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MARMOT DAM REMOVAL

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ABSTRACT

Marmot Dam was the upstream diversion dam for Portland General Electric Company's Bull Run Hydropower Project Decommissioning. This paper will present the design and construction for the removal of Marmot Dam located at RM 30 on the Sandy River in northwestern Oregon. The dam was a 57-foot high roller compacted concrete (RCC) structure with a spillway crest length of 345 feet. The current dam was constructed in 1989 at the site of a much older timber crib dam that was originally constructed in 1913. PGE completely removed the RCC dam to the level of the original river bed, including a section of the original timber crib dam just upstream, the canal inlet and headworks, and the fish ladder within one construction season, from July 1 to October 15, 2007. This work was accomplished during an extended in-water work period approved by the Oregon Department of Fish and Wildlife (ODFW). An upstream cofferdam was designed to withstand flows up to a three-year return flood. Dewatering wells were installed to maintain stability and allow removal of the concrete structures in the dry. Controlled blasting and excavators were used to remove the RCC concrete and remaining timber crib dam section, and fish ladder. A controlled failure of the cofferdam and initial release of the retained sediments was allowed to occur on October 19, 2007 during a fall storm event. This selected alternative for removal in a single season will eventually deliver approximately 960,000 cubic yards of sediment downstream.

INTRODUCTION AND SCOPE

Over the past several years, the removal of dams has become a more frequent undertaking and indications are that many more are sure to occur. We now recognize that dam removals require significant engineering and scientific effort to accomplish. This project was unique in how well the planning, design, and removal processes were executed to achieve success with very little impact. Issues such as how to deal with the upstream impounded sediment, how best to safely and efficiently remove the primary and appurtenant structures and, the best way to minimize downstream impacts to the river, fish and wildlife and public property, were very successfully addressed to the satisfaction of a wide variety of stakeholders. The removal of Marmot Dam will very likely be used as a model for similar dam removal projects for years to come.

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This paper provides details of the final design and actual removal of the temporary cofferdams, bridges, and access roads necessary for the demolition and removal of Marmot Dam and appurtenant structures. Geotechnical design information and parameters, as well as the hydrologic basis and hydraulic analysis for selecting the river flow used to size the upstream cofferdam are presented. Also included are the detailed sequence for constructing the temporary cofferdams, removing the RCC structure, and the breach removal process.

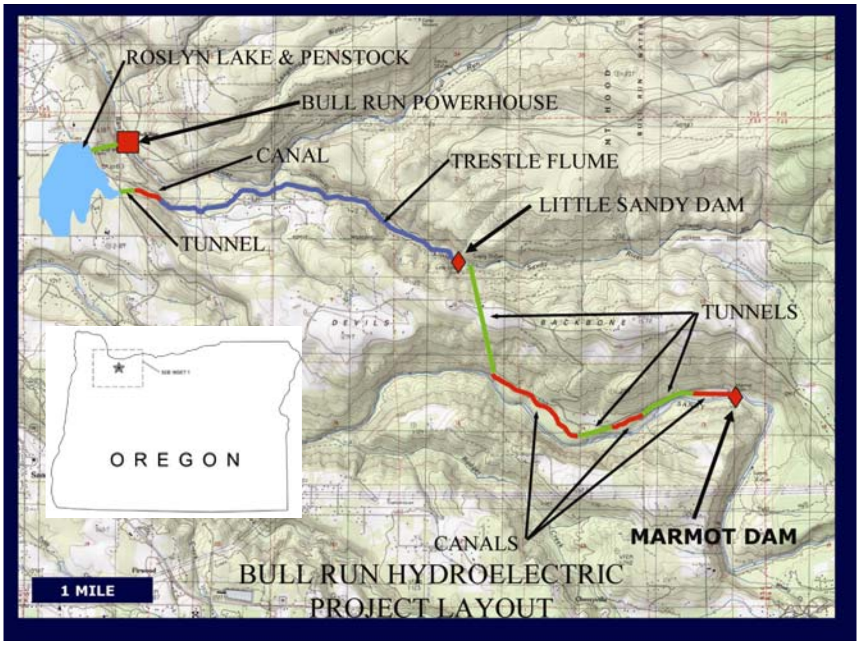

Figure 1. Vicinity and Location Map

Located on the Sandy River (see Figure 1), Marmot Dam was a roller compacted concrete (RCC) structure with a conventional reinforced concrete overflow spillway crest length of 345 feet and elevation of approximately 733 feet mean sea level (msl). Figure 2 is a photo that shows the conditions that existed prior to the dam removal. As can be seen in the photo, impounded sediment had reached the top of the dam crest by the time it was removed. The concrete dam was constructed in 1989 at the site of a much older timber crib dam that was originally constructed in 1913. The main section of the dam was 195 feet long. A fish ladder on the south side of Marmot dam provided upstream passage. On the north end of the dam, a concrete gravity-section wing dam extended downstream to provide 140 feet of additional spillway, and to direct water to an intake structure. The intake structure had a trash rack and two tainter gates that regulated the diversion flow into a canal system. Figure 3 is an aerial photograph that shows these various features of the project. Marmot Dam was completely removed to the level of the original river bed. This included a section of the original timber crib dam that was buried in the impounded sediments just upstream of the structure. Appurtenant structures also removed included the diversion power canal inlet and headworks, and the fish ladder.

Figure 2. Photo of Marmot Dam

PROJECT HISTORY

In 1999 the Portland General Electric Company (PGE) decided for economic reasons to decommission their Bull Run Hydropower Project. Following preparation of a detailed Settlement Agreement and Decommissioning Plan, FERC (Federal Energy Regulatory Commission) issued a Surrender Order in 2004 which allowed PGE to continue to operate the Bull Run Hydropower Project until the removal work began. As the upstream diversion dam for the Bull Run Hydropower Project, Marmot Dam was the first major feature of the hydropower project to be removed. Marmot Dam is the largest dam removal project accomplished to date in the northwest. Cornforth Consultants, Inc. worked for PGE since 1999 as the geotechnical design firm of record for the removal of Marmot Dam. Major tasks included: developing and evaluating dam and sediment removal alternatives and selecting a feasible design; final environmental testing and characterization of the impounded sediments; preparing permitting documents (including the joint federal and state Section 404 Permit, which included the Section 401 Clean Water Certification permit by ODEQ); preparation of a final design report; preparation of contract plans and specifications; and providing construction observation during the dam removal work.

In September 2000 Cornforth Consultants, Inc. prepared a report titled "Preliminary Plans and Details for Cofferdams and River Diversion Structures Marmot Dam and Sediment Removal Plan" for PGE. Subsequent to that preliminary design, PGE examined proposed alternatives that included dam removal methods in one or two construction seasons, with sediment excavation options that ranged from as much as one-third the total retained quantity to the minimal absolutely necessary. The preferred decommissioning plan eventually selected included complete removal of the existing RCC dam to the level of the original river bed, the remnant of the older timber crib dam, the canal inlet and headworks, and the fish ladder (Figure 3). This work was completed from July 1 to October 31, 2007, during the period normally designated by the Oregon Department of Fish and Wildlife (ODFW) for in-water work. Non-in-water preparatory work was performed in May and June. The prime Contractor for this project was the Natt McDougall Company of Portland, Oregon. Blasting was performed by a subcontractor, Superior Blasting of Nampa, Idaho. Dewatering wells were completed by Malcolm Drilling of Seattle, Washington.

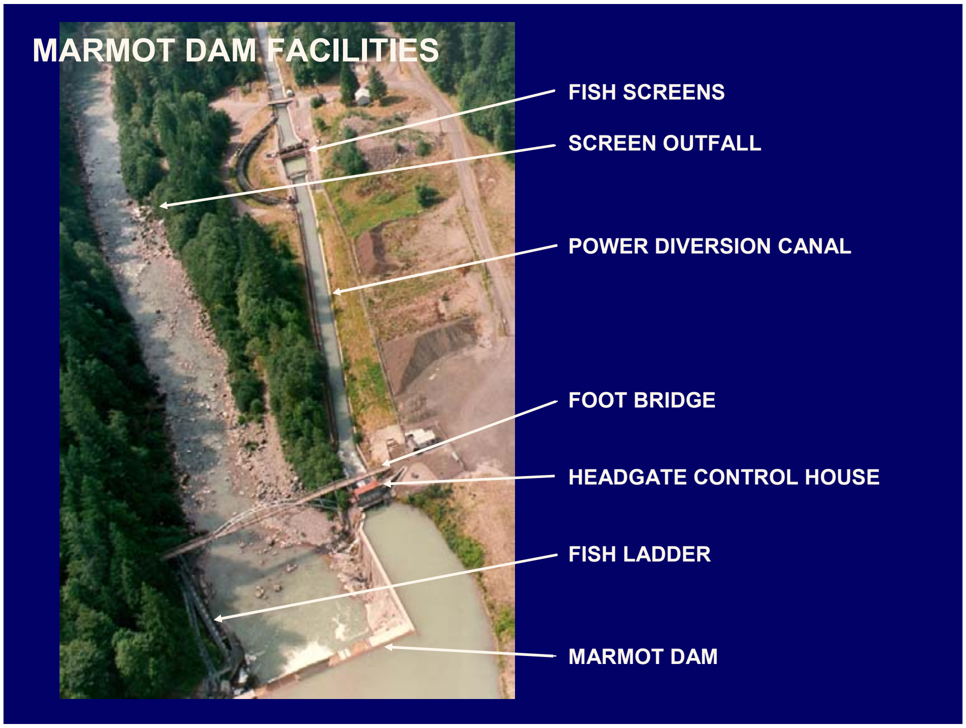

Figure 3. Aerial Photo of Marmot and Dam Facilities

To accomplish the demolition of the in-stream structures, a cofferdam was constructed approximately 180 feet upstream of the RCC dam, and another placed a short distance downstream as shown in Figures 4 and 5. The upstream cofferdam was designed to withstand flows up to approximately 1,900 cfs and fail during the winter season flows after dam removal was completed.

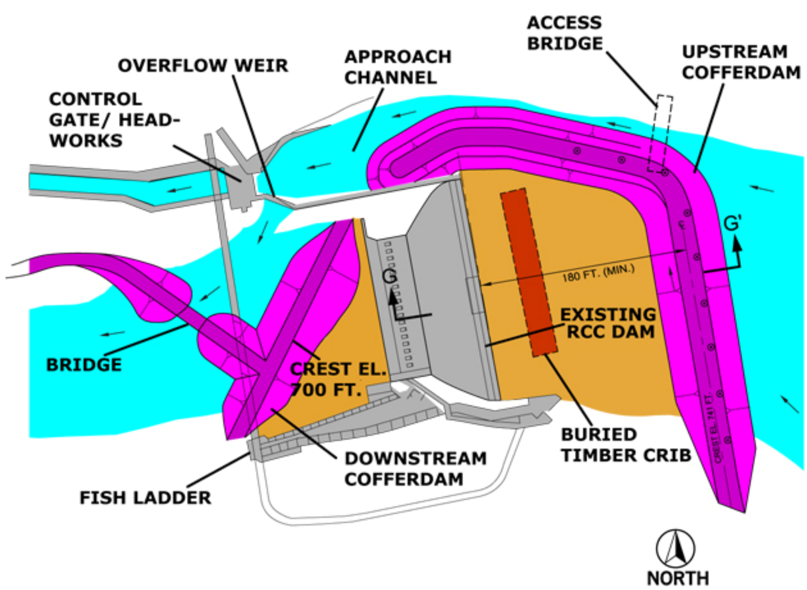

Figure 4. Cofferdam/Diversion Plan

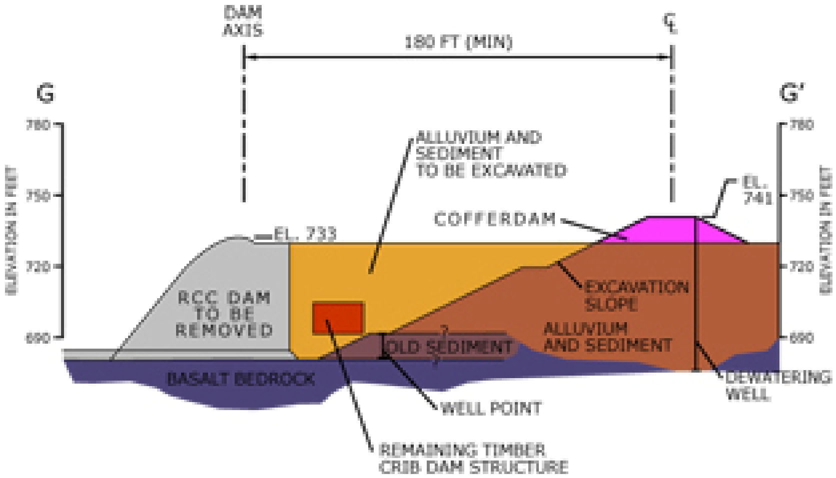

Figure 5. Cross Section

The upstream cofferdam design required dewatering wells to maintain stability of the excavation slopes and to allow the dam removal work to be done in dry conditions. These wells were shut down and removed when the higher flows arrived in late October, 2007 to expedite the breaching of the cofferdam. The downstream cofferdam was also designed to fail at the same time as the upstream cofferdam.

Controlled blasting and excavators were used to remove the concrete and the remaining timber crib dam section, fish ladder, and other appurtenant structures. Excavation of the stored sediment material between the upstream cofferdam and the RCC structure progressed very well. Material gradation and distribution appeared to be very close to what was expected. The demolished concrete has been rubblized and temporarily stockpiled on site in an area on the right bank adjacent to the dam, and utilized for future road surfacing, structural fill material or concrete production.

HYDROLOGY AND HYDRAULIC DESIGN

Assistance in the areas of hydrologic and hydraulic analyses was provided by ENSR International of Redmond, Washington. The previous hydraulic studies for the RCC dam construction in 1989 provided our design team with a preliminary basis for the present dam removal project. The 1989 data were re-evaluated by ENSR using updated analysis methods and data/flow records from the Sandy River. A summary of the hydrologic analysis and hydraulic design criteria adopted for the dam removal cofferdam design is provided below.

Design Flood Frequency and Flow

Although the 1989 cofferdam was designed to a flood frequency return period of three years, there is no current regulatory agency criterion mandating this as a design standard. Therefore, the design analyses evaluated the associated risk for return periods of two, three, and five years to check the sensitivity to different intervals. The analyses focused on the July through October in-water work period, using approximately 97 years of hydrologic data. The hydraulic analysis method is discussed below.

Preliminary results of ENSR's hydraulic analyses were reviewed with PGE personnel in fall 2005. At that time, it was concluded that a three year flood frequency return period would be appropriate for the cofferdam design. Key reasons for this are: (1) the dam removal construction time was short, (2) a failure would not endanger the general public, (3) the cofferdam provided a diversion only, and did not raise or impound water above its normal level, and (4) the three year period provided a reasonably conservative estimate of the expected flood conditions.

Hydraulic Analysis and Risk Assessment

The hydraulic analysis was performed to estimate the water surface elevation for the selected design flood flow. The analysis determined a combined stage-discharge relationship for the outlet structures and the computation of backwater profiles to estimate water surface elevations to determine the appropriate cofferdam height. Surveyed cross sections were utilized to develop representative river cross-sectional profiles to a distance of approximately 1,200 feet upstream of the gate control structure. This data was imported into a hydrodynamic model (HEC-RAS) to determine backwater profiles.

Initial calculations for the three year flood flow frequency suggested that the river discharge in October would be significantly higher than the July-August time period. Subsequently, a close inspection of the historic flow records revealed that the data for the last two weeks in October skew the discharge forecasts to much higher levels. As a result, a work window of July 1 through October 15 was selected to help reduce the risk of overtopping the cofferdam. Based on ENSR's calculations, the peak daily discharge rate for a three year flood frequency during the July 1 through October 15 window is approximately 1,400 cfs. This flow would result in a water surface elevation of 737½ feet. By applying a 105% confidence limit (or maximum risk reduction for this period), a mean flood flow of 1,400 cfs increases to approximately 1,900 cfs, which results in a water surface elevation of nearly 740 feet. To ensure sufficient freeboard at an acceptable risk, the top of the cofferdam was selected to be elevation 741 feet.

ENSR's computational model also determined the maximum cross-sectional average flow velocity for the cofferdam design at 9.5 feet per second (ft/s), occurring along the approach channel that leads to the gate structure and canal shown in Figure 3. This value was used to select materials for providing erosion protection along the face of the cofferdams.

GEOTECHNICAL DESIGN

Geotechnical Investigations

The subsurface information obtained from original geologic investigations conducted for the 1989 reconstruction of the dam were reviewed and utilized for the dam decommissioning design. Site geology was reported in the April 1989 Geotechnical Report by EBASCO based on the four borings drilled and three test pits excavated at that time. The dam itself, located in a narrow canyon of the Sandy River, was founded on bedrock of highly fractured andesite in the valley and left abutment, and massive volcanic breccia on the right abutment. Terrace alluvium exists on both river banks, with a partially cemented conglomerate unit found in places on the right bank sandwiched between the terrace alluvium and the volcanic breccia. Three test pits were used to evaluate the terrace alluvium materials on the right bank adjacent and just downstream of the dam for use in the 1989 cofferdam construction. For the present dam removal project, no new borings were considered necessary for the final design of the cofferdams. However, a series of test pits were performed on the right abutment area to investigate potential borrow sources. Conditions encountered in test pit explorations are summarized below.

In a report published in February 2000 for PGE by Squier Associates of Portland, Oregon, the results of an extensive study were provided that characterized the physical and chemical properties of the sediment retained behind the dam. The following table summarizes the grain size distribution of the impounded sediments. Layer thicknesses varied, but the units were generally oriented with Unit 1 progressively underlain by Units 2 and 3.

Table 1. Summary of Grain Size Properties for Sediment Units Behind Marmot Dam

Strati-graphic Unit	General Sediment Description	Interpreted Range of Grain Size (% by Weight)				
		Silt/Clay	Sand	Gravel	Cobble	Boulder
Unit 1	GRAVEL with Sand, Cobbles and Boulders	0 – 1	15 – 29	30 – 45	25 – 45	0 - 10
Unit 2	SAND with Silt to SAND with Silt and Gravel	5 – 15	70 – 85	0 – 23	0 – 2	0
Unit 3	GRAVEL with Sand, Cobbles and Boulders	0 – 1	20 – 39	25 – 35	20 – 25	5 - 30

Site Topography

Elevations in the vicinity of the dam range from about 750 feet at the dam to approximately 1,200 feet at the canyon rim. On the right bank of the river at and just downstream of the dam, the terrace elevation ranges from 740 to 755. This relatively flat terrace is about 250 feet wide and about 800 feet long. This area was designated in the plans to be utilized by the Contractor as a borrow source for the cofferdam materials, an area for temporary stockpiling of excavated materials, and general use area.

Construction Materials

Cofferdam materials for the 1989 construction were borrowed from the right bank alluvial terrace. Subsequently, the excavated river sediments, old timber crib rockfill, and cofferdam soils from the 1989 work were returned to this area and loosely dumped and spread. On November 15, 2005, test pit explorations were performed on the right bank terrace for the dam removal project. In general, the soils encountered varied from loose to dense, silty, sandy GRAVEL with frequent cobbles and boulders; and medium stiff to stiff, slightly clayey, fine sandy SILT. The gravel, cobbles and boulders are typically rounded to subrounded. The maximum size of cobbles and boulders in test pits typically ranged from 9 to 14 inches, however, occasional boulders up to 30 inches maximum dimension were observed.

On the basis of the test pits and additional test excavations by the dam removal Contractor, borrow areas were identified that avoided unsuitable fill and construction debris. The borrow material consisted primarily of granular terrace alluvium (i.e., the sandy GRAVEL layer) for cofferdam embankment fill. These borrow areas produced sufficient material to construct both the upstream and downstream cofferdams.

Upstream Cofferdam

A representation of the upstream cofferdam layout is shown on Figure 4, with a representative cofferdam cross section shown on Figure 5. The fill quantity needed to construct the completed upstream cofferdam was approximately 9,000 cubic yards. The first phase consisted of filling across the approach channel and tying into the existing wing wall. This diverted the flow over the RCC dam, and dried-up the approach channel to allow completion of the cofferdam embankment and installation of erosion and seepage control protection at the connection between the cofferdam and the wing wall. Flash boards were then constructed along the wing wall to provide water containment from elevation 741 feet at the cofferdam embankment to elevation 738 feet at the overflow weir just before the gate control structure. This restricted any possible overtopping to an acceptable level of risk by providing 4½ feet of capacity above the wing wall, or ½ feet of freeboard above the design flood flow water surface elevation of 737½ feet. When the upstream cofferdam embankment reached its design height (elevation 741), dewatering wells were installed and pumping initiated as each well was completed.

Once the flash boards were constructed along the wing wall, the cofferdam was breached and a temporary bridge installed to allow flow to enter the approach channel, which allowed continued power generation at PGE's Bull Run Powerhouse. At this point, the remaining portion of the upstream cofferdam was constructed across the river and tied

into the left bank of the river channel. Construction of the downstream cofferdam started immediately after the upstream cofferdam was completed.
Cofferdam fill was required to be dumped or pushed off the end of the embankment to advance the cofferdam across the river. Gradation tests of the coarse-grained right bank borrow materials indicate approximately 4% to 9% by weight of minus #200 size silt/clay particles, which suggested that there would be temporary increases in turbidity during construction.

Due to access limitations, cofferdam fill placed below the water level of the river was placed in relatively thick lifts with minimal compaction. The specifications required the Contractor to make an effort to use larger coarser grained materials, because it more readily compacts underwater. It was recommended that the contractor tamp the surface of the submerged fill with a backhoe bucket to densify it. Once above the water level, the specifications recommended that the soil be placed in 18-inch lifts, and compacted with four complete coverages with the tracks of a D-5 dozer or similar spreading equipment. In the approach channel, where the cofferdam fill slopes are shown to be 1H:1V, the embankment was required to be reinforced with horizontal layers of Tensar Geogrid at approximately 2½ foot vertical spacing.

Abutment connections for the upstream cofferdam at the right bank terrace and the left river bank did not require any special treatment, with the exception of additional attention to ensure adequate compaction. The connection to the wing wall required tight compaction control to ensure a watertight interface between the embankment and the wing wall concrete.

The upstream cofferdam diverted the river flow through the approach channel during RCC dam demolition. During this period the river flow was required to pass through the approach channel that was partially constricted by the cofferdam embankment, resulting in a higher flow velocity (up to 9.5 ft/s). To help prevent seepage through the embankment and scour from occurring along the approach channel, the final design included "Fabriform" revetment. Fabriform consists of a double layered nylon fabric specially woven for optimum strength, stability, adhesion, and filtering characteristics. Highly fluid sand/cement grout was pumped into the Fabriform envelope once placed on the slope. Fabriform was also used successfully in the cofferdam construction during the 1989 RCC dam construction.

Based on the 1989 cofferdam work, it was estimated that a total discharge of 4,000 to 5,000 gallons per minute (gpm) would be necessary to maintain the work area in a dry condition during excavation and demolition. On that basis, dewatering wells, well points and possibly sumps were specified to dewater the excavation. It was determined to be critical for the stability of the excavation slopes in the river sediment to remain drained (see "Stability Analyses" paragraph below).

It was anticipated during design that complete dewatering would require at least 20 wells. The design was generally based on the dewatering system used in 1989, and included 3 contingency wells to be located during construction. Previous records from the 1989 construction indicated that dewatering was one of the most difficult aspects of the RCC dam construction, and that seepage problems impacted the project schedule. Therefore, for budgeting purposes, for the contract documents included an additional 5 optional wells, up to 20 well points, and 3 excavated sumps, installed at locations selected by the Contractor to completely dewater the excavation.

Well pumps and casings, and all the other elements of the dewatering system were required to be removed from the cofferdam and excavation following the demolition and prior to allowing the upstream cofferdam to breach. The contract specifications required that the dewatering system be installed, operated and removed by a specialty subcontractor experienced in dewatering work. Final design of the dewatering system was the Contractor's responsibility. However, for bidding purposes it was recommended that the specifications require the following basic features:

- Dewatering wells drilled to a diameter of approximately 12 inches using temporary casing through the unconsolidated sand, gravel, cobbles and boulders.
- Wells bottomed 5 to 10 feet into bedrock.
- A 4-inch backpack of pea-gravel installed between the production casing and the outer surface of the drillhole.
- Production well casing consisting of 6-inch diameter PVC with 0.25 inch machined slots, wrapped with a geo-fabric material for the screened sections.
- Each well equipped with a 500 gpm submersible pump, producing a yield of approximately 250 gpm per well.

Stability analyses were performed on critical cross sections for the upstream cofferdam embankment to ensure an adequate safety factor against failure. Analyses were performed using the computer software model SLOPE/W. The analyses indicated the critical nature of the dewatering to achieve and maintain stable excavation slopes and cofferdam stability during demolition.

The stability analyses were performed to check the calculated factor of safety (FS) for various failure surfaces and groundwater levels. The trial failure surfaces included: (i) a deeper failure beneath the upstream cofferdam, (ii) a mid-depth failure beneath the excavation slope, and (iii) a shallow failure near the toe of the excavation slope. The trial groundwater levels included: (i) a higher level where the groundwater daylights on the excavation slope, which represents an ineffective dewatering system, and (ii) a deeper level with groundwater below the excavation slope. In general, the calculated FS was significantly lower with the excavation slope under saturated conditions. When dewatering was achieved below the bottom of the excavation, the potential for slope failure diminished. The lowest calculated FS was 1.0 for a shallow failure at the toe of the slope under saturated conditions, which is the point of incipient failure. The FS for the same trial failure surface was 1.8 for a dewatered slope. These values highlighted the need to maintain an effective dewatering system during construction.

Downstream Cofferdam

Figure 4 shows the designed layout of the downstream cofferdam. The minimum crest elevation of the downstream cofferdam was required to be elevation 700 feet. The primary function of this cofferdam was to control the downstream flow and prevent water from backing up into the demolition area. The closure section across the main river channel was spanned with a temporary bridge. The design of the temporary bridge was left to the Contractor. Once the demolition of Marmot Dam was completed, removing the downstream cofferdam involved the following steps: 1) Prior to breaching the upstream cofferdam, the contractor would remove the temporary downstream bridge along with bridge abutment materials and any erosion protection material, 2) Prior to breaching the upstream cofferdam, the contractor would be required to also knockdown and spread or level most of the downstream cofferdam, but not excavate and remove it. 3) The flattened/knocked down cofferdam material would be left in place and eroded/transported along with the stored upstream sediment once the upstream cofferdam was breached.

EROSION AND SEDIMENT CONTROL, AND TURBIDITY MANAGEMENT

The Oregon Department of Environmental Quality (DEQ) issued a Clean Water Act 401 Certification on October 22, 2003, based on the Decommissioning Plan as set forth in PGE's October 24, 2002 "Settlement Agreement." Conditions for approval by DEQ included addressing water quality issues including sediment discharge, turbidity, protection of beneficial uses of salmonid habitat, temperature and general project issues that may affect water quality. A subsequent Turbidity Management Plan developed in October 2005 addressed these issues and outlined specific conditions for conducting turbidity monitoring before, during, and after Project removal. The Plan contained specific management actions to be implemented during removal activities at all Project sites to control turbidity originating from project lands disturbed by demolition activity. All actions indicated in this Plan were specified during the removal of Marmot Dam. This resulted in a continuous monitoring system that constantly provided turbidity levels both upstream and downstream of the project site.

An "Erosion and Sediment Control Plan" (ESCP) was prepared for the Bull Run Hydropower Project Decommissioning and submitted to the appropriate regulatory agencies in May 2005. This document was incorporated into the demolition/construction plans and specifications. The purposes of the ESCP were as follows: 1) address erosion and sedimentation control prior to, during, and following decommissioning activities, 2) to minimize sediment discharge into waterways during and following decommissioning, and 3) to minimize on-site erosion and its subsequent sedimentation effects.

The erosion and sediment control measures and requirements contained in the ESCP were required to be in place prior to the initiation of any work on this project. Specific measures implemented at the site during the dam removal included the use of erosion blankets, sediment fences, sediment traps, straw mulch and plastic sheeting. On-going site restoration efforts include placing fill and re-grading in accordance with PGE's final "Revegetation, Noxious Weed Control and Site Restoration Plan" dated May 2005.

TEMPORARY FISH PASSAGE

Once the existing fish ladder system was taken out of service, fish passage for upstream migrating adult steelhead and salmon was achieved by constructing a temporary Denile trap and haul structure approximately 800 feet downstream from the dam structure. During the dam removal period, fishery biologists and personnel from the Oregon Department of Fish and Wildlife worked together to manually capture, trap, and haul several hundred adult fish. The wild fish were trucked around the dam and allowed to continue on upstream, while the hatchery fish were returned to the downstream hatchery.

CONTROLLED BLASTING DURING CONSTRUCTION

Marmot Dam was demolished using conventional controlled blasting techniques in four separate vertical lifts, with each lift averaging approximately 10 to 12 feet. See Figure 6 for a photo during blasting and excavation work. Sometimes there were more than one shot per each lift, but generally each lift was shot in one blast. Blasts for individual lifts ranged in total explosive weight from 4,500 pounds to over 10,500 pounds. Individual blast plan reports were required by the specifications.

Figure 6. Dam Demolition in Progress

The main objective of the blast design concept was to use enough explosive energy to sufficiently fracture the concrete so that it could be excavated and hauled with conventional earthmoving equipment. Blast designs were also intended to incorporate adequate control of flyrock, seismic vibration and airblast. These objectives were achieved by the proper selection of blasting parameters such as: borehole diameters, burden and spacing distance, subdrilling, stemming, explosive weight per delay, explosive type, and explosive column distribution to match conditions. Blasthole patterns were based on variables such as: concrete characteristics (conventional reinforced concrete versus roller compacted concrete), excavation limits proximity to sensitive structures, blasthole diameter and explosive energy. For the RCC, the production blasthole pattern was 5 feet by 5 feet, while for the reinforced conventional concrete the pattern was reduced to 3 feet by 3 feet. Blasthole diameters used in the conventional concrete were 2.5 to 2.75 inches, while 3.0 inch diameter holes were used for the RCC. Blasting delays used were non-electric millisecond type detonators. Sequencing the blastholes with delayed detonators provided lateral relief for concrete movement, and improved fragmentation, flyrock control, and airblast control. In addition to these, other techniques used to improve fragmentation consisted of: an open trench (sometimes filled with sand or water) excavated immediately upstream of each blasting lift to provide relief and a free face; angled blastholes in the conventional reinforced concrete; and decked loading (separating explosive charges by stemming) within some of the blastholes. Stemming used between the top explosive charge and the ground surface (and between decked charges) consisted of an imported crushed gravel product obtained from a commercial source. The stemming material was uniformly graded 3/8 inch, clean, rock chips. High explosives used were Powerditch 1000 (an ammonia gelatin dynamite) and Magnum Powersplit (a continuous packaged emulsion explosive). Blasting agents used were Apex Ultra II (a film packaged, booster sensitive emulsion explosive), and Amix WR (a packaged blend of ammonium nitrate and fuel oil).

Vibration and airblast monitoring for any seismically sensitive structures was required by the specifications and was performed using two Instantel DS 477 BMII Seismographs. One seismograph was placed on the upstream cofferdam and the other at the foundation of the Pedestrian Bridge that crossed the river just downstream of Marmot Dam. No excessive vibration or air blast was recorded at either location during the blasting to remove the dam.

Blasting was extremely successful in fragmenting the concrete to facilitate removal by large excavators and hydraulic rams to remove the structure. After blasting, the reinforcing steel and conventional concrete within the overflow spillway were easily separated and hauled to respective stockpiles. Fragments of the conventional concrete usually ranged from cobble size to approximately four feet. The RCC concrete was easily reduced in size from sand to coarse gravel and cobble size pieces by the time it was placed in the disposal stockpiles.

CHANGES DURING CONSTRUCTION

A few significant changes during construction played a major role in the successful removal of the dam and are worthy of mention.

Cofferdams

Construction of the upstream cofferdam across the river was very successful. Placement was performed using the tracked excavators to place the material, and the dozer to push, level, and supply material from the initial temporary stockpile of material obtained from the borrow sources. By placing the material by the excavator bucket and tamping the underwater portions during the placing operation, there was essentially no lateral spread and loss of material from river flow during the placement operation.

The approach channel portion of the cofferdam that tied into the wingwall also went very well. NMC asked and was allowed to change the crest width and flatten the slopes to avoid constructing the compound slope with geogrid reinforcing in the upper part of the embankment, as shown in the drawings. NMC also requested and was allowed to widen the approach channel by excavating about 10 extra feet further into the right bank. The entire upstream slope face of this portion of the cofferdam was covered with Fabriform to protect against erosion. The Fabriform was anchored in a trench excavated at the toe of the embankment slope. The upstream cofferdam performed throughout the dam removal period with outstanding stability, water tightness, and erosion resistance, as intended, and probably better than expected.

Dewatering Wells

Based on the 1989 cofferdam work, it was estimated that a total discharge of 4,000 to 5,000 gallons per minute (gpm) was necessary to maintain the work area in a dry condition during excavation and demolition. On that basis, dewatering wells, well points and possibly sumps would likely be necessary to dewater the excavation. The contract specifications require the Contractor to "Design, install, and operate temporary dewatering measures to lower groundwater at least three feet below working level to permit Marmot Dam excavation and demolition operations to proceed under dry conditions." Prior to construction, NMC submitted a design for dewatering wells different than what was indicated in the contract drawings. Larger diameter dewatering wells with coarser-grained filter packs were installed to top of bedrock and submersible pumps installed near the bottoms of the wells. Dewatering wells were drilled by Malcolm Drilling using a very large hydraulic rotary drill rig (Soilmec 825). Wells were drilled using the following precut steel casings: 11 feet of 54 inch diameter, 24 feet of 48 inch diameter, and 40 feet of 36 inch diameter. Well production casings were 18 inch diameter HDPE pipe with ½ inch perforations in the bottom 30 feet.

A total of 9 dewatering wells were drilled through the upstream cofferdam. They ranged in depth from 75 (WW-4 was drilled approximately 20 feet through volcanic breccia before bottoming in the hard andesitic basalt) to about 20 feet (WW-9 along the approach channel portion of the cofferdam). The submersible pumps installed are capable of pumping an estimated 400 + gallons per minute at 50 feet of head. Eight of the nine wells pumped continuously from July 17th till October 19th when they were shut down to help initiate cofferdam breaching. Development was accomplished by initial airlift surging and pumping and then a few hours of test pumping. Following development, all wells have continued to flow clear water. The dewatering wells were very effective in drawing the water level down and maintaining a stable and dry excavation. A Contractor's proposal to use sumps instead of additional wells as necessary for any further dewatering of the excavation area was accepted by PGE.

COFFERDAM BREACHING

Several alternatives were considered for the safe breaching of the upstream cofferdam. The approved Decommissioning Plan and the Section 404 Permit required that the upstream cofferdam be allowed to breach by the winter floods subsequent the demolition work. Failure of the upstream cofferdam would initiate a breach and the flushing of the stored sediment downstream. While the complete downstream transport of the entire stored sediment discharge will take several years, previous design studies have indicated that the retained sediment mound immediately upstream of the cofferdam would be reduced by about 20 feet or nearly one-half of the total amount over the first water-year.

Different methods for initiating a failure breach of the upstream cofferdam were considered that included use of explosives, and also use of a "fuseplug", or removable or weakened section. After analysis of the options, the selected method was to: excavate a section of the cofferdam to an elevation just above the upstream water level; and then remove the dewatering wells and other elements of the dewatering system, thereby destabilizing the excavated slope and upstream cofferdam. These actions would assure overtopping and failure of the cofferdam, and release of the sediments by the winter storm flows.

Selected Breaching Alternative

The upstream cofferdam breach occurred on October 19th, 2007. At a flow of approximately 1,900 cfs the temporary bridge allowing water flow through the approach channel was compromised by erosion from the high flow. Once the dewatering system components were removed from the upstream cofferdam and the excavation/demolition prism, a 20-foot long section of the cofferdam near the left bank was lowered to within just a few inches of the river water level. Following this, the flow into the approach channel was partially blocked by placing dumped fill to divert the majority of flow from the approach channel. These actions facilitated overtopping flow and failure of the cofferdam embankment through the breach section within an hour. The initial breach widened rapidly into a full failure that by the next morning had completely removed the cofferdams and made a significant start on eroding the impounded sediment. Figure 7 shows a photo of the site where Marmot Dam was removed.

ESTIMATED COSTS

Removal of Marmot Dam is part of the ongoing Bull Run Hydropower Project Decommissioning which has been estimated at over $17 million and is scheduled to be completed in 2009. In addition to the removal of Marmot Dam, the Decommissioning Project includes the removal of: a second smaller concrete dam; removal of approximately 6 miles of water conveyance system of open canals, flumes, and tunnels; re-grading of the forebay lake; permanently sealing the penstocks and various tunnels; and complete removal of the 22mw powerhouse complex. Pre-removal monitoring and preparation for the entire Decommissioning Project resulted in the expenditure of