#### 4.1.4.2.3 DCP Test Results

DCP testing began on November 16, 2011, and was completed on December 2, 2011. Thiele Geotech performed the DCP tests with a 10.1 pound hammer recording blow counts for every 2 in. of cone penetration, or as close to each 2-in. penetration interval as possible. The data and related calculated bearing capacity in psf and pounds per square inch (psi) is presented in Attachment 6A.

The DCP test is useful in identifying zones that are soft or loose (with low blow counts) relative to the surrounding fill, as stated in ASTM D6951/D6951M, Note 1. For the purpose of this discussion, any zone that drove with the weight of the hammer without a drop of the hammer or 4 in. or more per one blow with the 8 kilogram (17.6 pound) hammer is considered a very loose zone that has been affected by the Triggering Mechanism. These zones will be referred to as negatively affected soils (NAS) for the remainder of this discussion. Zones of soil within which the DCP tip drove less than 4 in. in one blow are referred to as unaffected soil. Previous density tests of fill in the vicinity of the Turbine Building during construction range from 87 to 105 percent compaction and N values of in situ soil under the Turbine Building from preconstruction borings yielded SPT N values of no lower than 2 blows per ft and commonly 4 to 11 blows per ft in the upper soil zone. There were no cases of weight of rod material (rod sinking under its own weight) in original borings. As noted previously, there is no direct correlation of DCP to SPT tests, but it is HDR's engineering opinion that material that allows a tip to drive through soil under weight of rods, weight of rods and hammer, or greater than 4 in. per one hammer blow provides evidence of extremely soft material that does not reflect conditions at the time of construction. These NAS zones do not include the void space between the floor slab and the top of subgrade because the DCP tests began at the top of subgrade.

A number of NAS zones were identified using the DCP. All of the 26 DCP tests from Phase I testing showed some NAS zones within the zone of tested soil. All of the 26 DCP holes had what is described as NAS at the upper portion of the subgrade. These zones at the top of the subgrade ranged in thickness from 0.1 to 4.6 ft (drill-hole location 2-8). In addition, drill-hole location 1-6 exhibited a zone of NAS of 7.1 ft. Twenty-two NAS zones were identified that exist at some depth within the subgrade at 12 of the drill-hole locations. These NAS zones range in thickness from 0.2 to 4.9 ft. The most notable NAS zones in this category are in drill-hole location 2-6 (4.9 ft) and drill-hole location 1-6 (3.0 ft). The deepest NAS zone is a 0.6-ft zone in drill-hole location 2-13 that occurs between 12.9 and 13.5 ft below the Turbine Building basement floor (el. 977.1 to 976.5 ft).

Seventeen of the drill-hole locations have NAS zones that occur below the bottom elevation of the pile caps, as shown in the DCP testing logs presented in Attachment 6A. These NAS zones range in thickness from 0.2 to 4.6 ft. The most significant of these zones were encountered in drill-hole locations 2-8 (4.6 ft), 2-6 (4.9 ft), and 1-6 (3.0 ft). A summary of the NAS encountered during the DCP investigation is presented in Attachment 6A.

The forensic investigation for KDI #1 continued in 2012. The description of the scope and results of that activity as well as conclusions and recommendations resulting from that work is described in Section 8.0.

## 4.2 KDI #2 – Pavement Failure and Surficial Void in Paved Access Area Between Intake Structure and Service Building

KDI #2 is the failure of paving and development of a surficial void below the roadway paving a few feet west of the Condensate Storage Tank. This roadway is part of a U-shaped area of paved surface that wraps around the northeast, east, and southeast perimeter of the contiguous Power Block buildings (Paved Access Area). The inside of the U-shaped Paved Access Area is defined as the north exterior face of the Maintenance Shop on the north, the east exterior face of the Maintenance Shop and the Service Building on the east, and the south exterior faces of the Turbine Building and Service Building on the south. The outside of the U shape is the south exterior face of the New Warehouse on the north, the Underground Cable Trench (Trenwa) along the Missouri River on the east, and the north exterior face of the Security Building and the Trenwa from the Security Building west to the end of the pavement on the south, which is generally aligned with the southeast corner of the Turbine Building South Switchyard.

The Paved Access Area overlies a number of structures (buried utilities) between the Service Building and the Intake Structure. The base below this area was excavated to el. 973 ft during construction. Current top-of-paved-surface elevation is approximately 1004.5 ft. Concrete pavement slabs at the surface are underlain by a crushed rock base. This pavement section overlies structural fill down to el. 973 ft with the exception of the area overlying the Circulating Water System, where fill is placed above the structure, which has a top elevation of 997 ft.

### 4.2.1 Physical Observations

A number of physical observations made during the facility assessments have been grouped under KDI #2:

- Softened subgrade
- Pavement joint offsets
- Void(s) under pavement
- Water hydrant failure
- Water seepage at [redacted] Manhole MH-5, Intake Structure, and Security Building

### 4.2.2 Triggering Mechanisms

Seven possible Triggering Mechanisms that might be the root cause of this KDI are as follows:

- Subsurface Erosion/Piping (due to pumping)
- Subsurface Erosion/Piping (due to river drawdown)
- Rapid Drawdown
- Soil Collapse (first time wetting)
- Frost Effects
- Hydrostatic Lateral Loading
- Buoyancy, Uplift Forces on Structures

#### 4.2.2.1 Subsurface Erosion/Piping (Due to Pumping)

Multiple connected seepage paths have the potential to exist in the soil backfill at the site. The paths could be exposed at some locations to the river floodwater (for example, a surficial void north of the Security Building). This potential network of seepage paths could be connected to several pumping sources: the sump in the Turbine Building, Manhole MH-5, and a series of surface pumps inside the perimeter of the Aqua Dam.[1] The dewatering pumps inside the Aqua Dam were operated for an extended period, maintaining a head differential on any potential seepage path networks. The gradient may have been sufficient to begin erosion of subsurface soil.

Unfiltered seepage into the Turbine Building sump provided the potential for subsurface erosion/piping and would continue until that seepage is completely stopped. The subsurface erosion/piping caused by the Turbine Building sump pumping could theoretically have extended under the Paved Access Area. Voids could be created under the pavement and along the utility trench walls or pipes. The potential damage could include settlement of pipe or thrust blocks. Settlement can overstress a pipe, can cause a pipe to break, or can cause the displacement of a thrust block, which, in turn, could cause failure of a pipe operating under pressure.

#### 4.2.2.2 Subsurface Erosion/Piping (Due to River Drawdown)

The Triggering Mechanism of Subsurface Erosion/Piping is initiated by river drawdown. Instead of pumping causing a significant groundwater gradient, the groundwater gradient is created by a rapidly receding river level. The river level drops faster than pore water pressure in the soil can dissipate. The resulting gradient could be sufficient to begin erosion of the soil along the seepage path.

#### 4.2.2.3 Rapid Drawdown

The Triggering Mechanism of Rapid Drawdown could cause slope failure or lateral spreading when the river level drops faster than pore water pressure in the soil can dissipate. The saturated soil is elevated above the dropping river level. The open bank of the river provides no lateral support for the saturated soil, and the result is an impending slope failure. If the soil's shear strength is exceeded, the slope will fail along the path of least resistance. Generally slope failures associated with rapid drawdown are relatively localized and shallow in nature.

#### 4.2.2.4 Soil Collapse (First Time Wetting)

The Triggering Mechanism of Soil Collapse (first time wetting) occurs when loose soil (soils with high void ratios and corresponding low dry densities) is saturated for the first time. Saturation of the soils lubricates the soil particles and increases the pore pressure in the soil, loosening the bond between the soil particles. This allows the soil particles to shift into a more compact alignment as the pore water pressure dissipates. The result is a decrease in the soil's

[1] An Aqua Dam is an engineered water barrier used to contain, divert, and control the flow of water. It consists of two polyethylene liners contained by a single woven geo-tech outer tube. When the two inner tubes are filled with water, the resulting pressure and mass create a stable, non-rolling wall of water (Layfield Environmental Systems, 2008).

void ratio and an increase in dry density. This change in volume is observed as settlement at the ground surface.

#### 4.2.2.5 Frost Effects

The Triggering Mechanism of Frost Effects occurs as soil freezes. Frost effects occur both as frost penetration and uplift, and as frost heave. Completely saturated soils allow frost to penetrate more deeply. Frost penetration and uplift occurs as the water contained in the soil void spaces freezes and expands. Frost heave occurs as ice lenses form and grow from capillary water movement. The change in volume as the water freezes, and as the ice loses form, causes heave at the ground surface.

#### 4.2.2.6 Hydrostatic Lateral Loading

The Triggering Mechanism of Hydrostatic Lateral Loading occurs when water levels rise, imposing additional lateral pressure on structures.

#### 4.2.2.7 Buoyancy, Uplift Forces on Structures

The Triggering Mechanism of Buoyancy, Uplift Forces on Structures occurs due to a rise in water or groundwater elevation. Uplift forces occur when the weight of the buried structures is less than the weight of the water or groundwater it displaces. Increased water or groundwater levels increase the buoyancy uplift force on the buried structure.

### 4.2.3 Structures and CPFMs Associated with Triggering Mechanisms

The Triggering Mechanisms outlined could apply to the following structures and CPFMs:

- Intake Structure
  - CPFM 12a – Rapid Drawdown. Riverbank slope failure and undermining surrounding structures.
  - CPFM 12b – Rapid Drawdown. Lateral spreading.
- Security Building
  - CPFM 3a – Subsurface Erosion/Piping. Undermining and settlement of shallow foundation/slab (due to pumping).
  - CPFM 3d – Subsurface Erosion/Piping. Undermining and settlement of shallow foundation/slab (due to river drawdown).
  - CPFM 12a and 12b – Rapid Drawdown. River bank slope failure/lateral spreading.
- Security BBREs
  - CPFM 3a – Subsurface Erosion/Piping. Undermining and settlement of shallow foundation/slab (due to pumping).
  - CPFM 3d – Subsurface Erosion/Piping. Undermining and settlement of shallow foundation/slab (due to river drawdown).
  - CPFM 12a and 12b – Rapid Drawdown. River bank slope failure/lateral spreading.
  - CPFM14a – Frost Effects.
- Turbine Building South Switchyard
  - CPFM 3a – Subsurface Erosion/Piping. Undermining and settlement of shallow foundation/slab (due to pumping).
  - CPFM 3b – Subsurface Erosion/Piping. Loss of lateral support for pile foundation (due to pumping).

- CPFM 3c – Subsurface Erosion/Piping. Undermined buried utilities (due to pumping).
- Condensate Storage Tank
  - CPFM 3c – Subsurface Erosion/Piping. Undermined buried utilities (due to pumping).
  - CPFM 3f – Subsurface Erosion/Piping. Undermined buried utilities (due to river drawdown).
  - CPFM 12a and 12b – Rapid Drawdown. River bank slope failure/lateral spreading.
- Underground Cable Trench (Trenwa)
  - CPFM 3a – Subsurface Erosion/Piping. Undermining and settlement of shallow foundation/slab (due to pumping).
  - CPFM 3c – Subsurface Erosion/Piping. Undermined buried utilities (due to pumping).
  - CPFM 3d – Subsurface Erosion/Piping. Undermining and settlement of shallow foundation/slab (due to river drawdown).
  - CPFM 3f – Subsurface Erosion/Piping. Undermined buried utilities (due to river drawdown).
  - CPFM 14a – Frost Effects.
- Circulating Water System
  - CPFM 3b – Subsurface Erosion/Piping. Loss of lateral support for pile foundation (due to pumping).
  - CPFM 12a and 12b – Rapid Drawdown. River bank slope failure/lateral spreading.
- Demineralized Water System
  - CPFM 3c – Subsurface Erosion/Piping. Undermined buried utilities (due to pumping).
  - CPFM 3f – Subsurface Erosion/Piping. Undermined buried utilities (due to river drawdown).
- Raw Water Piping
  - CPFM 3a – Subsurface Erosion/Piping. Undermining and settlement of shallow foundation/slab (due to pumping).
  - CPFM 3c – Subsurface Erosion/Piping. Undermined buried utilities (due to pumping).
  - CPFM 3d – Subsurface Erosion/Piping. Undermining and settlement of shallow foundation/slab (due to river drawdown).
  - CPFM 3f – Subsurface Erosion/Piping. Undermined buried utilities (due to river drawdown).
- Fire Protection System Piping
  - CPFM 3a – Subsurface Erosion/Piping. Undermining and settlement of shallow foundation/slab (due to pumping).
  - CPFM 3c – Subsurface Erosion/Piping. Undermined buried utilities (due to pumping).
  - CPFM 3d – Subsurface Erosion/Piping. Undermining and settlement of shallow foundation/slab (due to river drawdown).
  - CPFM 3f – Subsurface Erosion/Piping. Undermined buried utilities (due to river drawdown).
- Waste Disposal Piping
  - CPFM 3a – Subsurface Erosion/Piping. Undermining and settlement of shallow foundation/slab (due to pumping).
  - CPFM 3c – Subsurface Erosion/Piping. Undermined buried utilities (due to pumping).
  - CPFM 3d – Subsurface Erosion/Piping. Undermining and settlement of shallow foundation/slab (due to river drawdown).
  - PFM 3f – Subsurface Erosion/Piping. Undermined buried utilities (due to river drawdown).
  - CPFM 12a and 12b – Rapid Drawdown. River bank slope failure/lateral spreading.
- Fuel Oil Storage Tanks and Piping
  - CPFM 3a – Subsurface Erosion/Piping. Undermining and settlement of shallow foundation/slab (due to pumping).
  - CPFM 3b – Subsurface Erosion/Piping. Loss of lateral support for pile foundation (due to pumping).
  - CPFM 3c – Subsurface Erosion/Piping. Undermined buried utilities (due to pumping).

  - CPFM 3d – Subsurface Erosion/Piping. Undermining and settlement of shallow foundation/slab (due to river drawdown).
  - CPFM 3f – Subsurface Erosion/Piping. Undermined buried utilities (due to river drawdown).
  - CPFM 4c – Hydrostatic Lateral Loading (water loading on structures). Wall failure in flexure.
  - CPFM 4d – Hydrostatic Lateral Loading (water loading on structures). Wall failure in shear.
  - CPFM 4e – Hydrostatic Lateral Loading (water loading on structures). Excess deflection.
  - CPFM 6a – Buoyancy, Uplift Forces on Structures. Fail tension piles.
  - CPFM 6b – Buoyancy, Uplift Forces on Structures. Cracked slabs, loss of structural support.
  - CPFM 6c – Buoyancy, Uplift Forces on Structures. Displaced structure/broken connections.
  - CPFM 12a and 12b – Rapid Drawdown. River bank slope failure/lateral spreading.
- Main Underground Cable Bank, Auxiliary Building to Intake Structure
  - CPFM 3a – Subsurface Erosion/Piping. Undermining and settlement of shallow foundation/slab (due to pumping).
  - CPFM 3c – Subsurface Erosion/Piping. Undermined buried utilities (due to pumping).
  - CPFM 3d – Subsurface Erosion/Piping. Undermining and settlement of shallow foundation/slab (due to river drawdown).
  - CPFM 3f – Subsurface Erosion/Piping. Undermined buried utilities (due to river drawdown).
  - CPFM 4c – Hydrostatic Lateral Loading (water loading on structures). Wall failure in flexure.
  - CPFM 4d – Hydrostatic Lateral Loading (water loading on structures). Wall failure in shear.
  - CPFM 4e – Hydrostatic Lateral Loading (water loading on structures). Excess deflection.
  - CPFM 6b – Buoyancy, Uplift Forces on Structures. Cracked slabs, loss of structural support.
  - CPFM 6c – Buoyancy, Uplift Forces on Structures. Displaced structure/broken connections.
  - CPFM 12a and 12b – Rapid Drawdown. River bank slope failure/lateral spreading.
- Blair Water System
  - CPFM 3a – Subsurface Erosion/Piping. Undermining and settlement of shallow foundation/slab (due to pumping).
  - CPFM 3c – Subsurface Erosion/Piping. Undermined buried utilities (due to pumping).
- Camera Towers and High Mast Lighting
  - CPFM 3a – Subsurface Erosion/Piping. Undermining and settlement of shallow foundation/slab (due to pumping).
  - CPFM 3d – Subsurface Erosion/Piping. Undermining and settlement of shallow foundation/slab (due to river drawdown).
  - CPFM 12a and 12b – Rapid Drawdown. River bank slope failure/lateral spreading.
- Service Building (Priority 2 Structure)
  - CPFM 3a – Subsurface Erosion/Piping. Undermining and settlement of shallow foundation/slab (due to pumping).
- Maintenance Shop (Priority 2 Structure)
  - CPFM 3a – Subsurface Erosion/Piping. Undermining and settlement of shallow foundation/slab (due to pumping).

### 4.2.4 Assessment Methods and Procedures

Assessments were conducted by walking the Paved Access Area and observing surface features of the system (manholes) and the ground surface. The surface assessment included using a fiberglass T-probe to hand probe the adjacent ground surface along the utility alignments and areas to determine relative soil strength. The assessment focused on identifying conditions indicative of potential flood-related impacts on or damage to the utility as follows:

- Ground surface conditions overlying and immediately adjacent to the Paved Access Area

- Soft ground surface areas as determined by probing
- Water accumulations and flows in subsurface system components (manholes and concrete cable encasement pipes)
- Damage to at-grade or above-grade system features
- Variance from normal installation conditions, including settled, tilted, or heaved system features and equipment
- Operation of the system and appurtenant equipment (that is, is the system operational?)

Additional investigations were performed to further characterize the subsurface at the site, including areas where conditions indicative of potential flood-related impacts or damage were observed. These included the following non-invasive geophysical and invasive geotechnical investigations. Results of these tests are described in Attachment 6 of this Assessment Report.

- GPR
- Seismic surveys (seismic refraction and refraction micro-tremor)
- Geotechnical investigations including test borings with field tests (SPT and CPT) and laboratory tests. OPPD required hydro-excavation for the first 10 ft of proposed test holes to avoid utility conflicts; therefore, test reports will not show soil conditions in the upper 10 ft of test boring logs.
- Paved areas evaluated with GPR and dynamic deflection methods (that is, using an FWD).

### 4.2.5 KDI #2 Forensic Investigation

Forensic investigation to address KDI #2 consisted of field observation and testing of subsurface soils exposed through test holes, excavation of trenches, removal of concrete pavement at selected locations, test borings and field and laboratory tests, and evaluation of inclinometer and survey monitoring data. KDI #2 consists of a number of individual distress indicators observed within the Paved Access Area, including softened subgrade, pavement settlement, a void beneath the pavement in one location, water hydrant failure, and water seepage at [redacted] F2, Manhole MH-5, and the Intake Structure and Security Building.

Forensic investigation as described above was performed where observed pavement distress was most prominent, at locations coincident with shallow underground structures and utilities, and where recent seismic surveys identified low velocity features (locations where potential for degradation related to the Triggering Mechanisms and CPFMs associated with KDI #2 were identified). The areas investigated are illustrated in Figure 4-5.

After detailed assessment of the structures (see Sections 5.0 and 6.0) associated with KDI #2, there are two remaining possible Triggering Mechanisms. They include:

- Subsurface erosion and piping (due to pumping)
- Subsurface erosion and piping (due to rapid river drawdown)

These Triggering Mechanisms and related structures and CPFMs are discussed in detail in Sections 4.2.2 and 4.2.3. Conclusions related to these are discussed below in Section 4.2.5.3.

The purpose of this investigation was to determine the presence and extents of potential voids and soft zones in the subsurface as well as lateral or vertical movement in the subsurface and to evaluate which of the Triggering Mechanisms and associated CPFMs identified for KDI #2, if any, appear to be responsible for the observed distresses.