14. Conclusions

In CH2M HILL's opinion, failure of the Swift No. 2 Power Canal embankment began when post-basalt alluvial/colluvial deposits forming the bottom of the forebay area eroded (piped) into an existing lava tube located within the Cave Basalt at TT 1. The loss of material by piping formed a large sinkhole in the northern part of the forebay area. Development of this piping path provided a direct connection for the water between the canal and potential flow paths within and under the Cave Basalt. The following conclusions are presented based on CH2M HILL's observations, analyses, and investigations:

- At the area where the large sinkhole developed in the forebay, there was approximately 30 feet of soil between the opening into the lava tube and the bottom of the forebay. Given that the water was approximately 27 feet deep and the soil above the lava tube was approximately 30 feet thick, the water head above the lava tube opening was about 57 feet. The proximity of the lava tube to the water in the canal created high hydraulic gradients through the soil, which led to piping. In CH2M HILL's opinion, once a piping path developed a flow channel to the lava tube, the tube provided a flow channel that distributed the water to the east and west along the lava tube alignment.

- Field investigations have revealed a connected flow path from the lava tube at the forebay area sinkhole through openings within and under the Cave Basalt. The flow path had sufficient capacity to convey a large volume of water from the canal/forebay sinkhole to the amphitheater. Field smoke testing demonstrated a direct connection by showing that air flow from the sinkhole to the amphitheater, a distance of approximately 500 feet, was communicated through passageways within seconds of being pressurized. The volume of the cavities along the passageways was large, however, as demonstrated by a delay of 30 minutes for dense smoke to flow from the sinkhole to the amphitheater. Information from borings indicates that the height of the cavities is 2 feet or more in many areas. The cavities are inaccessible and unmapped; however, the evidence demonstrates that these passageways delivered large flows of water and exerted high pressure on the foundation on the downstream side of the embankment. CH2M HILL's opinion is that the water head was sufficient to cause uplift pressure that exceeded the weight of the soil and basalt near the toe of the embankment, resulting in hydraulic uplift and fracturing at the base of the basalt in areas downstream of the embankment. This action led to erosion of the pre-basalt Lewis River alluvial/colluvial soils below the Cave Basalt, resulting in loss of support, caving and settling, and eventual failure of the basalt foundation at the toe of the embankment near SR 503.

- The flow along the lava tube and through cavities caused an enlargement of the sinkhole in the forebay area. The erosion along the lava tube also caused other cracks to form along the flow path, and several other sinkholes started to develop along the north contact of the Cave Basalt with the pre-basalt Lewis River alluvium/colluvium. Erosion in these areas contributed to the sediment load and flow of water being carried under the Cave Basalt.

- Eyewitness accounts establish that water was initially discharging from the toe of the embankment in an area where the Cave Basalt is thin, fractured and jointed, scoriaceous, and of poor quality. It is also believed that this area was underlain by the easily

erodable, sandy pre-basalt Lewis River alluvial/colluvial sediments. Eyewitnesses reported that the canal embankment failed progressively during a period when the flow from under the basalt increased rapidly. Large rocks and blocks of soil fell into the eroded cavity as the failure enlarged, causing the erosion to extend laterally. Once the erosion reached the crest of the embankment, the remaining narrow crest and oversteepened downstream slope failed and allowed the water in the canal to be released through the failed section of the embankment. The tremendous erosive force of the water discharging over the damaged, unprotected face of the embankment led to rapid erosion and removal of the remaining earth fill from the embankment.