spill was discovered.

- Losses from Coulee Start downstream to Lake Sakakawea assume channel infiltration rates of 0.3 inches/hour and a pond infiltration rate of 0.1 inches/hour (the reason that the beaver ponds did not dry up despite the assumption of a 0.1 inch per hour loss rate through the pond bottoms is that there was a constant year-round inflow assumed of 10 gpm based on field observations by WWE and Crestwood staff).

The model that resulted from this effort is depicted graphically in Figure 5-2. This refined and calibrated version of the initial model is thought to provide a more accurate representation of the fate of the produced water than the initial model described in Section 5.1. However, both models are acceptable at a conceptual level, depending on the approach and assumptions, particularly for an analysis that is qualitative to semi-quantitative in nature.

This refined model indicates that as of July 9, 2014 (the end date of the updated model evaluation period and before pumping started) a very large percentage of the spilled fluids had infiltrated into the unconsolidated materials beneath the flow path with approximately 95 percent retained between the spill location and Dam 1. In addition about 3.5 percent infiltrated from the beaver ponds and the stream channel downstream of Dam 1. This left approximately 1.5 percent, or as much as roughly 400 bbl, of spill fluid that flowed in diluted amounts to Lake Sakakawea. Note that the 400 bbl of diluted spill fluid represents the upper end of a 250-400 bbl range considered reasonable by WWE (see Section 5.2.1).

Figure 5-2 – Refined Conceptual Model Using Calibration Data – July 3 to July 9, 2014



		Volume (MG)	Concentration (mg/L)	Fate of Chloride on July 9 (Barrels)
A	Spill (26,000 bbls)	1.1	87,600	
B	Infiltration above Coulee Start	0.81	87,600	19,220
C	Pumped out from ponding above Coulee Start	0.06	87,600	1,510
D	Infiltration in channel between Coulee Start and Beaver Ponds	0.08	62,000	1,280
E	Streamflow	0.09	0	0
F	Evaporation	0.04	0	0
G	Storage	0.36	0	2,610
H,I	Infiltration Downstream and beneath Beaver Ponds	0.14	26,600	980
J	**Entering Lake Sakakawea**	**0.06**	**26,600**	**400***

*This is the upper end of a 250 – 400 barrel range of diluted spill fluid considered reasonable by WWE.

6.0 CONCLUSIONS

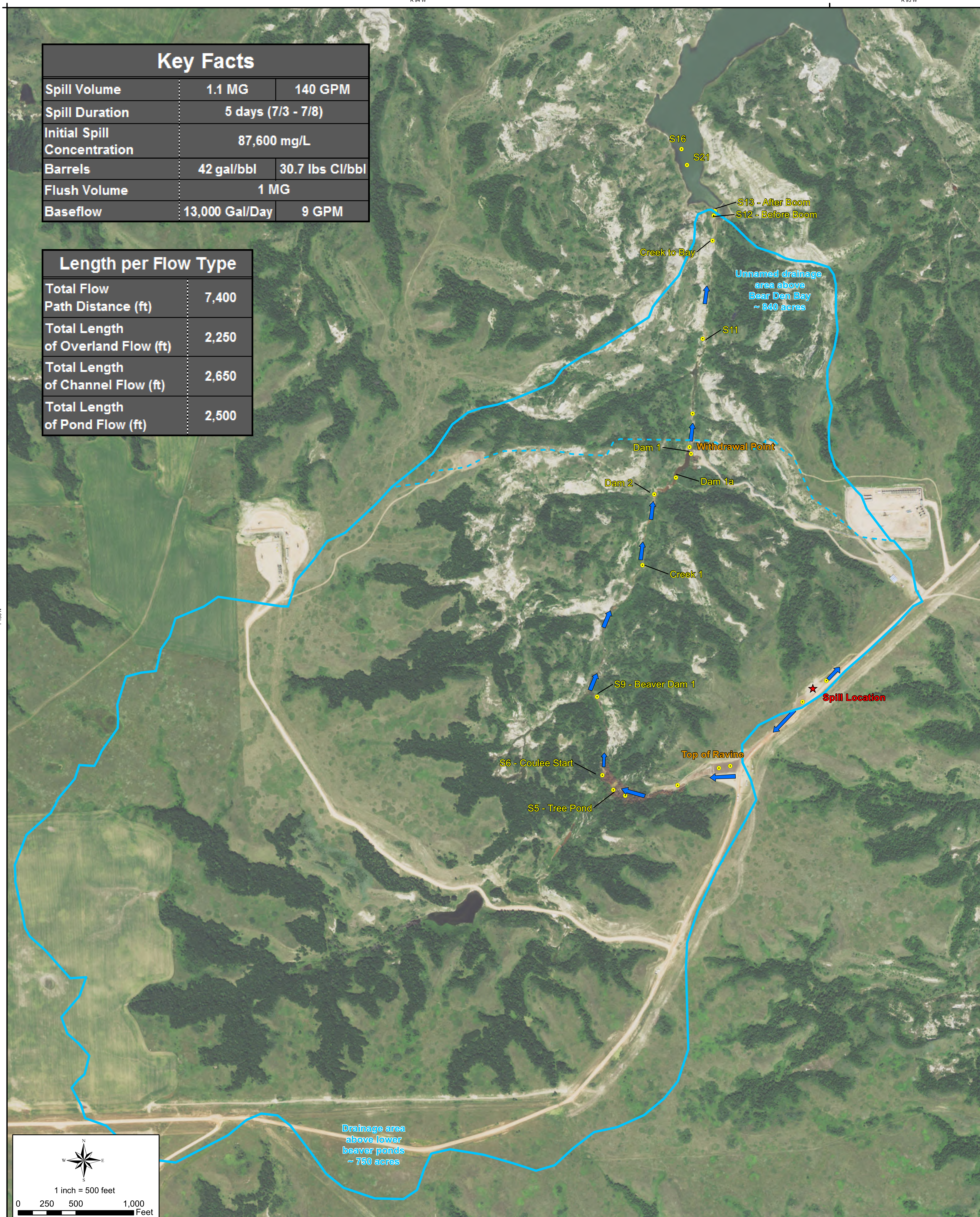
Based on the information and data presented in the report, WWE has reached the following conclusions regarding the fate of the produced water during the Crestwood pipeline spill (July 3, 2014 to July 7, 2014):

- Two conceptual models were developed to assess the fate of fluids released from the pipeline spill as discussed in Section 5.0. While the first focused on the balance of only the water within the system (Section 5.1), the second is a refinement of the first using chloride concentration for calibration (Sections 5.2). While the second model is a refinement of the first, both provide a result suggesting that a small percentage of the diluted spilled fluid reached Lake Sakakawea.
- Both conceptual water models are qualitative to semi-qualitative in nature and provide a means to address issues associated with likely distribution of the spilled fluids from the July 2014 event and can be used as a basis for developing appropriate next steps to complete restoration activities.
- Each of the conceptual models demonstrate that a large percentage of the spilled fluids infiltrated into the unconsolidated materials beneath the flow path.
- Due to limitations in available site-specific data, much of the information needed for development of the conceptual models in this report is not exact and should be considered within a reasonable range. For example, the refined model described in Section 5.2 cites an estimated flow of as much as 400 bbl of diluted spill fluid to Lake Sakakawea prior to the installation of a pumping system from Dam 1 based on the most refined model. It is likely that this flow to the lake falls in the range of 250 to 400 bbl, based on the available data and approaches.
- It is expected that the spilled fluids infiltrated or flushed below the vegetative root zone will have limited mobility unless driven by additional water from heavy precipitation and/or snowmelt and where elevation change will allow lateral flow to the surface. It is expected that some of the infiltrated spilled fluids along the flow path between the Top of Ravine and Coulee Start will migrate toward the unnamed drainage and attenuate and be

diluted by interaction with natural flows. Continued cycles of rainfall and snowmelt runoff will provide the mechanism to attenuate/dilute these fluids over time.

- Vertical movement of spilled fluids will be limited by the fined-grained bedrock units within the Sentinel Butte Formation thus forcing lateral movement if sufficient hydrologic influences exist. At present, it is unknown at what depth the bedrock exists along the flow path. While some limited movement of these fluids into the Sentinel Butte Formation is possible, this formation is considered to be of limited use for groundwater supplies in the spill area based on lack of water well permit records. No spilled fluids are expected to reach the deeper regional aquifer within the Tongue River Formation.
- Chloride concentrations obtained from sample locations below Dam 1 in 2015 show a decline to levels below the 250 mg/L Class II stream standard in North Dakota. Of note is that a 250 mg/L chloride concentration is also the groundwater cleanup standard cited by the North Dakota Department of Health in their Guidelines for the Assessment and Cleanup of Saltwater Releases and the secondary (non-health risk) drinking water standard from the U.S. Environmental Protection Agency. A 230 mg/L chloride concentration (4-day average once every three years) is cited as an aquatic life standard by the U.S. Environmental Protection Agency in their Ambient Water Quality Criteria for chloride.
- Although there are limited laboratory data for metals in the spill, it is probable that large percentages of metals were removed from the system due to the high infiltration and high cation exchange capacity of the soils.
- Assumptions in this report are consistent with field observations from those on the ground at the time of the spill and during the initial response.

MAPS



Key Facts

Spill Volume	1.1 MG	140 GPM
Spill Duration	5 days (7/3 - 7/8)	
Initial Spill Concentration	87,600 mg/L	
Barrels	42 gal/bbl	30.7 lbs Cl/bbl
Flush Volume	1 MG	
Baseflow	13,000 Gal/Day	9 GPM

Length per Flow Type

Total Flow Path Distance (ft)	7,400
Total Length of Overland Flow (ft)	2,250
Total Length of Channel Flow (ft)	2,650
Total Length of Pond Flow (ft)	2,500

Path: Z:\Project Files\15\151-066\151-066.000\CAD-GIS\GIS\MXD\Map1.mxd

Statewide North Dakota Aerial Imagery

WWE
WRIGHT WATER ENGINEERS, INC.
2490 W 26TH AVE 100A
DENVER, CO. 80211
(303) 480-1700

DRAINAGE AREA AND FLOW PATH

CRESTWOOD SPILL ASSESSMENT

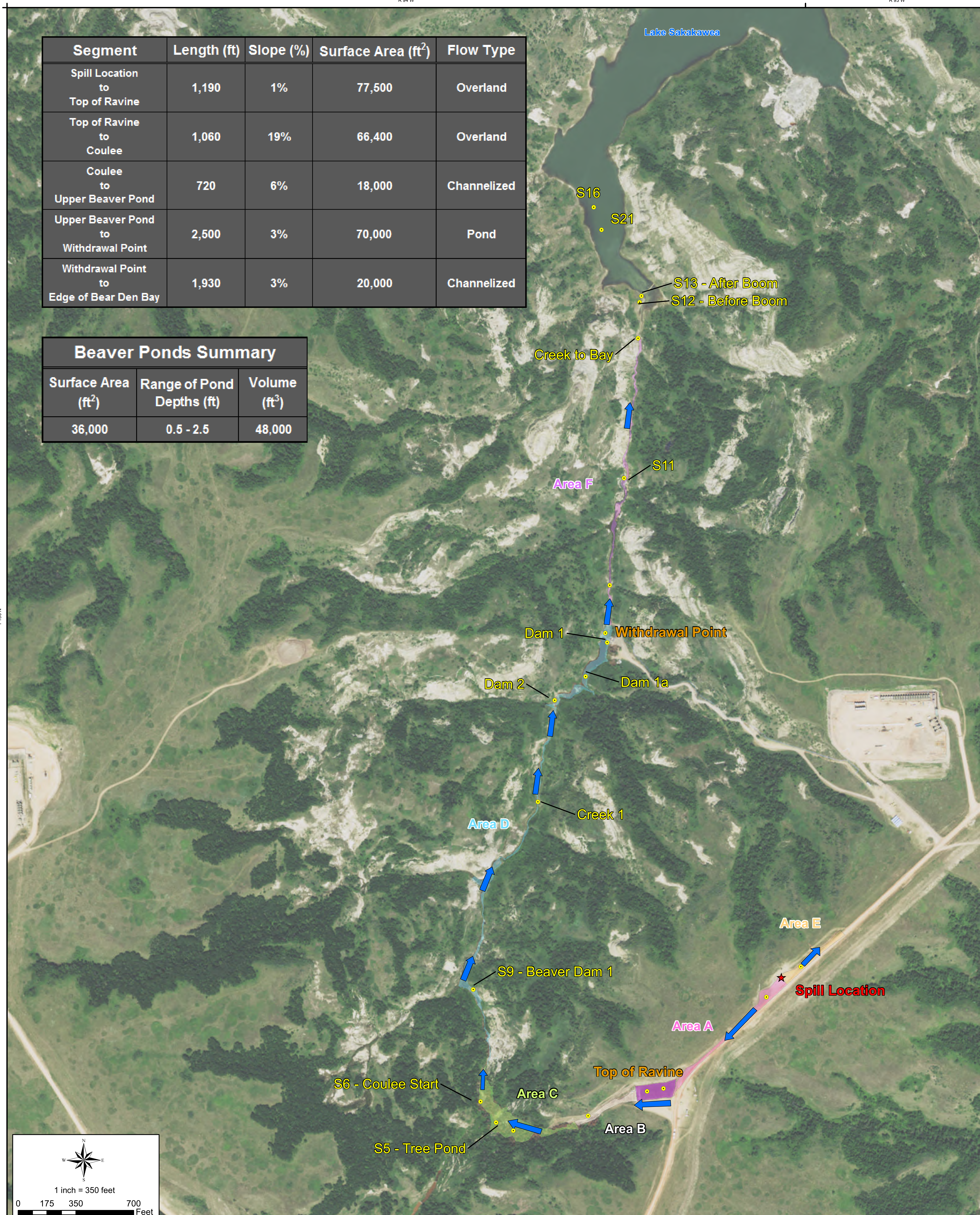
PROJECT NO. 151-066.000

Map 1

Segment	Length (ft)	Slope (%)	Surface Area (ft^2)	Flow Type
Spill Location to Top of Ravine	1,190	1%	77,500	Overland
Top of Ravine to Coulee	1,060	19%	66,400	Overland
Coulee to Upper Beaver Pond	720	6%	18,000	Channelized
Upper Beaver Pond to Withdrawal Point	2,500	3%	70,000	Pond
Withdrawal Point to Edge of Bear Den Bay	1,930	3%	20,000	Channelized

Beaver Ponds Summary

Surface Area (ft^2)	Range of Pond Depths (ft)	Volume (ft^3)
36,000	0.5 - 2.5	48,000



Path: Z:\Project Files\15\151-066\151-066.000\CAD-GIS\GIS\MXD\Map2.mxd

Statewide North Dakota Aerial Imagery

WWE
WRIGHT WATER ENGINEERS, INC.
2490 W 26TH AVE 100A
DENVER, CO. 80211
(303) 480-1700

FLOW PATH AND SAMPLE LOCATIONS

CRESTWOOD SPILL ASSESSMENT

PROJECT NO. 151-066.000

Map 2

ATTACHMENT A

August 2015 Photographs Taken along Flow Path

View across spill area north and west of Turnuey Ridge Road
—*looking southwest*.

Area adjacent to Turnuey Ridge Road where spilled fluids pooled before dropping into ravine —*looking northwest*.

Start of steep drop from road into ravine near area 58—*looking north*.

View from Trees (S4) toward Toe of Slope (S3) and Turnuey Ridge Road—*looking northeast*.

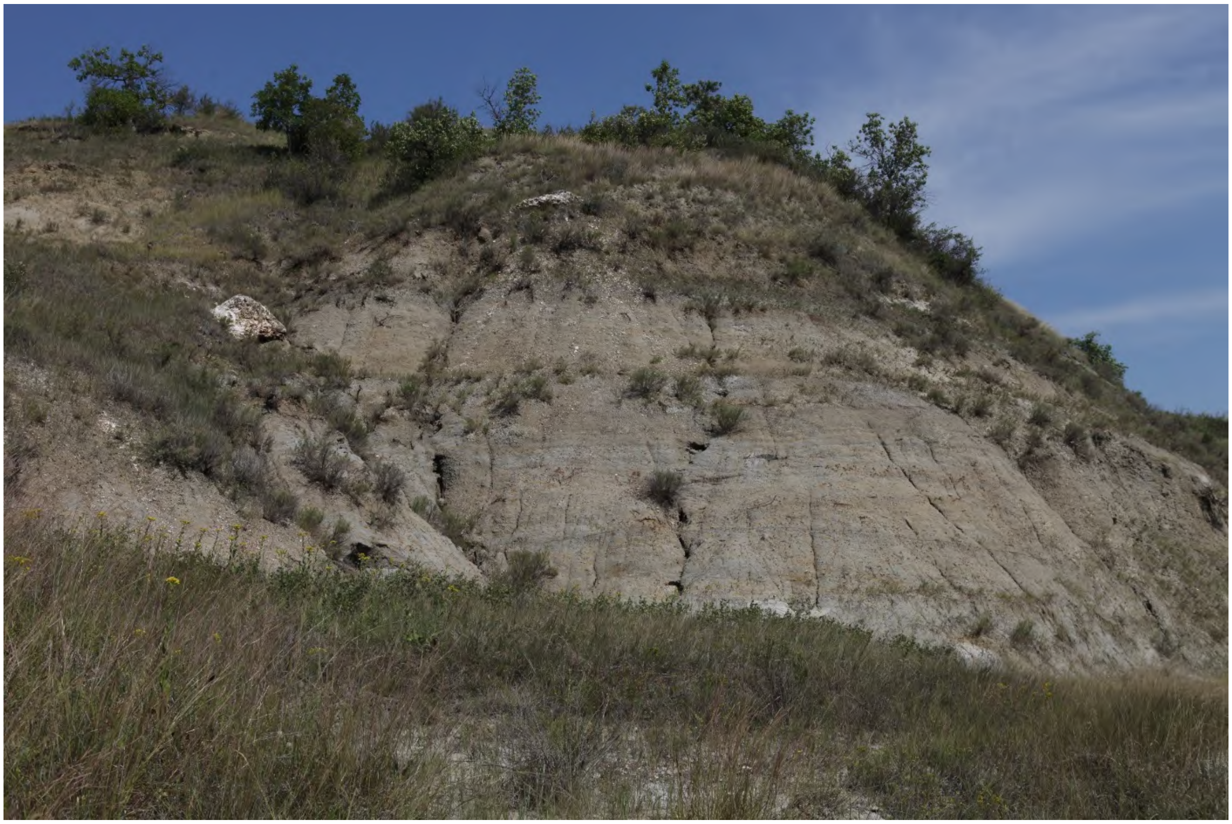
Representative landslide feature on the east side of unnamed drainage near Coulee Start (S6) —*looking north/northeast*.

Example groundwater discharge location below landslide uninfluenced by spill—*looking northwest.*

View downstream across Beaver Dam 1 (S9)
—looking northwest.

View of a sediment-filled beaver pond from across Beaver Dam 1 (S9)—*looking east.*

Unnamed drainage channel downstream of Beaver Dam 1 (29)—*looking east/northeast.*



Typical geologic outcrop showing rounded “Badland” topography of easily erodible fine-grained strata *—looking northwest.*

Stream channel above abandoned beaver dam *—looking upstream.*

Abandoned beaver dam and pond near Dam 1a
—*looking southwest.*

View of common sag pond that collects precipitation
and seepage from west side, above drainage bottom
—*looking north.*

Unnamed drainage at its confluence with Bear Ben Bay (S13)—*looking northeast.*

Unnamed channel upstream of Bear Den Bay near
Creek to Bay sample location—*looking south.*

ATTACHMENT B

McKenzie County Geology Map

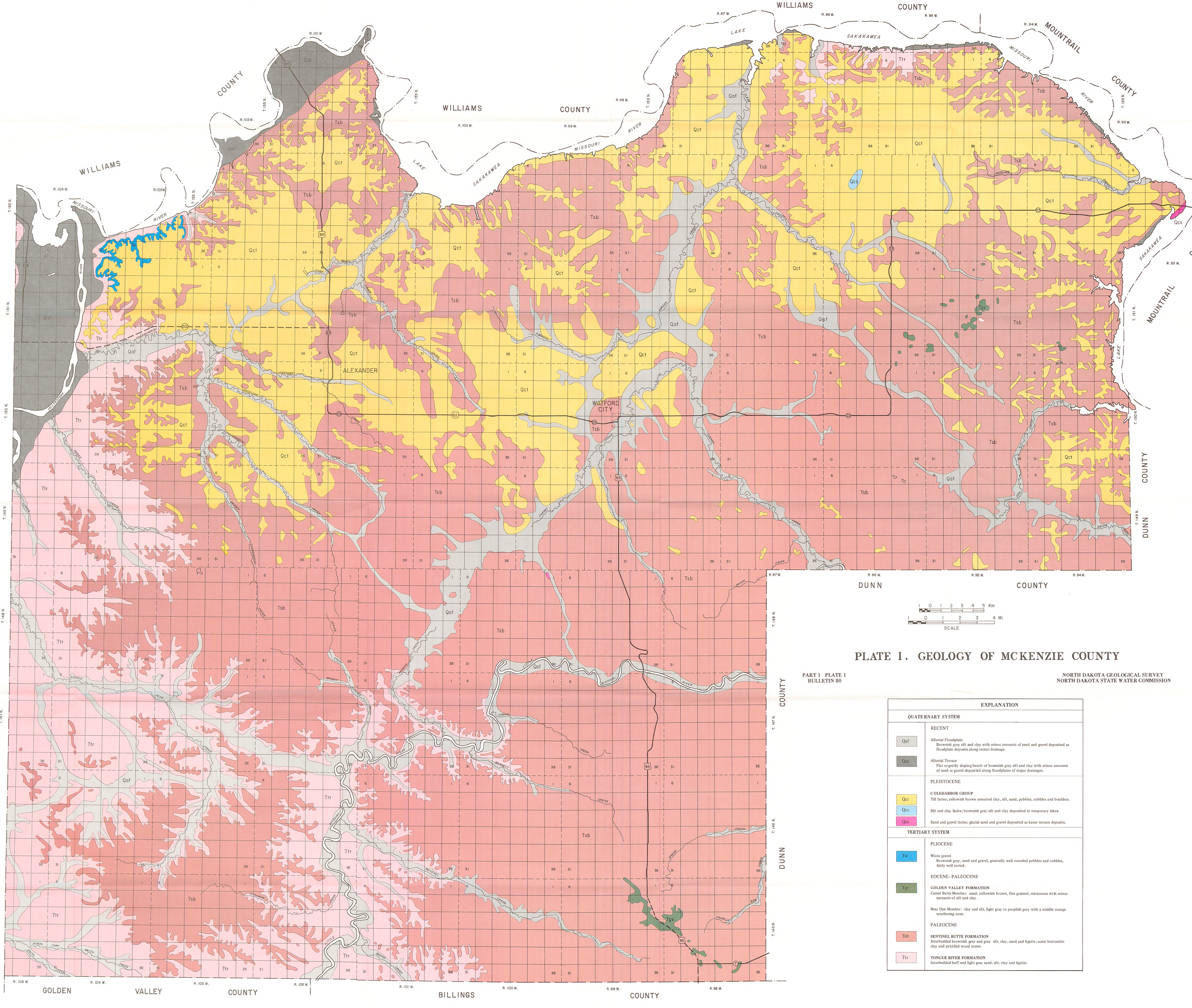


PLATE 1. GEOLOGY OF MCKENZIE COUNTY

PART 1 PLATE 1
BULLETIN 80

NORTH DAKOTA GEOLOGICAL SURVEY
NORTH DAKOTA STATE WATER COMMISSION

EXPLANATION

QUATERNARY SYSTEM

RECENT

Qaf	Alluvial Floodplain Brownish gray silt and clay with minor amounts of sand and gravel deposited as floodplain deposits along recent drainage.
Qat	Alluvial Terrace Flat or gently sloping bench of brownish gray silt and clay with minor amounts of sand or gravel deposited along floodplains of major drainages.

PLEISTOCENE

COLEHARBOR GROUP

Qct	Till facies; yellowish brown unsorted clay, silt, sand, pebbles, cobbles and boulders.
Qcc	Silt and clay facies; brownish gray silt and clay deposited in temporary lakes.
Qcs	Sand and gravel facies; glacial sand and gravel deposited as kame terrace deposits.

TERTIARY SYSTEM

PLIOCENE

Tw	Wiota gravel Brownish gray, sand and gravel, generally well rounded pebbles and cobbles, fairly well sorted.

EOCENE–PALEOCENE

Tgv	**GOLDEN VALLEY FORMATION** Camel Butte Member: sand, yellowish brown, fine grained, micaceous with minor amounts of silt and clay . Bear Den Member: clay and silt, light gray to purplish gray with a middle orange weathering zone.

PALEOCENE

Tsb	**SENTINEL BUTTE FORMATION** Interbedded brownish gray and gray silt, clay, sand and lignite; some bentonitic clay and petrified wood zones.
Ttr	**TONGUE RIVER FORMATION** Interbedded buff and light gray sand, silt, clay and lignite.

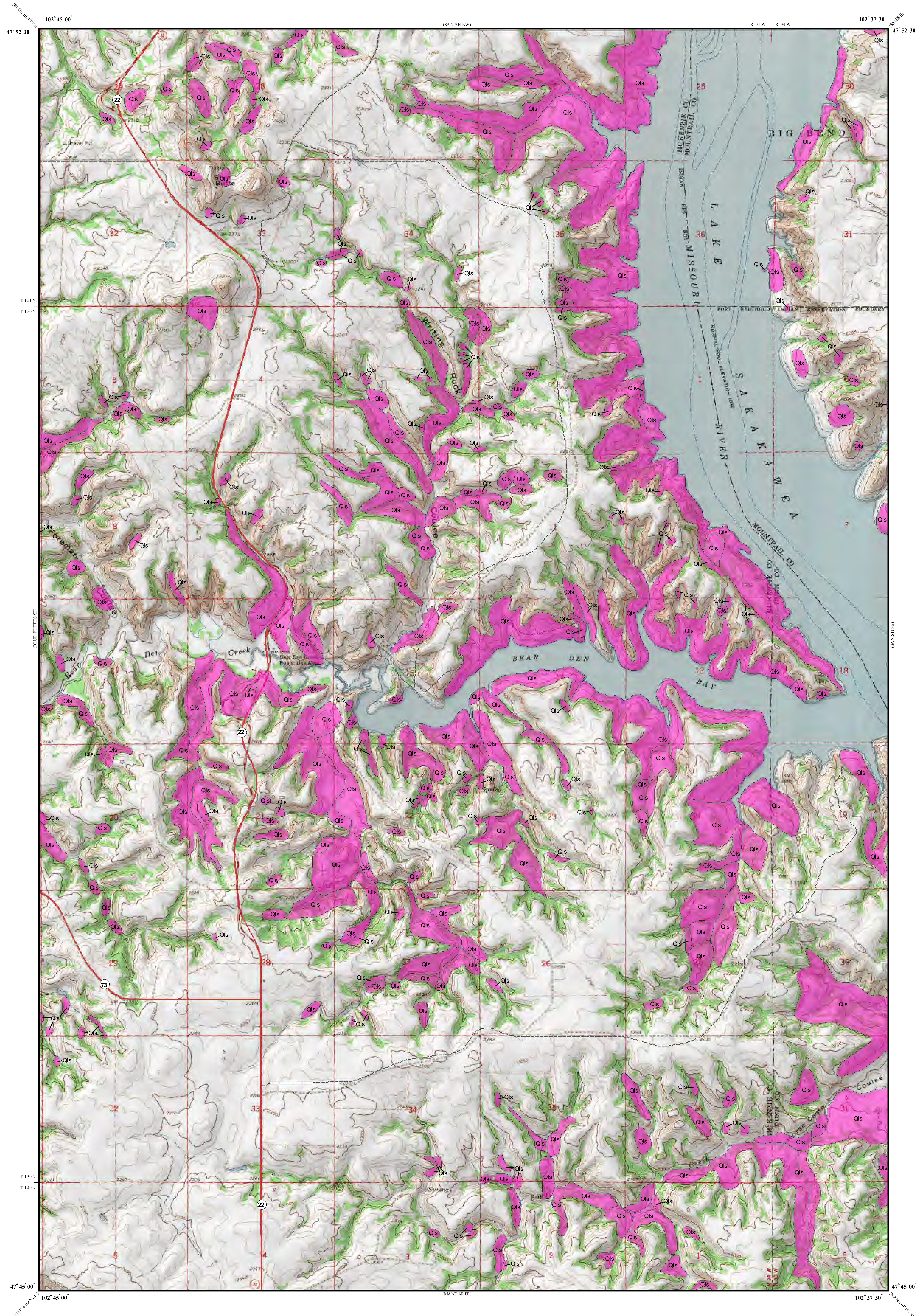
ATTACHMENT C

Areas of Landslides – Sanish SW Quadrangle

North Dakota Geological Survey
24K: Snsh SW - 1

Edward C. Murphy, State Geologist
Lynn D. Helms, Director Dept. of Mineral Resources

Areas of Landslides
Sanish SW Quadrangle, North Dakota



Edward C. Murphy

2010

UNIT DESCRIPTIONS

Geology Undifferentiated

QUATERNARY SYSTEM

RECENT/PLEISTOCENE

Qls **Landslide Deposits**

Variable mixture of strata and deposits that have slid to the base of steep slopes. Most of the landslides in this area are hundreds, if not thousands, of years old.

Geologic Symbols

Known contact between two geologic units.

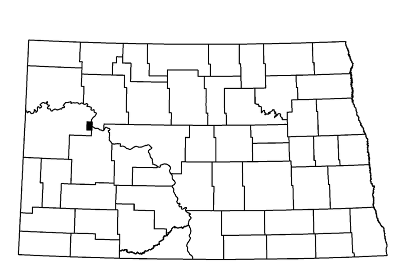
Other Features

22 State Highway

Unpaved Road

Trail

Landslides identified on this quadrangle were mapped from stereo pairs, black and white 1:20,000 scale aerial photographs flown between 6-6-58 and 9-7-58. As a result these maps can be used to identify areas that are vulnerable to slope failure, but are not an up to date assessment of all landslides for the area.



Sanish SW Quadrangle, North Dakota

Scale 1:24,000

0 0.5 1

Miles

Lambert Conformal Conic Projection Standard Parallels 47° 45' 00" and 47° 52' 30"
1927 North American Datum NGVD 1929
USGS 7.5 Minute Topographic Map Contour Interval 20 Feet
Road Layer Rectified to 2003 NAIP Digital Orthophoto

14°
MN
1967 Magnetic North
Declination at Center of Sheet

Cartographic Compilation: E. L. Kadrmas & S.S. Kranich

DENVER
2490 W. 26th Avenue Suite 100A
Denver, Colorado 80211
Phone: 303.480.1700
Fax: 303.480.1020

GLENWOOD SPRINGS
818 Colorado Avenue
P.O.Box 219
Glenwood Springs, Colorado 81602
Phone: 970.945.7755
Fax: 970.945.9210

DURANGO
1666 N. Main Avenue Suite C
Durango, Colorado 81301
Phone: 970.259.7411
Fax: 970.259.8758

www.wrightwater.com

Wright Water Engineers, Inc.