Geology Technical Report

for the

Halligan Water Supply Project Environmental Impact Statement

Prepared for

U.S. Army Corps of Engineers

Omaha District

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<td>AF</td>
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<tr>
<td>BLM</td>
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<td>CEQ</td>
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1 Introduction

A technical consulting team prepared this Geology technical report for the Halligan Water Supply Project (Halligan Project). The Halligan Project Environmental Impact Statement (EIS) will summarize the information in this report. This report presents descriptions of potential environmental effects to Geology associated with the City of Fort Collins' (Fort Collins) Proposed Action, three alternatives to Fort Collins' Proposed Action, and the No-Action Alternative.

1.1 Description of Alternatives

The U.S. Army Corps of Engineers (Corps) conducted a screening process to identify alternatives to Fort Collins' Proposed Action that met the future water demands for Fort Collins as stated in the "Purpose and Need Report" (WEST et al. 2015). "The Alternatives Screening Report" (DiNatale Water Consultants and CDM Smith 2015) presents the screening process and the three alternatives identified along with the No-Action Alternative. As part of the screening process, Fort Collins provided details regarding the construction, water conveyance, technical aspects and assumptions for the Fort Collins' Proposed Action, three alternatives, and the No-Action Alternative that are discussed in the "Final Alternatives Description Report" (MWH 2015). The hydrologic models utilized and the associated outputs are described in the "Hydrologic Modeling Technical Report" (CDM Smith and DiNatale Water Consultants 2015).

For this report, we present a brief overview of the Fort Collins' Proposed Action, three alternatives, and the No-Action Alternative for a general understanding.

All of the alternatives include water storage with the exception of the No-Action Alternative. Under Fort Collins' Proposed Action and each alternative, Fort Collins proposed to store the same existing water rights including converted Southside Ditch rights, reusable Water Supply and Storage Company rights, the conditional Grey Mountain right, and the conditional water right associated with the enlarged Halligan Reservoir with a priority date of December 10, 2013, if approved.

1.1.1 Fort Collins' Proposed Action

Fort Collins' Proposed Action is to enlarge the Halligan Reservoir, which is located on the North Fork Cache La Poudre River (North Fork) about 25 miles northwest of Fort Collins. Currently, the North Poudre Irrigation Company (NPIC) owns the entire water storage capacity of 6,400 acre-feet (AF) at the Halligan Reservoir. Fort Collins would increase the capacity by 8,125 AF for a total water storage capacity of 14,525 AF. The current maximum surface area of the Halligan Reservoir is 253 acres, while the maximum surface area of the enlarged reservoir would be approximately 386 acres. Fort Collins has applied for a conditional water right for the storage of water in the enlarged Halligan Reservoir with a priority date of December 10, 2013. To enlarge the existing reservoir, Fort Collins would raise the existing dam an estimated 25 feet.
In general, Fort Collins would enlarge the reservoir by expanding the foundation on the downstream face of the dam approximately 8 to 12 feet and make the dam thicker and taller while maintaining geometry similar to the existing dam. Preparation for the foundation would require rock excavation along the abutments and valley bottom outside of the existing footprint. During construction, the North Fork would bypass the construction activity via a temporary cofferdam and outlet pipes.

Fort Collins cannot directly divert water released from Halligan Reservoir into its existing intake facilities that convey water to the Fort Collins water treatment facility. Under its Proposed Action, Fort Collins would release water from Halligan Reservoir into the North Fork and allow that water to flow down the North Fork into and through the Seaman Reservoir until it reaches the Cache La Poudre River (Poudre River). Fort Collins would divert a similar amount of water at its intakes located on the Poudre River above the confluence with the North Fork. This process is referred to as an exchange and must be authorized by a court issued exchange decree. Fort Collins has two separate intakes on the main stem of the Poudre River: 1) the existing City of Fort Collins Pipeline via its diversion structure located at Gateway Park, and 2) the Pleasant Valley Pipeline via the existing Munroe Canal (a.k.a. North Poudre Supply Canal or Munroe Gravity Ditch) diversion structure.

Fort Collins would develop the following infrastructure and construction areas in association with this alternative (Figure 1-1): the raised Halligan dam, new outlet works, a cofferdam and temporary outlet pipes, a temporary bridge below the existing dam to access both sides of the North Fork during construction, staging areas, a batch plant, burrow pits, and access roads.
Figure 1-1. Fort Collins' Proposed Action.
1.1.2 Expanded Glade Alternative

The Expanded Glade Alternative would provide Fort Collins with 6,075 AF of water storage through the expansion of the proposed Glade Reservoir. The Expanded Glade Alternative is contingent on the Corps permitting the Glade Reservoir. Glade Reservoir is a 170,000 AF reservoir that is part of Northern Colorado Water Conservancy District’s (Northern Water) proposed action analyzed in the Northern Integrated Supply Project Supplemental Draft EIS (NISP SDEIS 2015). Under this alternative Fort Collins would operate its storage in the enlarged Glade Reservoir independently, enlarging and using several components of the proposed Glade Reservoir infrastructure to store and release water from the reservoir. Fort Collins would require some additional infrastructure. The expansion would require raising the dam approximately 4 feet higher than the NISP design. The maximum surface area of the expanded Glade Reservoir is expected to be approximately 1,693 acres, which is 57 acres more than the maximum surface area of the Glade Reservoir proposed by NISP.

Fort Collins would deliver water through the Poudre Valley Canal to the NISP proposed diversion point into Glade Reservoir. This diversion point and the Poudre Valley Canal would need to be enlarged to accommodate both NISP and Fort Collins water inflows simultaneously. Fort Collins would temporarily retain the diverted water in the Glade Forebay and then pump it into the reservoir. Fort Collins would release water through the Glade Dam infrastructure and either route the water to the Poudre River for use in an exchange or send it directly into Fort Collins existing raw water supply lines. Fort Collins would construct a new pipeline that would connect the Glade Reservoir outlet pipeline to Fort Collins' existing pipelines and the Pleasant Valley Pipeline. Fort Collins could release water into Fort Collins' new pipeline and then into the Poudre River at a river turnout in exchange for water diverted by Fort Collins upstream of the confluence with the North Fork. Alternatively, Fort Collins could direct water to a new pretreatment facility co-located with the Glade Pump Station at the foot of the dam and then convey the water through its new pipeline to its existing raw water supply lines.

Fort Collins would develop the following infrastructure in association with this alternative (Figure 1-2): the raised Glade dam, increased depth to the NISP proposed forebay, larger or additional pumps located at the NISP pump station, a pretreatment facility, a pipeline from the pretreatment facility to the raw water supply lines, and a river turnout on the new pipeline.
Figure 1-2. Expanded Glade Alternative.
1.1.3 Gravel Pits Alternative

The Gravel Pits and Joe Wright Reservoir Reoperation Alternative (hereafter Gravel Pits Alternative) would involve using a complex of gravel pits on the north side of the Poudre River near Taft Hill Road for water storage. The eight interconnected cells at the gravel pit complex would provide approximately 3,875 AF of combined water storage. After the gravel pits are completed, Fort Collins would excavate additional storage within the area of the permitted gravel pit, if needed, to achieve the desired water storage. Two of the existing pits outside the floodplain would likely require above-grade storage achieved by the construction of 20-foot tall berms around the perimeter of the pit. Twenty-foot-high berms are classified as jurisdictional dams under the Colorado Division of Safety of Dam criteria (Colorado Division of Water Resources 2016) and would require specific design standards provided by the Colorado State Engineer. The final design would require the approval of the Colorado State Engineer prior to construction.

Generally, Fort Collins would convey water from the Poudre River to the gravel pits and then release the water from the gravel pits back to the Poudre River for exchange or into the existing Fort Collins raw water pipelines. To move water to the gravel pits, Fort Collins would divert water from the Larimer County No. 2 Canal diversion structure south of the Poudre River. Fort Collins would install a 42-inch pipeline beneath the riverbed to carry water north to the gravel pits. Water would enter the gravel pit complex at the Stenger pit or Home Office pit, and would flow to other pits by gravity, or in some cases, by pumping into the North Shores No. 1 pit, depending on the difference in water levels between the Stenger and North Shore pits.

For an exchange, Fort Collins would release water from the gravel pits into new pipelines and then into the Poudre River at a turnout located on the north bank in exchange for water diverted into its intakes higher up on the Poudre River. The other option would be for Fort Collins to pump water to a pretreatment facility. The pretreatment facility would improve the water quality to levels similar to the water diverted at Fort Collins' intakes, and would deliver this pretreated water directly into the Fort Collins raw water supply lines.

As part of this alternative, Fort Collins would store more water over the winter at Joe Wright Reservoir by authorizing fewer single use water trades with the NPIC. No physical changes are required for this operational change.

Fort Collins would develop the following infrastructure in association with this alternative (Figure 1-3): new pipelines, three pump stations, a pretreatment facility, diversion structure, staging areas, and access roads.
Figure 1-3. Gravel Pits Alternative.
1.1.4 Agricultural Reservoirs Alternative

For the Agricultural Reservoirs Alternative, Fort Collins would achieve additional water storage by procuring dedicated space in two existing reservoirs: NPIC Reservoir No. 5 and Reservoir No. 6. These reservoirs are interconnected and can be operated as a single element. The reservoirs are located approximately 9 miles northeast of the Fort Collins water treatment facility. The feasibility of this alternative depends on Fort Collins and NPIC being able to manage its storage capacity independently. The combined reservoirs have a capacity of 17,830 AF, so Fort Collins would need to acquire 6,475 AF of storage that would constitute approximately 36 percent of the available combined capacity of the two reservoirs. Fort Collins would acquire the storage in the reservoirs through a purchase and operating agreement with NPIC. Fort Collins would need to independently own, operate, and otherwise control the water storage for it to count towards its safety factor. For an acquisition to be possible, Fort Collins would need to compensate NPIC for loss of water capacity, loss of water rights, and any detrimental consequences inflicted to NPIC's system or shareholders.

Fort Collins would divert water from the Poudre River at the Munroe Canal diversion structure and convey the water by gravity into the Pleasant Valley Pipeline and through a new bi-directional 48-inch diameter pipe ending at the control valve by the Reservoir No. 6 outlet. From Reservoir No. 6, a new dedicated pipeline would convey the water to Reservoir No. 5 using a pressurized conveyance system eliminating the need for a pump.

Similar to the Gravel Pits alternative, Fort Collins would have two options for water released from Reservoirs Nos. 5 and 6: either to use the water in an exchange or direct the water into Fort Collins existing raw water supply lines. For an exchange, Fort Collins would release water from the reservoirs into the bi-directional pipeline and then into the Poudre River at a turnout located on the north bank in exchange for water diverted into its intakes on the Poudre River above the confluence with the North Fork. The other option would be for Fort Collins to pump water to a pretreatment facility and then into the Fort Collins' raw water supply lines. The pretreatment facility would improve the water quality to levels similar to the water diverted at Fort Collins' raw water intakes. Fort Collins would release water for exchanges when possible to reduce the amount of pumping required.

Fort Collins would develop the following infrastructure in association with this alternative (Figure 1-4): new pipelines, a valve house, a pump station, a pretreatment facility, diversion structure, staging areas, and access roads.
Figure 1-4. Agricultural Reservoir Alternative.
1.1.5 No-Action Alternative

The No-Action Alternative, unlike the action alternatives, does not involve structural changes to existing infrastructure or development of new structures associated with the Fort Collins water supply system. The No-Action Alternative is an administrative approach to try to meet as much of the city's purpose and need as possible with the three following measures.

- Fort Collins would change its operational procedures at its existing Joe Wright Reservoir to store more water over the winter.
- Fort Collins would acquire additional NPIC shares either through direct purchase of shares or by requiring residential and commercial development to provide dedicated shares.
- Fort Collins would implement mandatory water use restrictions during drought periods and system failures.

All components of the No-Action Alternative are non-structural and require no ground disturbance of any type.

Under the first measure of its No-Action Alternative, Fort Collins would conduct fewer single-use water transactions with NPIC to maintain a higher water level at the Joe Wright Reservoir over the winter, similar to the Gravel Pits Alternative. Fort Collins would set the winter carryover capacity for Joe Wright Reservoir at 3,200 AF. To sustain this level, Fort Collins would need to cut the amount of late summer and fall distribution of single-use water for subsequent exchange with NPIC. NPIC has previously accepted these single use exchanges of Joe Wright Reservoir water for NPIC’s Colorado-Big Thompson (C-BT) water stored in Horsetooth Reservoir, which has been mutually beneficial for Fort Collins and NPIC. Fort Collins benefitted from the water exchanges by reducing the amount of single use water stored in Joe Wright Reservoir allowing storage space for more reusable use water collected in the spring from Michigan Ditch. For NPIC, the exchanges allowed water diversion at Munroe Canal during times when the exchange potential for moving C-BT water upstream to the Munroe Canal was low. This reoperation option would require no new infrastructure and would provide no new storage capacity for Fort Collins.

Under the second measure of its No-Action Alternative, Fort Collins would either directly purchase NPIC shares or require future developers to dedicate NPIC shares to Fort Collins as a condition of future development. NPIC shares would specifically need to have a C-BT storage component. Acquiring NPIC shares provides Fort Collins additional C-BT water and its associated storage. Northern Water has imposed limitations on the amount of additional C-BT shares Fort Collins can directly purchase. However, it would be permissible for Fort Collins to acquire C-BT units by purchasing NPIC shares or through dedication from developers. Fort Collins has deliberately focused on developing its Poudre River sources to diversify its system, as it already owns a large amount of C-BT shares.
The third measure Fort Collins would enact as part of the No-Action Alternative is to impose more frequent and severe mandatory water restrictions. Fort Collins has already implemented a Water Supply Shortage Response Plan (2003; revised in 2013) to address drought and emergency water supply situations. The plan provides four response levels to address various levels of supply shortage severity. Since its inception in 2003, Fort Collins has imposed mandatory water restrictions (Response Level 1) twice—in 2003 to respond to the early 2000s drought, and in 2013 in response to drought and water quality impacts of the High Park Fire. Under the No-Action Alternative, water supply shortages would likely be more frequent and severe and water restrictions would be implemented more frequently, would be more severe, and would last longer. Mandatory water use restrictions would not create additional firm water yield or storage capacity, but the approach would extend available supplies during a drought or interruption in water supply. However, modeling suggests that during the design drought, even with restrictions, Fort Collins would not be able to maintain a reserve of water equal to 15 percent of Fort Collins' average annual demand as a buffer in case of storage or delivery system failure, forest fire, adverse unexpected water court rulings, or other unanticipated stressors on its water delivery system. This would make Fort Collins vulnerable to water shortages and the possibility of water shutoffs if an unforeseen event disrupted the water supply system.

For further details on this alternative or the other proposed alternatives, please see the "Final Alternatives Description Report" (MWH 2015).

1.2 Regulatory and Management Framework

There are various state and federal laws regulating mining of minerals and other geologic resource materials as well as oil and gas production. Geologic resources on state and federal property are protected and require permits from managing agencies to mine, collect, or exploit those geologic resources. There is no regulatory authority over the potential specific impacts of Halligan Project on geologic resources, however, under NEPA the potential impacts of the Halligan Project on geologic resources and potential mitigation in the EIS are required to be considered.

We describe the presence of geologic resources requiring agency regulation for the Proposed Action and the three alternatives in the sections below. Any future potential mining, collection, exploitation or development of the geologic resources or oil and gas related production within the footprint of the Proposed Action and the three alternatives would require a patent, such as a mineral patent, or permit issuance by the governing agency.
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2 Methods

CDM Smith collected geologic resource information near the Fort Collins' Proposed Action and the other alternatives using existing information collected from published data sources and reports from the United States Geological Survey (USGS), the Colorado Geologic Survey and other available geologic mapping, including geologic quadrangle maps near the alternatives. The references reviewed during the evaluation of the geological resources are included in Section 6, Literature Cited.

We examined the Geologic 7.5-minute quadrangle maps of the specific areas covering the Fort Collins' Proposed Action and the other alternatives within Larimer County, Colorado. The geologic quadrangle maps prepared by the USGS are a collection of geologic maps produced at a 1:24,000 scale. Each quadrangle map contains geologic formation contacts, fault, structure, and attitude of bedding (strike and dip) data at a 1:24,000 scale. The maps also include a cross-section, correlation and description of map units, references, and a stratigraphic column for the quadrangle.

The primary purpose of these geologic maps is to show the geologic formations and map units present at the surface at a 1:24,000 scale. Interpretations are made of the geologic units where outcrops were covered by unconsolidated sediment or vegetation. Cross-sections are typically drawn using surficial data projected into the subsurface. The sections below summarize the information presented on the relevant quadrangle maps related to the geologic setting presented in the quadrangle map.

We also evaluated the geologic hazards and material sources based on the geologic unit information provided on the maps. The USGS Earthquake and Landslide Hazards Programs provided the data about potential of geologic hazards presented below.

The USGS developed the National Seismic Hazard Map, which displays the probability of earthquake ground motion across the United States. The National Seismic Hazard Map is derived from seismic hazard curves based on a location grid describing the annual frequency of exceeding a set of ground motions values. The USGS National Seismic Hazard Map we reviewed depicts the 2 percent probability of exceedance within 50 years of a probabilistic ground motion or peak ground acceleration value. The map we evaluated expressed peak ground acceleration value as a fraction of standard gravity (g) (Petersen 2015).

We also reviewed the Landslide Overview Map of the Conterminous United States to evaluate the general susceptibility of the footprints of the alternatives to landslides. The USGS created this map by classifying the susceptibility and incidence (number of landslides) of potential landslides associated with formations or groups of formations shown on the geologic map of the United States as being of high, medium, or low. High, medium, and low general susceptibility categories were defined by the percentages classifying the incidence of landslides (USGS 1997).
We present the general susceptibility for each alternative footprint below. The USGS map also depicts surficial deposit susceptibility to slope movement. The USGS classified the map units into three incidence categories according to the percentage of the area involved in landslide processes. The areas involved in landslides were assigned a value of incidence: >15 percent was High; 1.5-15 percent was Medium; <1.5 percent was Low (USGS 1997).
3 Affected Environment

The Fort Collins' Proposed Action and the alternatives described in Section 1.2 are located within the physiographic province of the Southern Rocky Mountains of the Rocky Mountains System (Corps 1981). The portion of the province within Colorado underlying the Fort Collins' Proposed Action and the other alternative footprint consists mostly of north-south trending mountain ranges with formerly overlying sedimentary strata. Periods of uplift caused the sedimentary strata to tilt away from the central portion of the mountains. During this period of uplift and tilting, referred to as the Laramide Orogeny, the structural configuration of the mountains changed to what is observed in present day.

The Southern Rocky Mountains Province underlying the Fort Collins' Proposed Action footprint consists of Precambrian igneous and metamorphic or granitic rocks of the Rocky Mountains (Corps 1981). The bedrock underlying the remaining alternatives consists of tilted Paleozoic and Mesozoic sedimentary strata ranging from Pennsylvanian-Permian to Cretaceous in age (Hershey and Schneider 1972). These lithologic units formed as the result of marine and terrestrial sedimentation related to fluctuations in relative sea level and regional tectonic activity (Weimer and Sonnenberg 1996). We describe the detailed geology underlying each alternative below.

3.1 Proposed Action – Enlarged Halligan Reservoir

The geologic resources within the Fort Collins' Proposed Action footprint consist predominantly of Precambrian-aged granitic rocks of the Silver Plume Granite Formation (Braddock 1989). Silver Plume granite typically occurs along the north central front range of the Rocky Mountains. The granite typically weathers to soil consisting of sand and gravel with some silts and clays. The northeastern side of the alternative footprint overlies early Proterozoic interlayered metamorphosed granitic gneiss. Along the Poudre River drainage and along the inlet into Halligan Reservoir, Quaternary Alluvium consisting of unconsolidated silt, sand, and gravel, including colluvium along the valley walls, overlies the bedrock units. (Figure 3-1) is the geologic map of the Proposed Action.
Figure 3-1. Fort Collins' Proposed Action geologic map.
3.1.1 Geologic Hazards

An inactive fault runs through the Fort Collins' Proposed Action footprint. The location of the inactive fault is approximated or inferred underlying the existing Halligan Reservoir. The inactive fault includes three unnamed northwest to southwest trending splays associated with the fault. These shear zones associated faulting or fracturing, are present where the inactive fault offset the Precambrian-aged rocks and runs through the existing Halligan Reservoir. The areas within the vicinity of the inactive faulting generally exhibit increased fracturing of the bedrock (Braddock 1989).

There is no record of earthquake epicenters after 1900 within the vicinity of the Fort Collins' Proposed Action footprint (USGS 2012). The Halligan Reservoir site is located within a moderate low hazard range of potential shaking from future earthquakes. The earthquake peak ground acceleration value with a 2 percent probability of exceedance (50-year recurrence interval) within the vicinity of the Fort Collins’ Proposed Action footprint ranges between 0.12 and 0.14 g (Peterson et al. 2015).

There are no documented landslide occurrences within the Fort Collins' Proposed Action footprint; however, there is documented potential for slope failure or the downslope movement of rock debris and soil, in response to gravitational stresses within the disturbance areas associated with the construction required to enlarge Halligan Reservoir (USGS 1997).

3.1.2 Material Sources

The Silver Plume granite that underlies the identified borrow area for the Fort Collins' Proposed Action may have potential use as a coarse aggregate. The granite could potentially be used as a source for riprap and possibly processed for sand and gravel-size material. In addition, the quaternary alluvium and the colluvium may have potential use as a low permeability material for dam construction or other intended uses.

3.1.3 Mineral Resources

Enlargement of Halligan Reservoir would inundate a portion of the Four Bees placer mining claim located on the northern and eastern portions of the existing Halligan Reservoir footprint (USGS 2015). There is no active mining operations on the split federal mineral estates present within the remaining portion of the Fort Collins' Proposed Action footprint. There are no permitted oil and gas wells identified within the Fort Collins' Proposed Action footprint or associated disturbance areas (USGS 2015).

3.2 Expanded Glade Alternative

The Expanded Glade Alternative is located along the Front Range hogback, which consists of the upturned outcrop of several bedrock formations. This alternative would be an expansion of the proposed Glade Reservoir proposed by NISP (ERO 2015). The geology within and adjacent to
the enlarged portion of the proposed Glade Reservoir consists of Cretaceous through Pennsylvanian bedrock formations and Precambrian granite, schist, and gneiss (Braddock 1988). (Figure 3-2) shows the geologic map of the Expanded Glade Alternative site.
Figure 3-2. Expanded Glade Alternative geologic map
The majority of the eastern, northern, and northwestern portions of the Expanded Glade Alternative inundation area overlie the Lower Permian Lyons Sandstone, Ingleside, and Owl Canyon formations. The Lyons Sandstone is approximately 30 feet thick and consists of orange to pink to pinkish-gray fine- to medium-grained, well-sorted quartz sandstone. It is well cemented with quartz cement, and characterized by large-scale dune crossbedding. The Lyons formation overlies the Owl Canyon Formation, which is approximately 200 feet thick and consists of red siltstone and red, fine-grained, ripple-laminated sandstone. Underlying the Owl Canyon Formation is the Ingleside Formation, which is approximately 200 feet thick and consists of reddish-pink, fine-grained quartz sandstone, commonly well cemented with quartz or calcite.

A small portion of the western edge of the enlarged inundation pool overlies the Lower Permian and Upper Middle Pennsylvanian Fountain Formation. The Fountain Formation underlies the Ingleside Formation and is approximately 800 feet thick. The formation generally consists of reddish-brown to purplish-gray arkosic conglomerate, medium- to coarse-grained feldspathic sandstone and dark-reddish-brown siltstone and shale.

A small portion of the northwestern edge of the enlarged inundation pool overlies the Lower Triassic and Upper Permian Lykins Formation. The Lykins Formation is approximately 700 feet thick and consists of dominantly red and reddish-brown siltstone and fine-grained sandstone containing several thin carbonate beds. A small portion of the enlargement area overlies the Upper Jurassic Morrison Formation. The formation overlies the Lykins Formation, is approximately 330 feet thick, and consists of green, red, yellow, and white blocky weathering claystone and siltstone and interbedded gray micrite and gray, fine- to medium-grained sandstone.

A small portion of the southeastern edge of the enlarged inundation pool overlies the Upper and Middle Jurassic and Upper Triassic Sundance Formation and Jelm Formation, undivided. The formations underlie the Morrison Formation and have a combined thickness ranging from approximately 150 feet to 200 feet. The Sundance and Jelm Formations are a mapped unit consisting of four separate members. The youngest member of the formations is the Windy Hill Sandstone Member of the Sundance Formation, which is approximately 13 feet thick and consists of flat-bedded, light-gray, fine-grained sandstone and gray clay shaly. The Windy Hill Sandstone unconformably overlies the Pine Butte Member of the Sundance Formation, is approximately 13 feet thick, consisting of massive to flat-bedded, fine-grained, and gray to white sandstone. The Pine Butte Member of the Sundance Formation conformably overlies the Canyon Springs Sandstone Member of the Sundance Formation. The Canyon Springs Sandstone Member is approximately 36 feet thick and consists of pink, orange-pink, or reddish-brown, fine- to medium-grained, cross-bedded calcareous sandstone. The Canyon Springs Sandstone Member unconformably overlies the Red Draw Member of the Jelm Formation, which consists of orange-pink or reddish-brown, fine-grained, cross bedded calcareous sandstone and is distinguishable by the presence of conspicuous chert pebbles. It ranges from approximately 90 feet to 135 feet thick.
The western edge of the enlarged inundation pool, and a portion of the potentially disturbed areas associated with construction of the alternative, overlies early Proterozoic metasedimentary quartzofeldspathic mica schist, knotted mica shist, and leucocratic gneiss and pegmatite. The quartzofeldspathic mica schist consists of biotite schist interbedded with quartzofeldspathic granofels and contains thin beds of knotted mica schist. The knotted mica schist contains abundant migmatite and consists of biotite and sillimanite-rich schist. It appears lumpy or knotted because of clots of intergrown quartz and sillimanite. The leucocratic gneiss and pegmatite consist of white to pink, fine-grained to very coarse-grained, weakly foliated gneiss and pegmatite, which are composed of quartz, plagioclase, and microcline.

A portion of the proposed pipeline associated with the Expanded Glade Alternative extends over two units of the Lower Cretaceous Dakota Group mapped as the Lytle Formation and the South Platte Formation. The Lytle Formation is approximately 80 feet thick and consists of gray to tan, coarse-grained to conglomeratic sandstone and blocky-weathering, varicolored non-carbonaceous mudstone. The Lytle Formation underlies the South Platte Formation, which consists of the first sandstone member, which is a gray to tan, well-sorted fine to medium-grained sandstone, and the middle shale member and Plainview Sandstone Member, undivided. The middle shale member is approximately 185 feet thick and consists of dark gray carbonaceous shale, thin bentonite, and thin gray siltstone and sandstone beds. The underlying Plainview Sandstone Member is gray to tan, thin-bedded, fine-grained carbonaceous sandstone. The pipeline also traverses areas of Upper Cretaceous Carlile Shale, Greenhorn Limestone and Graneros Shale, and Lower Cretaceous Mowry Shale. This unit is approximately 495 feet thick and is not mapped separately because of poor exposure at the surface.

A large portion of the surface geology affected by the proposed pipelines, the pump station/pretreatment plant, potential construction disturbance, borrow, and staging areas, is overlain by relatively thin Quaternary Colluvium. Mass wasting mostly formed the colluvium present. Quaternary Alluvium is present in deposits up to 40 feet thick in areas along intermittent streams and along the floors of valleys formed from the weathering of uplifted Paleozoic sedimentary rocks near the Expanded Glade Alternative.

### 3.2.1 Geologic Hazards

Several inactive north-northwest to south-southeast trending faults are present within the expanded inundation pool, conveyance system, and associated disturbance areas. The Bellvue Fault, the Livermore Fault, and the North Fork Fault are three of the larger inactive faults within the vicinity of the Expanded Glade Alternative. There are no active faults within at least 50 miles of the Expanded Glade Alternative (Braddock 1989).
No earthquake epicenters have been recorded after 1900 within at least 20 miles of the Expanded Glade Alternative (USGS 2012). The expanded inundation pool is located within a moderate low hazard range of potential shaking from future earthquakes. The earthquake peak ground acceleration value with a 2 percent probability of exceedance (50-year recurrence interval) within the vicinity of the Expanded Glade Alternative footprint ranges between 0.10 and 0.14 g (Peterson et al. 2015).

There are documented quaternary landslides that have occurred adjacent to the southern edge and near the western edge of the footprint of the enlarged reservoir and portions of the proposed conveyance system locations (USGS 1997).

3.2.2 Material Sources

The Quaternary Alluvium and Colluvium, which underlie a large portion of the Expanded Glade Alternative, may be potential borrow material sources for use as a low permeability material for construction or other potential uses. The underlying bedrock within the potential borrow areas could be utilized for riprap, bedding materials, or for other construction purposes, however, no borrow materials sources are required within the alternative footprint.

3.2.3 Mineral Resources

There are no past or present mining operations, quarries, recognized mineral resources, or oil and gas permitted wells within the footprint of the Expanded Glade Alternative (USGS 2015).

3.3 Gravel Pits Alternative

The surface geology overlying the designated storage unit footprint, a portion of the proposed pipeline and associated disturbance areas of the Gravel Pits Alternative is Quaternary Alluvium. The Quaternary Alluvium, as described in Section 3.2.1, is present in deposits up to 40 feet thick in areas along intermittent streams and along the floors of valleys formed from the weathering of uplifted late Paleozoic to Mesozoic sedimentary rocks near the Gravel Pits Alternative (Braddock 1973; 1988). (Figure 3-3) shows the geologic map of the Gravel Pits Alternative.
Figure 3-3. Gravel Pits Alternative geologic map.
A portion of the proposed pipeline and associated disturbance areas associated with the Gravel Pits Alternative extend across several Cretaceous geologic units. The topmost unit is the Upper Cretaceous, Lower Pierre Shale, which consists of three lower members of the formation—Mitten Black Shale Member, Sharon Springs Member, and Gammon Ferruginous Member. The formation, which is approximately 1,900 feet thick, consists of mostly dark-olive-gray shale and sandy shale containing limestone and ironstone concretions. Bentonite beds are common in lower parts of the formation. The Smoky Hill Shale Member of the Upper Cretaceous Niobrara Formation underlies the Pierre Shale and is a very fissile calcareous shale. The Smoky Hill Member is approximately 335 feet thick and is dark gray on fresh surfaces and weathers to light gray. Approximately 4 miles of the pipeline would traverse an area with Upper Cretaceous Carlile Shale, Greenhorn Limestone and Granerous Shale, and the Lower Cretaceous Mowry Shale underlies the Smoky Hill Shale and is approximately 485 feet thick. These units are not described separately because of poor surface exposure (Braddock 1989).

3.3.1 Geologic Hazards

Several inactive north-northwest to south-southeast trending faults, including the Bellvue Fault are known to exist approximately 5 miles west and northwest of the Gravel Pits Alternative. The areas within the vicinity of the inactive fault generally also exhibit increased fracturing of the bedrock. There are no active faults within at least 60 miles of the Gravel Pits Alternative (Braddock 1988).

No earthquake epicenters have been recorded after 1900 within at least 20 miles of the Gravel Pits Alternative (USGS 2012). The Gravel Pits Alternative is located within a moderate low hazard range of potential shaking from future earthquakes. The earthquake peak ground acceleration value with a 2 percent probability of exceedance (50-year recurrence interval) within the vicinity of the Gravel Pits Alternative footprint ranges between 0.10 and 0.14 g (Peterson et al. 2015).

There are no documented landslide occurrences within the alternative water storage units or conveyance pipeline areas. However, there have been documented landslides and debris slides within the footprint of the western most potential staging area associated with construction of the alternative conveyance system (USGS 1997).

3.3.2 Material Sources

The Quaternary Alluvium and Colluvium, present within a large portion of the Gravel Pits Alternative footprint, may be potential borrow material sources for use as a low permeability material as needed for construction or other intended uses. In addition, the underlying bedrock formations within the potential disturbance footprint could be utilized for other construction purposes, however, no borrow materials sources are required within the alternative footprint.

It is assumed that 50 percent of the gravel pits will be excavated prior to initiation of the project. The estimated volume of materials required for construction of this alternative is approximately equivalent to the remaining estimated volume of materials to be excavated at the initiation of the
project from the gravel pits. The final design will incorporate as much of the excavated material as possible for berm construction. However, the quantity of excavated materials suitable for construction of the berms is dependent on geotechnical characteristics of in-situ material.

3.3.3 Mineral Resources

A portion of the Gravel Pits Alternative conveyance system and associated construction and disturbance areas overlie Quaternary Alluvial sand and gravel deposits. Active mining of the alluvial sand and gravel deposits present in and along the valley of the Poudre River has historically occurred since at least the 1970s. These deposits excavated from the gravel pits present in the vicinity of the alternative serve as the principal source of aggregate for the urban development and infrastructure in the area. The implementation of the alternative will incorporate gravel pits which are currently being excavated or that have already been excavated and can function as a set of interconnected storage vessels.

For implementation of this alternative, Fort Collins would develop additional water storage at the Overland Gravel Pits complex located along the Poudre River northwest of the City of Fort Collins. The Overland Gravel Pits complex consists of over 15 existing and potential gravel pit sites located south and north of the Poudre River. The existing pits located on the south side of the Poudre River are currently owned and operated for water storage by Greeley and the Tri-Districts. Therefore, the gravel pits considered for this alternative are located north of the Poudre River on existing or proposed gravel pit sites in the complex. The currently selected set of gravel pits is one of many different potential configurations that may be available to Fort Collins that incorporate pits that currently are being excavated or that have already been excavated and can function as a set of interconnected storage vessels.

The Overland Gravel Pits would be utilized as water storage units once mining of the area is complete as part of the alternative. The currently selected set of gravel pits is one of many different potential configurations that may be available to Fort Collins. The gravel pit sites the alternative incorporates in the selected configuration for this alternative include: North Shore Reservoirs, Taft Hill Reservoir-A, Stegner Farms and the Home Office Mine pits. There are no recognized mineral resources or oil and gas permitted wells identified within the potentially disturbed areas associated with the conveyance system or construction of the alternative (USGS 2015).

3.4 Agricultural Reservoirs Alternative

Eolian sand underlies a portion of the existing NPIC Reservoirs Nos. 5 and 6, sections of the eastern portion of the proposed pipeline, and associated disturbance areas. Eolian sand is wind-blown sand that formed sand dunes. The eolian sand generally consists of rounded mineral grains, commonly quartz, having diameters ranging from 0.1 to 1 mm. The remaining portion of the designated storage unit footprints and sections of the eastern portion of the proposed pipeline and associated disturbance areas for the alternative extend over the Upper Cretaceous Upper Pierre Shale. The Upper Pierre Shale is of marine origin and is typically dark gray and
fossiliferous. (Figure 3-4) shows the geologic map of the Agricultural Reservoirs Alternative site. The figure was prepared using two different geologic maps because the USGS quadrangle maps have not been prepared for that area to date.
Figure 3-4. Agricultural Reservoir Alternative geologic map.
Quaternary Alluvium underlies a small portion of the proposed pipeline and associated disturbance areas of the alternative. The remaining portion of the proposed pipeline and associated disturbance areas extends over several Cretaceous geologic units as described in association with the Gravel Pits Alternative in Section 3.3.1.

### 3.4.1 Geologic Hazards

Several inactive faults are present within 8 miles west of the existing reservoirs and within 1.5 miles of the proposed pipeline (Tweto 1976). There are no active faults near the existing reservoirs or the proposed pipeline (Braddock 1988).

No earthquake epicenters have been recorded after 1900 within at least 20 miles of the Gravel Pits Alternative (USGS 2012). The alternative area is located within a moderate low hazard range of potential shaking from future earthquakes. The earthquake peak ground acceleration value with a 2 percent probability of exceedance (50-year recurrence interval) within the vicinity of the Agricultural Reservoir Alternative footprint ranges between 0.08 and 0.14 g (Peterson et al. 2015).

There are no documented landslides within the alternative area; however, there have been documented landslides and debris slides within the footprint of the western most potential staging area associated with construction of the alternative conveyance system (USGS 1997).

### 3.4.2 Material Sources

Currently the use of borrow materials is not required for completion of the Agricultural Reservoirs Alternative. However, the Quaternary Alluvium and Eolian sand deposits, which underlie a large portion of the alternative, may be potential borrow material sources for use as a low permeability material as needed for construction or other intended uses. In addition, the underlying bedrock formations within the potential footprint areas could be utilized as needed for other construction purposes.

### 3.4.3 Mineral Resources

A portion of the alternative conveyance system and associated construction and disturbance areas overlie Quaternary Eolian and alluvial sand and gravel deposits. However, there are no past or present mining operations or quarries located within the footprint of the potentially disturbed areas associated with the conveyance system or construction of the Alternative, and no existing leases were documented in the USGS mineral resources data. Similarly, within the water storage footprint or other disturbance areas, there are no recognized mineral resources or oil and gas permitted wells (USGS 2015).
3.5 No-Action Alternative

The No Action Alternative would not require any construction activities or disturbance of any geologic resources.
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4 Environmental Consequences

Potential impacts on geologic resources are minor and summarized for each alternative below. These potential impacts include permanent loss of surface accessibility of material resources as a result of the inundation of outcrop materials under reservoir enlargement areas and the placement of other alternative permanent infrastructure, excavation of material resources in borrow areas, potential impacts from geologic hazards and potential loss of access to mineral resources. Alternatively, based on the geologic resources identified underling locations associated with construction of the alternative or borrow area excavations, subsurface mining could potentially be used to access certain geologic resources.

The disturbance areas we identified in this technical report for each alternatives described below are considered potential maximums. The preliminary nature of each of the alternative designs conservatively estimates the maximum footprint extents for the inundation areas, borrow areas, staging areas, and infrastructure such as pipeline corridors, therefore the estimated disturbance areas are presented as maximum possible disturbances. We evaluated potential maximum impacts for each alternative based on the geology present and information available in published data, and described them below. The permanent acreage loss of accessibility for each alternative is summarized in (Table 4-1).

Table 4-1. Summary of total acreage of permanent loss of accessibility of geologic resources.

<table>
<thead>
<tr>
<th>Alternative Name</th>
<th>Acres</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fort Collins' Proposed Action</strong></td>
<td></td>
</tr>
<tr>
<td>Inundation Area</td>
<td>132.5</td>
</tr>
<tr>
<td>Permanent Access Roads</td>
<td>5.0</td>
</tr>
<tr>
<td>Dam Footprint</td>
<td>&lt;0.5</td>
</tr>
<tr>
<td>Borrow Areas</td>
<td>22.4</td>
</tr>
<tr>
<td>Mineral Resources (Placer Mine Claim)</td>
<td>9</td>
</tr>
<tr>
<td><strong>Expanded Glade Alternative (Fort Collins Impacts only)</strong></td>
<td></td>
</tr>
<tr>
<td>Inundation Area, from NISP level to Fort Collins Level</td>
<td>57.0</td>
</tr>
<tr>
<td>Permanent Access Roads</td>
<td>3.0</td>
</tr>
<tr>
<td>Borrow Areas</td>
<td>N/A</td>
</tr>
<tr>
<td>Mineral Resources</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Gravel Pits Alternative</strong></td>
<td></td>
</tr>
<tr>
<td>Gravel Pits Storage (Surrounding Berms)</td>
<td>6.0</td>
</tr>
<tr>
<td>Permanent Access Roads</td>
<td>12.5</td>
</tr>
<tr>
<td>Pump Stations (3)</td>
<td>4.5</td>
</tr>
<tr>
<td>Pretreatment</td>
<td>0.5</td>
</tr>
<tr>
<td>River Turn Out</td>
<td>&lt;0.5</td>
</tr>
</tbody>
</table>
### Alternative Name

<table>
<thead>
<tr>
<th>Alternative Name</th>
<th>Acres</th>
</tr>
</thead>
<tbody>
<tr>
<td>Valve House</td>
<td>&lt;0.5</td>
</tr>
<tr>
<td>Borrow Areas</td>
<td>N/A</td>
</tr>
<tr>
<td>Mineral Resources (Other than the Overland Gravel Pits Complex)</td>
<td>N/A</td>
</tr>
</tbody>
</table>

#### Agricultural Reservoirs Alternative

| Permanent Access Roads       | 9.0          |
| Pump Station/Pretreatment    | 2.0          |
| Valve House-3                | <0.5         |
| River Turn Out               | <0.5         |
| Mineral Resources            | N/A          |

Note: Areas indicated have been rounded to the nearest half-acre due to limited accuracy of available data.

NA- Not Applicable

### 4.1 Proposed Action

#### 4.1.1 Material Resources

The Fort Collins' Proposed Action would result in a permanent loss of surface accessibility of approximately 132.5 acres of material resources from inundation and less than 0.5 acres from the enlarged footprint of the dam. The proposed borrow areas are currently outside of the reservoir footprint; therefore, there is additional potential loss of 22.4 acres of geologic resources from extraction of material for dam construction. Approximately 22.4 acres of borrow materials have been identified within the vicinity of the alternative footprint overlying the Silver Plume Granite Formation. The specific borrow materials required to complete the alternative will depend on the final design and could include core, shell, filter/drain, riprap and bedding material, and concrete aggregate. Geologic reconnaissance and a detailed exploration program will need to be completed to confirm the availability and quantity of suitable materials at the designated borrow areas. The borrow sources should be characterized and representative samples collected to evaluate the suitability of the materials as borrow materials for the intended use. The tests completed to characterize and evaluate the sample may include determination of the geotechnical properties and shear strength tests and aggregate durability tests.

#### 4.1.2 Geologic Hazards

The Fort Collins' Proposed Action is located in an area designated as a low incidence of landslide occurrence potential. Low incidence occurrence indicates less than 1.5 percent of the area surrounding the alternative footprint has been affected by landslides based on the occurrence of documented landslides (Radbruch-Hall et al. 1982).
4.1.3 Mineral Resources

The Fort Collins' Proposed Action would result in a permanent loss of surface accessibility of approximately 9 acres of the Four Bees placer mining claim, which would be impacted because of the reservoir expansion. However, the mining claim will not be impacted outside the reservoir inundation area. In addition, The City of Fort Collins intends to secure a right of way from the Bureau of Land Management (BLM) to inundate additional BLM property, requiring an agreement with the mining claimants. There are no other known mineral resources or oil and gas resources identified within the enlarged Halligan Reservoir footprint, potential borrow areas, or disturbance areas that would be impacted by the construction of the alternative (USGS 2015).

4.2 Expanded Glade Alternative

4.2.1 Material Resources

The Expanded Glade Alternative would result in a permanent loss of surface accessibility of approximately 57.0 acres of geologic resources from inundation. There are no borrow areas associated with the construction of this alternative; therefore, no significant additional potential loss of geologic resources from extraction of material resources for dam construction or other infrastructure. Fort Collins will source onsite materials from the proposed NISP borrow pit; therefore, there is not a net increase in surface disturbance associated with Fort Collins' actions.

4.2.2 Geologic Hazards

Although quaternary landslides have previously occurred within the footprint of the alternative, the majority of the alternative footprint is located in an area designated as a low incidence of landslide occurrence based on the occurrence of documented landslides (Radbruch-Hall et al. 1982). Low incidence occurrence indicates less than 1.5 percent of the area surrounding the alternative footprint has been affected by landslides based on the occurrence of documented landslides (Radbruch-Hall et al. 1982). A portion of the western side of the enlarged area and a portion of the pipeline system and associated disturbed areas are located within an area designated as a medium incidence of landslide occurrence potential. Medium incidence occurrence indicates between 15 and 1.5 percent of the area surrounding the alternative footprint has been affected by landslides based on the occurrence of documented landslides (Radbruch-Hall et al. 1982).

4.2.3 Mineral Resources

There are no known mineral resources or oil and gas resources identified within the Expanded Glade Alternative footprint or disturbance areas. Therefore, there are no mineral resources that would be impacted by the construction of the alternative.
4.3 Gravel Pits Alternative

4.3.1 Material Resources

The development of this alternative would result in a permanent loss of surface accessibility of 6 acres of geologic resources associated with the construction of berms around proposed storage pit areas, if needed, to achieve the desired water storage within the gravel pits identified for use located at the Overland Gravel Pits complex. It is assumed that 50 percent of the gravel pits will be excavated prior to initiation of the project. The final design will incorporate as much of the excavated material as possible for berm construction. However, the quantity of excavated materials suitable for construction of the berms is dependent on geotechnical characteristics of in-situ material.

There is an additional permanent loss of 18 acres associated with the placement of permanent infrastructure associated with the alternative. The potential borrow materials of this alternative are located within the existing footprint being extracted to achieve the desired water storage capacity. The specific borrow materials required to complete the alternative will depend on the final design and could include core, shell, filter/drain, riprap and bedding material, and concrete aggregate. Geologic reconnaissance and a detailed exploration program to confirm the availability and quantity of local material source deposits at the potential borrow areas need to be completed. The potential borrow sources should be characterized and representative samples collected to evaluate the suitability of the materials as borrow materials for the intended use. The tests completed to characterize and evaluate the sample may include determination of the geotechnical properties and shear strength tests and aggregate durability tests.

4.3.2 Geologic Hazards

Although there have been documented landslides and debris slides within the footprint of the western most potential staging area associated with construction of the alternative conveyance system, the Gravel Pits Alternative is located within an area designated as a medium incidence of landslide occurrence potential. Medium incidence occurrence indicates between 15 and 1.5 percent of the area surrounding the alternative footprint has been affected by landslides based on the occurrence of documented landslides (Radbruch-Hall et al. 1982).

4.3.3 Mineral Resources

The development of this alternative would result in a permanent loss of geologic resources during extraction by Fort Collins for additional storage within the permitted gravel pit area, if needed, to achieve the desired water storage within the gravel pits identified for use located at the Overland Gravel Pits complex. Additionally, a portion of the alternative conveyance system and associated construction and disturbance areas overlies quaternary alluvial sand and gravel deposits. However, there are no known mineral resources or oil and gas resources identified within the alternative study area construction areas, potential borrow areas or disturbance areas that would be impacted by the construction of the alternative.
4.4 Agricultural Reservoirs Alternative

4.4.1 Material Resources

The development of this alternative would result in a permanent loss of accessibility of 12 acres of geologic resources associated with placement of permanent infrastructure associated with the alternative. There are no proposed borrow areas for construction. There are no identified borrow areas or requirements for this alternative.

4.4.2 Geologic Hazards

The Agricultural Reservoirs Alternative is located between two landslide potential designated areas. The western portion of the alternative is located within an area designated as a medium incidence of landslide occurrence potential. Medium incidence occurrence indicates between 15 and 1.5 percent of the area surrounding the alternative footprint has been affected by landslides based on the occurrence of documented landslides (Radbruch-Hall et al. 1982). The eastern portion of the alternative is located within an area designated as having high susceptibility to landslides but low incidence of landslide occurrence based on the occurrence of documented landslides (Radbruch-Hall et al. 1982).

4.4.3 Mineral Resources

A portion of the alternative conveyance system and associated construction and disturbance areas overlies quaternary alluvial sand and gravel deposits. However, there are no known mineral resources or oil and gas resources identified within the alternative study area construction areas, potential borrow areas, or disturbance areas that would be impacted by the construction of the alternative.

4.5 No-Action Alternatives

The No-Action Alternative would not require any structural concepts, construction activities, or disturbance of any geologic resources.
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5  Summary of Effects

We evaluated the potential maximum impacts to geologic resources for each alternative described in Section 1.2. The permanent loss and disturbance areas we identified in this technical report for each alternatives are considered potential maximums. The preliminary nature of each of the alternative designs conservatively estimates the maximum footprint extents for the inundation areas, borrow areas, staging areas, and infrastructure such as pipeline corridors, therefore the estimated disturbance areas are presented as maximum possible disturbances. Most of the impacts on geologic resources associated with each of the alternatives would be minor associated with permanent acreage accessibility loss or material resources loss within the enlarged reservoir areas and storage areas or permanent infrastructure or borrow areas. Table 4-1 shows the summary of these acreages impacted.

The Fort Collins' Proposed Action Alternative would affect a portion of a placer mine claim as described above; however, there are no other known mineral resources with the alternative footprint. There were no known mineral resources or mining claims identified for the other alternatives.
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6 Literature Cited


Colorado Department of Natural Resources. 2016. Design Review and Construction Inspection. Colorado Division of Water Resources, Department of Natural Resources. Information Available at: http://water.state.co.us/SurfaceWater/DamSafety/DesignConstruction/Pages/default.aspx


Appendix A: Glossary of Terms

Alluvium - unconsolidated (not cemented together into a solid rock) soil or sediments, which has been eroded, reshaped by water in some form, and redeposited in a non-marine setting.

Bedrock - consolidated rock underlying the ground surface

Colluvium - unconsolidated sediments that deposited at the base of hillslopes by rain-wash, sheet wash, slow continuous downslope creep, or a variable combination of these processes

Earthquake - the perceptible shaking of the earth’s surface

Eolian sand - wind-blown sand that forms sand dunes

Epicenters - the point on the Earth’s surface that is directly above the point where an earthquake originates

Faults - rock fractures which show evidence of relative movement

Gravel - granular material that ranges in size from granule to boulder-sized fragments composed of divided rock and mineral particles

Landslide - a geological phenomenon that includes a wide range of ground movements. Rockfalls, deep failure of slopes and shallow debris flows

Precambrian - the largest span of time in Earth's history that spans from the formation of Earth to about 4.6 billion years ago

Quaternary - the current and most recent of the three periods of the Cenozoic Era in the geologic time scale of the International Commission on Stratigraphy

Sand - granular material that is finer than gravel and coarser than silt composed of finely divided rock and mineral particles.

Slope Failure - the downslope movement of rock debris and soil in response to gravitational stresses