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AN OVERVIEW OF ENGINEERING GEOLOGY APPLIED TO FACILITIES IN OREGON

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Abstract

Engineering geologic evaluations are often conducted for significant facilities in Oregon including dams, power plants, harbors, public buildings, and a natural gas field. Oregon has over 3,500 dams that are over ten feet in height or contain greater than or equal to 9.2 acre-feet of storage (John Falk, 1997, personal communication). For power generation, Oregon has 116 dams associated with hydro-electric power, two coal-fired powered plants, one decommissioned nuclear plant, and one decommissioned wind-powered plant. Major harbor facilities are in Portland, Astoria, Newport and Coos Bay. The natural gas field and storage facility is near Mist in the northern Coast Range.

Geologic conditions impact the engineering design of a facility and its foundation. The widespread and differing problems with foundations in Oregon reflect the state's diverse geology. Engineering foresight must be used when facilities are constructed over buried valleys or in volcanic, glacial, and landslide terrain. Some of the common geologic influences on dams are the variable permeability of volcanic rocks and glacial deposits, decomposed volcanic rocks and the formation of smectite (montmorillonite) and halloysite clays, the great thickness of decomposed

rock soils, slope stability, and recent advancements in the understanding of seismicity in the region.

Introduction

Engineering geologic or geologic evaluations are often conducted during design and maintenance studies for significant facilities. In Oregon, some of the significant facilities consist of dams, power plants, harbors, a natural gas field, hospitals, schools, and large buildings. Chapter 3 presents an introduction to some of Oregon's dams and foundation characteristics of some of the buildings in Portland. Facilities associated with transportation are discussed in Chapter 4.

Overview of Facilities

Dams are far and wide the greatest number of facilities in Oregon. They range from small earthfill dikes to a 469 feet high concrete arch dam and a 519 feet high zoned earth and rockfill dam. The Dam Safety section of the Oregon Department of Water Resources Technical Services Division has the authority over approximately 1,254 dams within, or bordering Oregon that are both ten feet and over in height and contain reservoirs greater than or equal to 9.2 acre-feet of water storage (John Falk, 1997, personal communication). The Portland District of the Federal Energy Regulation Committee (FERC) oversees the safety programs and licenses for 116 dams associated with the generation of hydro-electric power in Oregon (Arthur Martin, 1997, personal communication). These FERC licensed dams range in height from as low as ten feet to the highest at 440 feet.

Some basic statistics on the height of dams are shown in Table 1. The vast majority of the dams are under 50 feet in height (87.5%) and the most common height is from 15 to 24 feet (34.4%). Only 4.6 percent are over 99 feet in height. Four dams are over 400 feet in height and one is over 500 feet. Table 2 lists basic data and information on most of the dams that are over 99 feet in height

Other electricity generating facilities in Oregon are: the Boardman coal-fired power plant, the gas-fired Beaver Plant near Clatskanie, the Trojan Nuclear Plant near Rainier that is presently being decommissioned, and a decommissioned wind-powered plant near Cape Blanco.

Geothermal resources have been explored in Oregon but not developed. Significant harbor facilities are in Portland, Astoria, Newport, and Coos Bay. One natural gas field and storage facility is in northwest Oregon near Mist.

Buildings are also a significant type of facility in Oregon; some have a unique influence due to their engineering geologic setting. One of these is the historic Crater Lake Lodge that is perched on the rim of a volcanic caldera. The foundation of the lodge is impacted by relatively rapid erosion of volcanic sediments at the top of the steep caldera slope. The Providence St. Vincent Medical Center was built overlying Boring Lava flows that contain lava tubes (Deacon and Wright, 1997).

Buildings constructed in a geologic environment often experience similar problems, such as settlement of structures built along the Columbia River. The Columbia River floodplain is actually a buried valley up to 300 feet deep. Sediment deposits within this buried valley consist of clay, silt, sand and gravel. The clay and silt is compressible and can attain thicknesses of over 200 feet. Such a layer can experience settlement of thee inches per one foot of fill or equivalent in weight of a building (Derek Cornforth, 1997, personal communication). This is a significant engineering problem when you consider how many structures are built in this area.

Other geologic environments in Oregon contain extensive landslide terrain. Certain geologic formations in Oregon are known for their susceptibility to sliding. Some of the well known formations are the Vantage Horizon in the Columbia River Basalt Group; Sandy River Mudstone and Portland Hills Silt in the Portland area; the Breitenbush, Rhododendron and Sardine formations in the Cascades; the Eocene formations in the Coast Range (Tyee, Yamhill, Spencer, Nestucca); and the Chenoweth Formation east of Mount Hood, just to name a few. Many cities built in areas underlain by a geologic unit susceptible to sliding experience serious concerns for safety and costs of remediation to maintain their facilities.

Dam Safety

Dam owners are responsible for maintenance and safety of the dams. Oregon Department of Water Resources Dam Safety has the jurisdictional ability to make inspections of structures and to review the design of a dam. At FERC licensed dams, an independent consultant inspection and review, including engineering geology issues, is conducted every five years. Dams that are considered High and Significant Hazard are reviewed by FERC yearly. Other dam owners and operators with safety programs include the following federal agencies: Bureau of Reclamation, Army Corps of Engineers, Forest Service, Bureau of Land Management, Bureau of Indian Affairs, and Fish and Wildlife.

Engineering Geology of Oregon Dams

Types of dams and dam foundations vary in the state of Oregon along with its diversity in geology. Although the type of dam and its site selection is dependant on hydrologic requirements, engineering geology of the foundation and available material resources play a significant role in dam construction and maintenance. A few common geologic influences on Oregon dams are: foundation rock consisting of volcanic lava flows and interbeds, weathering and decomposition of volcanic material, seismicity, glaciation, and landslides.

Lavas and sediments, common in the state, pose difficulties for dam foundations due to the differential permeabilities of the bedded material. A massive lava flow may form a good foundation. However, the fractured and rubbly top and bottom of a flow and granular volcanic interflow sediments are often highly permeable. And vice versa, the jointed lava flow can be permeable, and the interflows can be weathered and clayey and have a low permeability. Many foundations in this material require extensive grouting programs to provide positive cutoff walls to groundwater. The construction of Round Butte Dam, Pelton Arch Dam, Bully Creek Dam, and Agate Dam are good examples of this.

Alteration of volcanic rock and sediment often results in the formation of smectite (montmorillonite) group clays. This clay is subject to swelling when wetted and contraction when dried. Halloysite, another clay common in Oregon, can also form as a result of alteration of volcanics. This clay is similar to kaolinite, but contains extra water molecules that are released if the clay structure is disturbed. Soils containing both these clays are difficult to work with. Special handling specifications are required when constructing earth fill dams out of soil containing them, especially when both occur together. Design and construction of Trask River Dam has been impacted by this soil.

High amounts of precipitation west of the Cascade Range have resulted in the development of thick residual bedrock soil. This soil has attained thicknesses of near 100 feet in the Coast Range. Due to the thickness of decomposed bedrock, it is often cost prohibitive to excavate to sound rock.

Recent advancements in the understanding of seismicity in the Pacific Northwest has resulted in re-evaluation of the seismic stability of many of the dams in Oregon. Ongoing research is developing new information on seismic hazards along the Cascadia Subduction Zone and in central and southern Oregon. This new information has resulted in an increased level and duration of ground shaking used to calculate the stability of a dam. Some of the dams in Oregon may need repairs to mitigate potential failures that are identified from new studies and calculations of ground shaking and liquefaction.

Landslides are a common occurrence in Oregon. This is especially the case in mountainous regions where multiple landslides cover vast areas. Many complex slides are on a scale of square miles in area. A number of Oregon dams are impacted by ancient, old, and recent slides. A few of the dams were constructed, during the early history of dam construction, on landslides that were not recognized at the time. These dams typically have extensive seepage problems, may have required substantial maintenance, and have a heightened degree of monitoring for safety. A few large dams with foundations on landslide debris include Bonneville, Bull Run No. 2, and Ochoco. Landslides around reservoirs are common, also requiring frequent monitoring. If a large slide goes into the reservoir, a wave can be generated that could overtop the dam. Examples of reservoir landslides are at Scoggins Dam in northwest Oregon and Owyhee Dam in east-central Oregon.

Engineering Geologic Interest at Dams

Engineering geology of the four dam projects on the lower Columbia River has previously been reviewed in papers published as part of the Washington Division of Geology and Earth Resources Bulletin 78 (Galster, 1989). These dams include the Bonneville, Dalles and John Day (Sager, 1989a, b, and c) and the McNary (Miklancic, 1989). A number of Oregon dams are reviewed in papers within this chapter. Many other dams are of special interest to us because of their unique geologic setting, foundation condition, or the type of dam. The following paragraphs provide a brief overview of some of these geologically interesting dams over 99 feet in height.

Applegate Dam. This project is located on the Applegate River in southwestern Oregon, an area now considered to have a very high seismic risk. Recent research of possible past earthquakes of very large magnitude just off the Pacific coastline has caused considerable upgrading of seismic ground motions for design of structures in this area. Peak ground acceleration in this area is now projected to be on the order of 0.4 to 0.5g for the maximum credible earthquake. As a result, the Corps of Engineers has begun to reevaluate the seismic safety of the structures at Applegate Dam to assure that this project does not pose a threat to life and property downstream of the dam if a very large earthquake were to occur. The dam is founded on firm metasedimentary bedrock so stability will be analyzed based on site-specific ground motions developed for a rock site.

Bull Run Dam No. 2. This project in the City of Portland's watershed in the western Cascades is a zoned earth and rockfill structure constructed on a large ancient landslide. The dam site is a narrow channel that the Bull Run River cut through the slide, down to Columbia River Basalt bedrock. The valley floor foundation consists of Columbia River Basalt (CRB), and the abutments consist of landslide debris overlying slightly cemented sand and gravel, and CRB. The landslide debris consists of a heterogeneous mixture of Western Cascade andesite/basalt rubble and blocks of Rhododendron Formation embedded in a matrix of clay, silt, sand, and gravel- to boulder-sized pieces of Rhododendron Formation. The landslide is not moving. However, following construction, the occurrence of a number of springs downstream of the dam resulted in an extensive grout curtain installation program. Numerous piezometers are monitored and reviewed to watch for changing conditions in the foundation of this dam.

Clear Branch Creek Dam. This project near Hood River is a zoned earth and rockfill structure constructed on sedimentary deposits of glacial drift, moraine, and lacustrine sand, silt and minor gravel. A much higher than anticipated horizontal permeability through the left abutment foundation material initially washed out backfill adjacent to the concrete spillway chute. A collection and drainage system was installed soon after the original construction to intercept the seepage and conduct it to a safe outlet. In addition, rockfill has been placed to enhance the stability of the dam. A new and larger spillway has recently been constructed.

Cougar Dam. This project is located in west-central Oregon in the western Cascades on the McKenzie River drainage. It is the highest dam in the state of Oregon. At a maximum height of 519 feet, it is one of the tallest structures of its kind anywhere. While the dam design is a fairly conventional zoned earth and rockfill structure, it has steeper than usual upstream and downstream slopes. As a result, it is a very impressive structure to view from the downstream side. The dam is founded mainly in a series of bedded tuffs, with a dacitic intrusive body (a sill structure) occupying much of the abutment slopes. The dacitic intrusive was originally called a basalt but was later mapped by State of Oregon geologists as a dacite (Priest and Vogt, 1983). The tuff unit consists of stratified tuff, lapilli tuff and tuff breccia with interbeds of mudstone and sandstone. The unit was given the informal name of “Tuffs of the Cougar Reservoir” by Priest and Vogt (1983).

Emigrant Dam. This project, located near Ashland in southern Oregon, was originally a concrete arch dam built in 1924. In 1960 and 1961 the dam was raised 81 feet and buried in a zoned earth and rockfill embankment. An ancient landslide on the upstream right abutment is a negligible hazard to the dam.

Green Peter Dam. This project is located in west-central Oregon in the western Cascades on the Middle Fork of the Santiam River. The project was constructed in the 1960's for power generation and flood control purposes. It is founded on a series of lava flows with a few interbeds and it may be the most highly instrumented dam in Oregon. Due to its size and numerous shear zones in the foundation, this large concrete gravity structure was instrumented with a variety of instrument types to monitor its long-term performances. Both foundation and structure monitoring instruments were included in the instrumentation program. Installed during construction were 30 multi-position extensometers, nine optical plummets, six deflectometers, five slope inclinometers, two strong motion accelerographs, several piezometers, and survey target points on the dam crest. The estimated cost of this instrumentation program in the 1960's was about $300,000.

Hells Canyon Dam. This project on the Snake River in northeast Oregon is a concrete gravity arch dam and was the highest of its kind when constructed in 1964 to 1967. It is considered a “proof-project” where construction rules were tested and developed. Internal stress relief cracks formed in the concrete. They permit a certain amount of seepage through the structure and adjust with expansion and contraction. There is no loss to the dams structural integrity due to the cracks.

Hills Creek Dam. This project is located in west-central Oregon in the western Cascades on the Middle Fork Willamette River. The foundation of Hills Creek Dam is rather unique in that it contains the intersection of two major fault structures, the Middle Fork Fault and the Hills Creek Fault. Although neither fault is considered active, the faulting produced intense jointing and crushing of the rock across the dam site area, resulting in increased permeability, deep weathering, and open joints partially filled with clay. These foundation problems required special treatment during construction (Griffiths, 1997)

Smith River Dam. This project is located in the High Cascades east of Eugene. There are no apparent special interests at the Smith River Dam, part of the Carmen-Smith Hydroelectric Power Project. This project consists of Carman Diversion Dam and tunnel, Smith River Dam and diversion tunnel, and Trail Bridge Dam. Construction of the Carmen Diversion Tunnel proved to be very difficult due to high permeability and excessive groundwater problems. Seepage ranging up to 27,000 gallons per minute was encountered in this tunnel requiring extensive grouting and concrete lining.

Willow Creek Dam. This project is located on Willow Creek in north-central Oregon just upstream from the town of Heppner. It was the world's first dam constructed entirely of roller-compacted concrete (RCC). The 435,000 cubic yards of RCC were placed in the amazingly short period of 125 days. The RCC is placed in a manner more like an earth embankment than a conventional concrete structure, which accounts for the rapid rate of placement. The structure is founded on the basalt flows of the Columbia River Basalt Group. The dam was built in 1982 primarily to protect the residents of Heppner from flooding. In 1903 a serious flood claimed 250 lives when Willow Creek overflowed its banks. In terms of lives lost, this disaster was among the most devastating ever recorded in the United States.

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TABLE 1. Statistics on Oregon Dams[1]

	Number of Dams								
	Height (in feet, greater than)								
County	Total	14	24	49	99	149	199	299	399
Baker	73	49	22	7	3	3	2	1	1
Benton	16	12	5	1	0	0	0	0	0
Clackamas	54	48	33	8	3	1	1	0	0
Clatsop	6	6	5	2	0	0	0	0	0
Columbia	6	5	5	0	0	0	0	0	0
Coos	17	10	4	1	0	0	0	0	0
Crook	41	37	26	7	2	1	0	0	0
Curry	8	6	2	2	0	0	0	0	0
Deschutes	16	12	7	2	1	0	0	0	0
Douglas	64	47	21	10	4	1	0	0	0
Gilliam	0	0	0	0	0	0	0	0	0
Grant	24	21	12	2	0	0	0	0	0
Harney	61	47	27	5	0	0	0	0	0
Hood River	6	6	4	1	1	0	0	0	0
Jackson	68	56	37	20	5	3	3	1	0
Jefferson	14	12	10	4	2	2	2	1	1
Josephine	17	15	7	0	0	0	0	0	0
Klamath	54	44	19	3	0	0	0	0	0
Lake	63	47	20	2	0	0	0	0	0
Lane	48	33	14	10	8	5	5	3	1
Lincoln	6	5	3	3	0	0	0	0	0
Linn	18	11	8	6	5	3	3	2	1
Malheur	91	49	32	12	5	1	1	1	0
Marion	54	39	20	2	0	0	0	0	0
Morrow	6	5	3	2	1	2	0	0	0
Multnomah	20	19	15	7	2	2	0	0	0
Polk	56	42	12	1	0	0	0	0	0
Sherman	11	11	6	1	1	0	0	0	0
Tillamook	2	2	1	0	0	0	0	0	0
Umatilla	14	8	8	4	3	2	0	0	0
Union	24	16	9	3	2	0	0	0	0
Wallowa	8	4	2	1	1	1	1	1	0
Wasco	22	17	13	5	2	0	0	0	0
Washington	80	52	18	3	1	0	0	0	0
Wheeler	15	16	10	1	0	0	0	0	0
Yamhill	46	34	14	3	0	0	0	0	0
TOTAL	1129	842	454	141	52	25	18	10	4
	100.0%	74.6%	40.2%	12.5%	4.6%	2.2%	1.6%	0.9%	0.4%
Dam Heights (feet)	9-14	15-24	25-49	50-99	100-149	150-199	200-299	300-399	400+
Number of Dams	287	388	313	89	27	7	8	6	4
	25.4%	34.4%	27.7%	7.9%	2.4%	0.6%	0.7%	0.5%	0.4%

[1]List of dams provided by Oregon Department of Water Resources Dam Safety

TABLE 2. Some of Oregon's Dams, 100 Feet and Over in Height[1]

Dam	County	Drainage	Operator	Engineer	Built
Agency Valley	Malheur	N. Fk. Malheur R.	Bureau of Rec.	Bureau of Rec.	1934-35
Applegate	Jackson	Applegate River	Corps of Engrs.	Corps of Engrs.	1978-80
Berry Creek	Douglas	Berry Creek	Douglas County	IECO[2]	1978-80
Big Cliff	Marion/Linn	N. Fk. Santiam R.	Corps of Engrs.	Corps of Engrs.	1951-53
Blue River	Lane	Blue River	Corps of Engrs.	Corps of Engrs.	1966-68
Brownlee	Baker	Snake River	Idaho Power		1955-58
Bull Run No. 1	Multnomah	Bull Run River	City of Portland		1927-28
Bull Run No. 2	Clackamas	Bull Run River	City of Portland	Stev. & Thompson	1956-61
Bully Creek	Malheur	Bully Creek	Bureau of Rec.	Bureau of Rec.	1962-63
Clear Branch Cr.	Hood River	Clear Branch Cr.	Irrigation Dist.	Soil Cons. Serv.	1967-68
Cold Springs	Umatilla	Cold Springs R.	Hermiston I. D.	Bureau of Rec.	1906-08
Cougar	Lane	S. Fk. McKenzie R.	Corps of Engrs.	Corps of Engrs.	1959-61
Crow Creek	Wasco	S. Fk. Mill Creek	City of T. Dalles	CH2M Hill	1967-68
Detroit	Marion/Linn	N. Fk. Santiam R.	Corps of Engrs.	Corps of Engrs.	1949-51
Dorena	Lane	Row River	Corps of Engrs.	Corps of Engrs.	1947-49
Emmigrant	Jackson	Emmigrant Creek	Talent Ir. Dist.	Bureau of Rec.	1924, '59-61
Fall Creek	Lane	Fall Creek	Corps of Engrs.	Corps of Engrs.	1964-65
Foster	Linn	S. Fk. Santiam R.	Corps of Engrs.	Corps of Engrs.	1964-67
Galesville	Douglas	Cow Creek	Douglas County	IECO[2]	1985-86
Green Peter	Linn	N. Fk. Santiam R.	Corps of Engrs.	Corps of Engrs.	1963-67
Hells Canyon	Wallowa	Snake River	Idaho Power		1964-67
Hills Creek	Lane	N. Fk. Willam. R.	Corps of Engrs.	Corps of Engrs.	1956-61
Howard Prairie	Jackson	Beaver Creek	Irrigation Dist.	Bureau of Rec.	1957-58
Lemolo No. 1	Douglas	N. Fk. Umpqua R.	Pacific Power	PSEC[3]	1953-55
Lookout Point	Lane	N. Fk. Willam. R.	Corps of Engrs.	Corps of Engrs.	1948-54
Lost Creek	Jackson	Rogue River	Corps of Engrs.	Corps of Engrs.	1972-76
Mason	Baker	Powder River	Bakerville I. D.	Bureau of Rec.	1967-68
McKay	Umatilla	McKay Creek	Bureau of Rec.	Bureau of Rec.	1923-27
North Fork	Clackamas	Clackamas River	PGE[3]		1957-58
Ochoco	Cook	Ochoco Creek	Ochoco Ir. Dist.	Bureau of Rec.	1918-20
Owyhee	Malheur	Owyhee River	Bureau of Rec.	Bureau of Rec.	1928-32
Oxbow	Baker	Snake River	Idaho Power		1959-61
Reeder Gulch	Jackson	Ashland Creek	City of Ashland	City/Consultants	1928
Smith River	Linn	Smith River	EWEB[5]	CH2M Hill/Bechtel	1961-63
Soda Springs	Douglas	N. Umpqua River	PacifiCorp	PSEC[3]	1950-52
Timothy Meadows	Clackamas	Oak Grove Fk.	PGE[4]	Ebasco Services	1954-56
Trask River	Washington	N. Fk. Trask River	Commission	STRR[6]/CCI[7]	'69-70, '96-97
Warm Springs	Malheur	Malheur River	Bureau of Rec.	Bureau of Rec.	pre 1926
Wickiup	Deschutes	Deschutes River	Irrigation Dist.	Bureau of Rec.	1938-40
Willow Creek	Morrow	Willow Creek	Corps of Engrs.	Corps of Engrs.	1982
Willow Creek 3	Malheur	Willow Creek	Water District	J. A. Green	1910-11
Wolf Creek	Union	Wolf Creek	Powd. Val. Wat.	Soil Cons. Serv.	1972-75

[1]Data collected from files maintained by Oregon Department of Water Resources Dam Safety
[2]IECO-International Engineering Company, Inc.
[3]PSEC-Pioneer Service and Engineering Company
[4]PGE-Portland General Electric
[5]EWEB-Eugene Water & Electric Board
[6]STRR-Stevens Thompson Runyan and Ries
[7]CCI-Cornforth Consultants, Inc.

TABLE 2. Some of Oregon's Dams, 100 Feet and Over in Height
(cont'd)

Dam	Height	Crest Length	Type of Dam	Foundation Materials
Agency Valley	110	1,850	Earth with concrete face	Basalt & tuff breccia
Applegate	242	1,300	Zoned earth & rockfill	Metasedimentary rock
Berry Creek	140	820	Zoned earthfill	Eocene conglomerate
Big Cliff	172	295	Concrete gravity	Tuff/lapilli tuff
Blue River	270	1,250	Zoned earth & rockfill	Lapilli tuff with andesite
Brownlee	400	1,380	Zoned earth & rockfill	Basalt
Bull Run No. 1	194	970	Concrete arch	Columbia River Basalt
Bull Run No. 2	145	900	Zoned earth & rockfill	Landslide
Bully Creek	124	3,080	Zoned earth & rockfill	Tertiary basalt & lacustrine
Clear Branch Creek	112	1,440	Zoned earth & rockfill	Glacial drift & lacustrine
Cold Springs	115	3,450	Zoned earthfill	Columbia River Basalt & lacustrine
Cougar	519	1,600	Zoned earth & rockfill	Dacitic intrusive & tuff
Crow Creek	100	800	Zoned earth & rockfill	Basalt & weathered conglomerate
Detroit	450	1,457	Concrete gravity	Andesite
Dorena	145	3,300	Zoned earthfill	Volcaniclastic/andesite
Emmigrant	196	750	Concrete arch, zoned fill	Tertiary andesite & sedimentary rock
Fall Creek	205	5,050	Zoned earth & rockfill	Volcanic sandstone/andesite
Foster	126	4,640	Zoned earth & rockfill	Tuff & basalt
Galesville	167	980	Roller-compacted concrete	Jurassic volcanics, metamorphosed
Green Peter	380	1,517	Concrete gravity	Basalt & tuff
Hells Canyon	330	910	Concrete gravity	Triassic volc. flows & tuffs, metamorph.
Hills Creek	304	1,920	Zoned earthfill	Tuff/tuff breccia
Howard Prairie	100	1,040	Zoned earthfill	Andesite/basalt & tuff breccia
Lemolo No. 1	120	775	Rock with concrete face	Andesite/basalt
Lookout Point	295	3,262	Zoned earthfill	Andesite/basalt
Lost Creek	345	3,600	Zoned earth & rockfill	Basalt & tuff
Mason	173	895	Zoned earth & rockfill	Andesite, metamorphosed & alluvium
McKay	165	2,700	Gravel with concrete face	Basalt & conglomerate
North Fork	207	676	Concrete arch	Andesite/basalt
Ochoco	128	950	Hydraulic & zoned fill	Tuff, fluviolacustrine, alluv. & landsl.
Owyhee	340	833	Concrete arch	Rhyolitic intrusive
Oxbow	209	960	Rockfill	Columbia River Basalt
Reeder Gulch	107	546	Concrete arch	Diorite & granodiorite intrusions
Smith River	228	1,150	Zoned earth & rockfill	Ande./basalt, pyroclastics & sediments
Soda Springs	112	153	Concrete arch	Basalt, andesite, rhyolite & tuff. sed's.
Timothy Meadows	110	600	Homogenous earthfill	High Cascade volcanics
Trask River	121	2,100	Zoned earth & rockfill	Basalt & decomposed basalt
Warm Springs	106	469	Concrete thin arch	Basalt
Wickiup	100	13,860	Zoned earthfill	High Cascade basalt & fluviolacustrine
Willow Creek	157	1,780	Roller-compacted concrete	Basalt
Willow Creek 3	125	650	Earthfill with puddled core	Basalt, tuff & sedimentary rock
Wolf Creek	130	1,600	Zoned earth & rockfill	Pre-tertiary volc. & sed. rock, meta'd.