FINAL TECHNICAL REPORT

AMERICAN RECOVERY AND REINVESTMENT ACT

NORTH FORK SKOKOMISH POWERHOUSE AT CUSHMAN NO. 2 DAM

CITY OF TACOMA

DEPARTMENT OF PUBLIC UTILITIES

LIGHT DIVISION (dba TACOMA POWER)

Prepared for the

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Office of Energy Efficiency and Renewable Energy

Wind & Water Power Program

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I. EXECUTIVE SUMMARY

The objective of this project was to add generating capacity on an in-stream flow release at Tacoma Power's Cushman hydroelectric project, Cushman No. 2 Dam, FERC Project P-460. The flow that is being used to generate additional electricity was being discharged from a valve at the base of the dam without recovery of the energy. A second objective to the project was to incorporate upstream fish passage by use of a fish collection structure attached to the draft tubes of the hydroelectric units. This will enable reintroduction of native anadromous fish above the dams which have blocked fish passage since the late 1920's. The project was funded in part by the American Recovery and Reinvestment Act through the Department of Energy, Office of Energy, Efficiency and Renewable Energy, Wind and Water Power Program.

The Cushman No. 2 power plant, located in Mason County on the Olympic Peninsula, receives water from the Cushman No. 2 dam and discharges directly into Hood Canal. The new North Fork Powerhouse discharges into the previously bypassed North Fork Skokomish channel at river mile 17.3. The new powerhouse will generate an estimated 21,950 MWh adding to the current generation of 173,000 MWh annually. This is a 13% increase in generation for the Cushman No. 2 Project. The flows used in the powerhouse are the minimum instream flows shaped by a Fisheries and Habitat Committee out of an allocation of 160,000 acre-ft per year. That flow varies from an allowable low of 100 cfs to a high of 300 cfs. Two turbines were used in the plant and each has a maximum measured capacity of 153 cfs. In the current plan, July and August have flows of 120 cfs and thus only one unit is operated

The project produced 267 Full Time Equivalent quarterly jobs during the course of design and construction. Significant other jobs were produced when considering the manufacture of the generator and switchgear in Ohio, the turbine, penstocks and control panels in Washington State, the transformers, breakers, turbine shutoff valves, hydraulic power units and all the other equipment built within the United States. Local economies were also stimulated by purchase of local goods such as concrete, rock products, lumber, steel, plumbing goods, hardware and paint.

The project also involved many challenges in a small space. Difficulties were encountered when unstable rock formations were uncovered in the course of scaling the abutment above the powerhouse. This coupled with discovery of significant voids in the rubble material under the powerhouse lead to slow progress in the early days partly due to safety concerns requiring stabilization of the canyon wall prior to work below. Dewatering was deemed not feasible for the project and thus much work was needed in water. Drilling, blasting and excavation were all done in the water while pumping contaminated water to a sediment pond. The project also had a unique design feature of constructing a significant structure above water and then lowering it to grade and placing draft tubes underwater with concrete encasement following. The powerhouse is also a wonder of space constraints fitting tightly between an existing valve house and the canyon wall.

Also in the scope of the project was 3600 feet of underground 13.8 kV generator bus line to a new step up substation on the existing 115 kV transmission line between Cushman No. 1 and No. 2.

Fish facilities involve a tram to transport fish from the collection structure at the powerhouse to near the top of the dam, a fish jib crane to take hoppers from the tram and place them into a sorting and handling facility for both adult and juvenile fish.

The construction was plagued with delays mostly relating to the foundation issues, in addition, the contractor further understaffed the construction and was unable to meet schedules after foundation issues were resolved. The project has been in commercial operation since February 2013 with a number of minor issues that are still being resolved.

The project was shown to be marginal without the ARRA grant when compared with Tacoma's BPA contract. The ARRA grant brought the project to a net positive benefit allowing an easy decision to proceed. Many engineering economists use a capital cost per annual generation and so we present here a final cost for the power plant portion of the project of $830/MWh without the ARRA grant and $630/MWh with the grant.

While the project is an overall success, a couple lessons can be learned from the design of the project and most specifically to the fish attraction design. The design uses discharge from the turbines to drive an upwelling pool for fish holding and a slot entrance for their attraction. Excess flow passes under the pool upwell grate and directly downstream to a tailrace diffuser (upwell). The split of that flow is created by restricting the amount of water going to the tailrace diffuser via gates. A physical hydraulic model was used to check the performance of the system in the design phase. While the model demonstrated that the flow splits could be achieved it did not accurately demonstrate the turbulence of flow that would occur under the pool upwell grate. This has resulted in a very difficult flow to achieve the desired uniform upwelling. Others considering this arrangement may desire to use a more elaborate porosity control under the pool upwell, such as baffle blocks to reduce surging, or more baffling in the draft tube exit, to straighten flows. It remains to be seen if more modifications need to be made to this system which may depend on studies of fish reaction.

A second area of consideration for future designs would be consideration of air introduction to the turbine stream. Air introduction is a very common design to smooth cavitation rough zones. It is usually a passive system that simply allows air into a negative pressure zone when present due to operating conditions. It is why many tailrace discharges are very effervescent. The specifications stated the air introduction system should be provided but that we preferred not use such design for fish reasons. Early examination of unit performance led to the installation of the air introduction system. The system works, but it causes serious bubbles in the fish collection pool. Measurements taken, show that these bubbles do not result in any appreciable increase in the Total Dissolved Gas value. However, those bubbles may cause fish rejection of the pool. There are ways to operate the two units unequally and avoid the most significant rough zones and have a pool without air bubbles, but it may lead to higher cavitation wear on the units. This is being reviewed by Tacoma and its turbine supplier.

II. INTRODUCTION

The City of Tacoma, Department of Public Utilities, Light Division (dba Tacoma Power) is one of three divisions of Tacoma Public Utilities. We are a municipally owned electric utility that has been serving customers in the Puget Sound region of Washington State since 1893. Our service territory covers 180 square miles, including the cities of Tacoma, Fircrest, and University Place; portions of the cities of Fife, Lakewood, Federal Way, and Steilacoom; and the Fort Lewis and McChord military bases.

Tacoma Power has seen steady customer growth and now serves approximately 168,000 residential, commercial and industrial customers in urban and rural areas. At this time the electrical demand on our system peaks around 1000 megawatts (MW).

Tacoma Power's primary energy source is clean, renewable hydropower. We own and operate seven hydroelectric dams and powerhouses with a total of 748 MW of installed capacity.

The North Fork Skokomish Powerhouse project adds 3.6 MW of generating capacity at an existing dam, Cushman No. 2, part of the Cushman Hydroelectric Project (FERC P-460) owned by Tacoma Power.

Two significant components make up this project with separate, but dependent mutually beneficial objectives:

- A new powerhouse was installed to generate additional clean, renewable energy using currently diverted, but previously unutilized water flow.
- An innovative fish collection and passage system was installed to provide fish passage opportunities that support the reintroduction of Washington's endangered Steelhead and Salmon populations upstream of the Cushman Hydroelectric Project.

The new powerhouse utilizes flow that was being discharged from a valve at the base of the dam without recovery of the energy. The new powerhouse provides a clean, renewable source of energy without incurring additional environmental impacts. The electricity generated each year from the new powerhouse (approximately 23,500 megawatt hours [MWH]) qualifies as renewable energy under Washington State's ambitious Renewable Portfolio Standard (Revised Code of Washington [RCW] 19.285).

The new powerhouse also contains a novel fish collection and passage system. Fish passage on the North Fork Skokomish River has been blocked since the two Cushman dams were first constructed in the late 1920's. The addition of the powerhouse enabled installation of a unique fish collection and passage system. This system will allow adult fish swimming upstream to the base of the dam to be trapped using a safe, passive-capture system and transported to the top of the dam, where they will be sorted, then hauled around the dams and released to the upper river.

Although fish passage over Cushman No 2 Dam was required as part of the newly-amended operating license from the Federal Energy Regulatory Commission (FERC), the decision to construct the powerhouse was based on numerous financial and operational factors.

The monetary support provided by this grant provided the final incentive necessary to tilt the decision to move forward with this project expeditiously.

Without one-time funding from the Recovery Act, the synergies created by the combined installation of the powerhouse and fish passage improvements, which include increased power generation, restored access to historical fish habitat, and the opportunity to create localized economic stimulus, may not have been realized. The near-term economic stimulus generated by heavy construction activity and the long-term economic development plus build-out potential provided by the additional power generation were therefore realized. The project also adds permanent jobs at the plant for the term of the license.

III. BACKGROUND

Cushman Hydroelectric Project

The Cushman Hydroelectric Project consists of two dams, two reservoirs, associated power tunnels, penstocks, powerhouses, and a 26.8-mile-long primary transmission system, The Project is located on the North Fork of the Skokomish River, on the Olympic Peninsula in the Puget Sound region of Washington State. (see Figure 1). The energy generated by the Project is transmitted across the Tacoma Narrows waterway to the City of Tacoma.

The Cushman No. 1 development, completed in 1926, includes of a 260-foot-high concrete arch dam that impounds Lake Cushman, a 9.6-mile-long storage reservoir with a 4,058-acre surface area. A powerhouse located approximately 600 feet downstream from the dam contains two single runner, vertical shaft Francis turbines with a hydraulic capacity of 2,800 cubic feet per second (cfs) and a total installed generating capacity of approximately 50 MW, generating enough energy enough to serve approximately 9,000 homes. A switchyard abuts the powerhouse and two 115-kilovolt (kV) primary transmission lines extend approximately five miles to the Cushman No. 2 switchyard.

The Cushman No. 2 development consists of a 230-foot-high concrete arch dam approximately two miles downstream of Dam No. 1, which impounds 150-acre Lake Kokanee. Appurtenances associated with the Cushman No. 2 development include a gated spillway structure abutting the dam; a power intake; a 2.5- mile-long, 17-foot-diameter pressure tunnel; a steel surge tank; and three 12-foot-diameter, 1,350-foot-long steel penstocks. Powerhouse No. 2, located on Highway 101, adjacent to Hood Canal, contains three turbine-generator units for a maximum hydraulic capacity of approximately 3,000 cfs and a total installed capacity of 81 MW, generating enough energy to serve approximately 12,500 homes . From a switchyard adjacent to Powerhouse No. 2, two 115-kv transmission lines transmit power to the City of Tacoma.

FERC License and Settlement Agreement

The original 50-year FERC license for the Cushman developments expired in 1974. The license was among the first in the U.S. to expire, and the FERC's relicensing process was still in its infancy. After 24 years of annually-issued permits, numerous studies and much contention, a license for continued dam operation was finally issued in 1998. This license was appealed by the City of Tacoma, the Skokomish Tribe and many other parties on several different grounds.

During the appeal process, several fish populations in Washington State became listed species under the Endangered Species Act (ESA). As a result, the Federal District Court requested that federal natural resource agencies reevaluate the license to account for potential impacts to the ESA listed fish populations. During this time, actions on the 1998 license were deferred pending the outcome of all the appeals.

In 2003, FERC issued its “Final” license incorporating the measures recommended by the federal agencies, which the City of Tacoma, the Skokomish Tribe and many others again challenged in Federal District Court. In 2006 the Washington D.C. Court of Appeals issued a ruling requiring Tacoma Power to install a new discharge valve at the base of Cushman No. 2 dam and begin releasing 240 cfs into the North Fork of the Skokomish River. The valve was installed and instream flows commenced in March 2008.

During this time, the Skokomish Tribe filed suit against the City of Tacoma and the Federal Government, requesting $5.8 billion in compensation for damages allegedly resulting from the Cushman project. The 9th Circuit Court of Appeals decided in favor of the City of Tacoma and the United States Supreme Court refused to hear the case. The Skokomish Tribe, however, again brought a claim before Federal District Court, this time based on common law claims. That claim was denied and again appealed to the 9th Circuit Court. Finally, the Tribe and the City of Tacoma were offered mediation by the 9th Circuit. The two parties embarked on a two-year journey toward settlement and reconciliation beginning in January 2007.

After two years of mediation and negotiations, in January, 2009 the City of Tacoma, the Skokomish Tribe, State and Federal agencies entered into a landmark comprehensive Settlement Agreement. The agreement provides Tacoma with a renewed FERC license for the Cushman Project and brought closure to the Tribe’s $5.8 billion dollar claim.

Among other things, the settlement provides for a new, more fish friendly instream flow regime, upstream and downstream fish passage, hatchery construction, wildlife mitigation, and recreation improvements. The settlement also includes an application for a non-capacity amendment for installing the new North Fork powerhouse at the base of Cushman No. 2 Dam.

The Cushman license was amended by the FERC, based on the Settlement Agreement, on July 15, 2010 (50 year licence from 1998, valid until 2048).

IV. RESULTS AND DISCUSSION

Project Description - North Fork Powerhouse and Substation

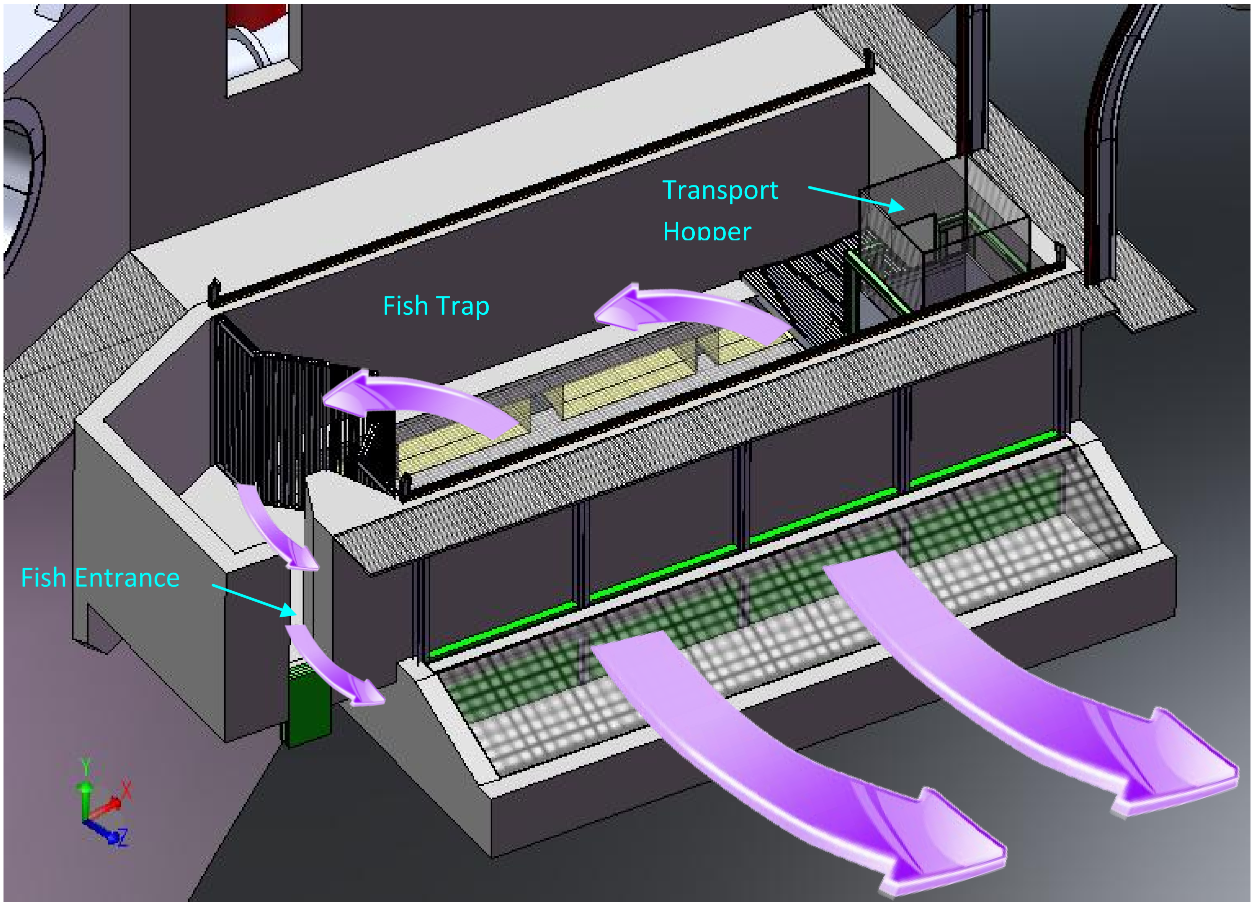
This project constructed a new powerhouse at the base of Cushman No. 2 Dam to utilize water released into the North Fork Skokomish River. The powerhouse is a two-story concrete structure approximately 46 feet by 20 feet (Figure 2). The new powerhouse penstock taps an existing 78-inch penstock between the butterfly guard valve and the butterfly discharge valve. The new 42-inch powerhouse penstocks each have butterfly shutoff valves.

The powerhouse contains two Francis turbine/generator units, each with 1.8 MW capacity. These units are projected to produce approximately 23,500 MWh in annual generation - enough energy to power approximately 1,700 average homes in Tacoma Power's service territory. The electricity from the new powerhouse is transmitted on underground cables to a new substation on the existing overhead transmission line, connecting the Cushman No. 1 and No. 2 powerhouses.

The substation consists of a 13.8 kV to 115 kV step up transformer, circuit breaker and small control house. The substation is fed by a 13.8 kV underground bus line from the powerhouse.

Project Description - North Fork Skokomish Fish Passage System

Integral to this project is an innovative fish passage system. A portion of the water discharged from the turbines is routed from the new powerhouse up through a screened floor of the concrete fish trap. Fish are attracted into the trap through a slotted inlet (fish entrance). Once in the trap, fish will be moved into a transport hopper and lifted to the top of the dam on a tram. There a jib crane will lift the hopper out of the tram and into a receiving tank where a new fish handling system will be used to separate, count and mark (as necessary) the fish. The fish will then be transported in tanks to their final destination, upstream of the two Cushman dams or to one of two hatcheries.



Water discharged from the turbines is used to attract the fish into a fish friendly entrance and trap

As juvenile fish begin their outmigration, they will be captured in Lake Cushman by a new downstream fish collection system and transported to the top of Cushman No. 2 Dam in transport tanks. They will then go through the fish handling system to count, mark and take other measurements felt vital to determine fish health. Smolts will then be gently lowered on the tram to the bottom of the dam where they will be released into the North Fork of the Skokomish River for their journey to the Pacific Ocean.

Project Construction

The project began by erecting a tower crane, constructing a sediment pond and isolating the powerhouse site behind a sediment containment dam. The dam was constructed by setting 1 cubic yard “Super Sacs” filled with spawning gravel. Spawning gravel is simply clean suitably sized gravel that can be used to enhance fish spawning sites. It was used in this instance so that the sacks would not have to be removed with the gravel and could be simply ripped open and dumped in the river at the end of the project. A dam of these sacks was made across the construction site and tarped to make it relatively impervious. During its construction the flow from the river outlet valve was stopped and flow from the spillway kept the river going. The spillway is not a suitable long term release method and is hard to keep steady so the dam was constructed in three days.

Sediment containment dam installation

Once completed, the river outlet valve was reopened and flow shot over the containment dam. Whenever turbid water was created or when concrete placements raised the pH, pumps were turned on to send water to the settling pond and create a positive flow from the river into the construction site.

Installing rock bolts on hillside

The next phase of construction was the excavation. First, rock was trimmed from the hillside by scaling loose rock and blasting certain areas to conform to the tramway design. At that point the hillside was drilled along the line of the powerhouse and fish pool to blast all the rock needing removal down to the tailwater level. An excavator at the base of the dam pulled all the loose rock into the water so as to build a level platform covering the entire fish pool and powerhouse site. At this stage it was discovered that there were certain portions of the hillside with unfavorable rock jointing including open "relieved" joints that could lead to failures. In fact one large joint adjacent to the future fish pool was certain to fail when excavation and blasting for the pool would undermine and expose the joint on the bottom side. A small rock bolting plan provided for in the contract was therefore expanded into a large rock bolting plan.

Once the bolting plan was completed the excavation below water level could commence. Drilling through the rubble mat proceeded to discover the extent of bedrock requiring blasting. Approximately one third of the footprint of the powerhouse and fish pool would be on bedrock. The remainder of the powerhouse sits on loose rubble extending to 60 feet deep near the center of the river. With the excavation completed, construction of the fish collection pool could begin.

Final excavation working toward far side of river

Tacoma had designed the fish pool to be constructed on a platform above tailwater and then lowered into the water to correct grade and grout pumped under the floor. The contractor agreed with the method and constructed a frame with attached formed footings that were lowered into the tailrace. The footings were then cast with concrete and a deck constructed thereon.

Deck for construction of fish collection structure

The fish collection structure was constructed upon the deck and when complete a second level of frame was erected over the structure.

Fish collection structure constructed on platform

Large hollow jacks were placed over Dwidag bars extending upward from the four corners of the pool. The jacks picked up the structure and the platform below was removed. Gradually the structure was lowered a few inches at a time until it was at its proper elevation. Grout was then pumped through injection pipes to the underside of the structure while divers watched to ensure the entire underside was completely filled.

The next step was to insert the draft tubes into their receiving frames in the fish pool underside and affix their upper end to the proper location and elevation just above the water line.

Lowering draft tubes into water to connect to fish collection structure

Corrugated metal pipe was also installed at each micropile location extending from the bottom of the excavation to above tailwater. This facilitated drilling and assured not drilling off course into a draft tube. At this point a 600 cubic yard underwater mass pour of concrete encased the draft tubes and formed the working slab for the powerhouse.

Micropile installation proceeded next. The plan was to drill through the rubble and into bedrock, insert a Dwidag bar, and grout it in place. Unfortunately the rubble was so loose that cuttings and material were being ejected from the ground laterally from the mass concrete and creating an unacceptable situation. It was decided that each hole would have to be predrilled with a smaller drill head using low pressure water to advance the hole, and then grout the area to firm it up so the larger drill could drill through a more solid material with cuttings coming up the hollow shaft. This plan worked, but effectively delayed construction by two months and cost $264,000.

While the powerhouse construction continued, the substation construction started. The substation is located on the transmission line connecting the Cushman No. 1 and Cushman No.2 switchyards. The route from the powerhouse to the dam is along residential roads with exiting underground power.

About 15 years ago while the City was in the midst of controversy over the Cushman Project, an underground project by local utilities were installing new buried power lines and phone lines along the road leading from the transmission line to the dam. Tacoma was unsure of the future but put in two four inch conduits to be used for communications and a possible small power plant. While the new plant is roughly four times larger capacity than was believed would be required, it was possible to fit underground cables at generator bus voltages into the conduit. Thus an underground generator bus feeds power electricity from the dam to the transmission line.

Substation ground work

At the substation, engineers measured the ground potential and found that the very sandy gravel soil would provide inadequate grounding for worker safety. A redesign of the grounding system required four times the number of ground rods and ground grid and the employment of a special perimeter grounding system using a special fluidized mixture called Ground Enhancing Material, GEM. This in addition to drilling each ground rod and installing bentonite chips in the holes added a significant cost to the substation construction.

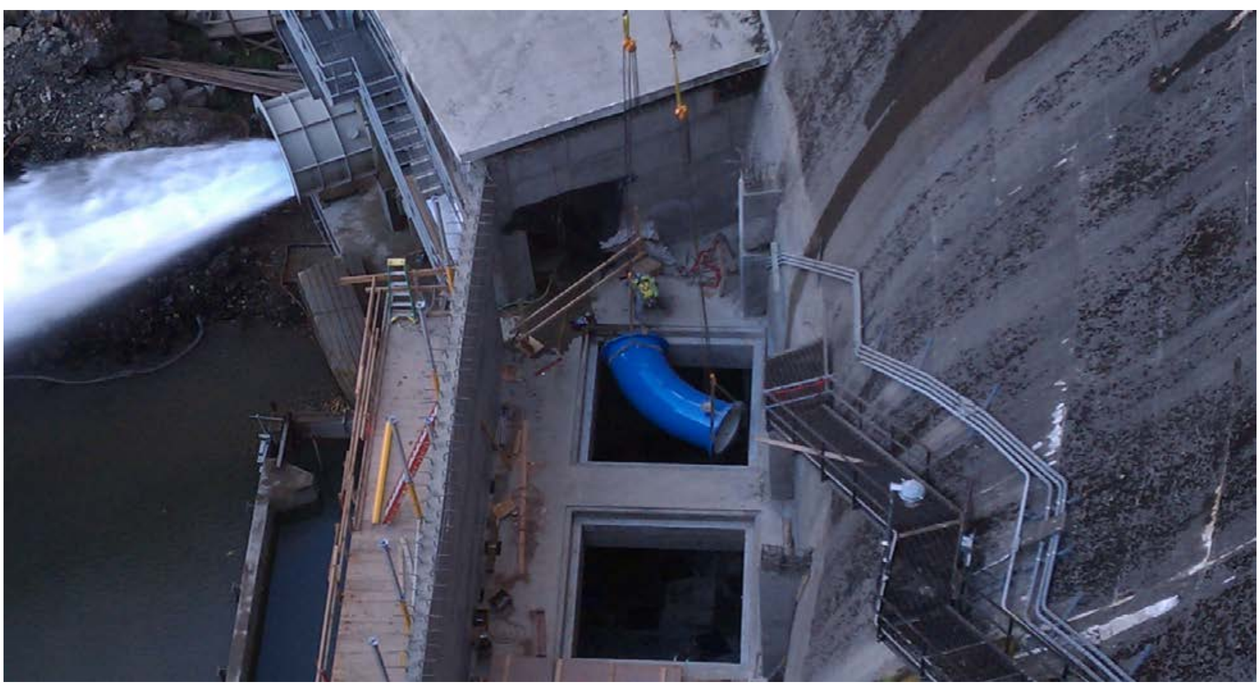
GEM slurry being poured into perimeter grounding trench

Preparation of powerhouse floor slab

Powerhouse construction proceeded with the normal issues of accounting for all embedded items or block outs. To the extent possible all wiring, piping and mechanical were planned to be surface mounted rather than embedded in floors or walls which greatly reduced the time required. There were no major issues; however, the limited space and work on the hillside above for the tramway all tended to cause things to take longer than the contractor scheduled. Thus while it was planned to make up lost time, more time was lost.

Powerhouse walls rising

As time was becoming an issue a plan was devised to lower the penstocks and turbines into the lower turbine/generator floor before forming was erected on the control floor for the roof. This allowed work to proceed on both levels at the same time and allowed the generators to be installed shortly after the roof was complete.



Lowering penstocks into turbine/generator floor

Setting penstocks and turbines

Lowering generators through roof and control floor

Forming tram hoist platform on canyon wall

Turbine/generator interconnect was a term for all the electrical, hydraulic and plumbing connections between all the owner supplied equipment. All turbines, generators, breakers and all their accessory equipment and electrical control panels fell into this category.

The sizes of all the pieces were known at the time of bid, but not the number of electrical cables or hydraulic lines or plumbing running between them. So at the time of bid an account was established to hold money in reserve to pay for interconnect. It was similar to home construction where a lighting budget is often set and the new homeowner goes to the store and picks out fixtures while trying to stay in budget. Both the estimated cost and complexity were underestimated. This required additional funds and the complexity led the field staff to decide they needed to create detailed plans allocating routing and air space for electrical conduits, hydraulic lines and cooling water lines. This is a necessary exercise for every hydroelectric plant and should not be left to the contractor.

We should point out that at this stage the contractor was so far behind that liquidated damage discussions were on the table. Thus, a settlement was agreed upon that settled all the past delay claims of extra rock bolting and micropile issues together with the slow pace of powerhouse construction and cost of interconnect. It basically assured the powerhouse would either begin startup testing on January 1, 2013 or the contractor would pay liquidated damages. The contractor was free to concentrate all activities on just those things necessary for start up to commence, and take any amount of additional time to finish non essential tasks later. When startup did begin on January 8, 2013, lighting wasn't complete, the bathroom wasn't even framed in, the fish facility equipment was not commissioned and some items not even installed.

Substantial completion was agreed to occur on July 1, 2013 with all the equipment installed but not yet accepted. A fair list of issues drug into August, almost all of which included fish equipment. Much of this equipment was bidder-designed. As of September 1, 2013 all costs were known, but a few issues remain before the final payment will be made.

Turbine/Generator startup proceeded with few issues. Much of the time spent was in adjusting the control system and ensuring proper start sequences and flow control between the turbines and discharge valves. Commissioning was considered substantially complete and the plant was considered in commercial operation on February 8, 2013, thirty one days after start of commissioning. Final efficiency curves from Andritz Hydro are presented in Appendix A.

Davis Bacon Act

Under the City's Finance Department, certified payrolls were reviewed and wage interviews were conducted. One violation of wages was found concerning a fencing subcontractor who went out of business. The general contractor rectified the problem by paying the wages due to the employees.

Economics

Before we begin a discussion of project economics we must point out an important accounting fact. Two sets of books were maintained for the project; those costs which were eligible under our ARRA grant, and those costs captured in the City's project accounting system. The largest share of the differences is in City labor. When the grant was applied for the City chose not to attempt to justify its Administrative and General (A&G) charges. This changed during the early course of the project from a 9% charge placed on all costs to a 44% charge placed only on City labor. These charges are supposed to represent the administrative and general costs of City employees working on capital projects. The application of these costs was a requirement of the State Auditor's office but the Finance Department chose not to prove these costs to the Federal Government and include them in the grant application funding.

Another Finance Department adjustment is what they call a "labor extrapolation." The City's financial system applies group rates for employee classifications and not the true cost of the actual person. It also has certain "benefit" costs that are not eligible under most Federal audits. Therefore they run a "labor extrapolation" for each person, for each reporting period, to adjust the labor charges shown in the accounting system to the eligible labor that may be claimed.

Several other items make up minor portions of the lower claimed costs. These are warehouse charges for receiving materials, equipment charges for vehicles, and meals not allowed under the grant stipulations. Thus the City's economic analysis is based on costs generated by the City's accounting system and not the lower costs of the items claimed under the grant. The grant application contained a cost of $23,356,520 with a 20% share for the DOE. The final SF 425 form shows the eligible costs at $26,753,930.48 and thus the DOE paid 17.5% of the final costs.

A copy of the final SF 425 and final quarterly report tables is included in Appendix B.

The final costs shown in the City's financial system for the total project are $28,813,903, which are composed of $4,671,304 of ARRA grant funds and $24,142,599 of City funds. This includes all ineligible costs incurred during the project and costs moved into the project from a previous project that were for preliminary engineering and work before the grant was approved. In the City's perception this is the true cost of the project.

The project is a combination of required fish passage features under the FERC project license and the option to construct a powerhouse. The cost of the whole project is not equal to the sum of individual project costs as the two join together to commonly use the water and shared benefits of joint construction. An example would be the silt containment dam and stabilization of the hillside above. Both projects would have needed those features alone and so the costs benefited both. Shared costs were split into accounts that represented fish or powerhouse costs as was deemed appropriate. The final cost split is $19,458,085 for the powerhouse and $9,103,616 for fish facilities.

Prior to the decision to accept the grant and proceed with the project a spreadsheet was developed to analyze the costs and benefits. It contained many variables and allowed choices such as: Did or did not the project receive the ARRA funding? Will we receive an "Apprenticeship Renewable Energy Credit (REC)" bonus created under state law for utilization of 15% minimum apprentice craft labor? What is the value of a REC? What will the cost of the powerhouse project really be? What are the costs of the shared benefits? In addition this analysis compares the cost of the project to Tacoma's BPA contract and not to other new generating resources or eligible renewable energy sources. In Appendix C we have included three print-outs covering different business cases.

The first is an assumption of no ARRA funding or Apprenticeship REC's. It uses the Higher cost scenario which is +12.5% above the final engineering estimate. The analysis shows a cost benefit ratio of 0.94 and a levelized benefit of -$2.67/MWh. So with these assumptions the project is shown to be uneconomic relative to purchasing power from BPA.

The second analysis assumes ARRA funding is received and assigns the entire benefit of ARRA funding to the powerhouse portion of the project. It continues to use the Higher cost scenario. The project is now shown to have a cost benefit ratio of 1.16 and a levelized benefit of $5.86/MWh. The project is considered economic in this scenario.

The third analysis closely reflects the true outcome of the project where nearly every variable went in favor of Tacoma. It uses the High cost scenario of $19,219,775 for the powerhouse whereas the final true cost is $19,458,085. It also uses the Apprenticeship REC's which will be realized and uses the ARRA funding that was received. Annual generation is reduced by 5% due to the fact that required discharge is per the USGS gage and there is apparently some additional flow between the plant and the USGS gage. It also uses the Clean Renewable Energy Bond interest rates that were awarded the project. The project now shows a cost benefit ratio of 1.65, a payback period of 8 years and a levelized benefit of $19.81/MWh.

In conclusion, the project is a very cost effective and environmentally beneficial project that was made possible by the ARRA grant. The author cannot conclude whether the project would have proceeded without the grant.

V. ACCOMPLISHMENTS

Control systems

This project utilizes a new integrated control system that will serve as a model for upgraded control systems at other Tacoma projects. The plant control system integrates turbine, generator, river outlet valve and fish facility control all on one platform. The uniqueness is that other Tacoma plant control systems are composed of several operating systems. In those, the plant control will tell a separately housed governor to start a unit. That program will often be a proprietary program of the governor manufacturer. Or there may be a spillway controller that in the event the turbines shut down the plant control system tells it that spillway flow is needed. In the system for the North Fork all these are housed directly in the plant control system.

The system also contains a high degree of sophistication. It will automatically decide when to start or stop units based on the flow setpoint entered. When a new setpoint is entered, it will decide how rapidly it can increase or decrease flow based on ramping criteria specified in the license, or even if it must wait until after dark as is required a certain times of the year. It will also operate each unit so as to keep it out of a rough operating zone. So it may put one unit above the rough zone and one unit below the rough zone when an equal setting would have resulted in both units operating in that area.

The control system also operates the river outlet valve such that if the plant shuts down it automatically opens the valve to the same flow that the plant was operating at. Once the plant is available to restart, reissuing the flow setpoint will trigger the plant control system to restart one unit at a time and reduce flow from the river outlet valve coinciding with the increased flow from the turbines. If a flow setpoint greater than the plant capacity is entered it will take the turbines to maximum flow and then add flow through the river outlet valve.

Another feature of the control system is operation of the fish attraction flow upwelling in the fish collection pool. Setting the fish collection pool at nine inches of head differential relative to the tailrace, in the plant control system, will result in the gradual operation of the diffuser gates closing down flow to the tailrace until the head differential is obtained. At this head differential the designed 80 cfs of attraction flow is rising through the fish collection pool grating and spilling out the slot entrance to attract fish. Changes in plant flow settings will not change the amount of water in the attraction flow as the diffuser gates will open or close as required to maintain the 9- inch head differential. This maintains the correct collection pool upwelling while varying the amount of water going to the tailrace diffuser downstream of the fish collection pool.

Fish Collection

This project utilizes an innovative method of creating a fish attraction flow directly from the turbines. The configuration was tested with a 1/5th scale model at Northwest Hydraulic Consultants office. A conference paper is included in Appendix D. The modeling demonstrated that the configuration could achieve the desired flows and resulted in a satisfactory tailrace diffuser strategy. What the modeling did not accurately simulate was the turbine flow.

Turbine flow produces changing eddies that result in non-uniform upwelling in the fish collection pool. This may have no impact on fish or fish collection and will need to be studied to see if further refinements are needed to baffle the upwelling flow.

Design

The project was designed almost exclusively by City staff. It was a very difficult site with many limiting features. This required the design to take into account how the project could be constructed. It meant coordinating the design with the construction process. The fish collection pool was designed to be lifted from its four corners. In reality during the jacking process it was in fact supported almost wholly on just two corners and no distress or cracking was observed. The micropile foundation for the powerhouse was also designed recognizing that the draft tubes would be inserted into the fish collection pool and mass concrete placed around them prior to piling installation. Thus pilings are located around the periphery of the draft tubes with one piling installed between the bifurcated draft tubes just before it enters the fish pool.

Another unique feature is the penstock configuration. The challenge was to utilize the existing dam's low level outlets as the supply penstock while not impacting their flow capacity for handling floods. The final design replaced an eight foot long pipe between two butterfly valves with a 78" by 66" tee section pointing down. The penstock then bifurcates in a wye to two 42" penstocks, which then turn 90 degrees to run horizontal and penetrate the powerhouse wall. The 1930 butterfly valve was also outfitted with a hood extension to control discharge into a more horizontal flow downstream. This makes the flow pass over the fish collection pool and not shoot into it. This was also hydraulically modeled and measured with the beneficial side effect of actually increasing the valve capacity for passing floods.

Every part of the design was laid out in inches of room to spare where a normal powerhouse has feet of clearance.

Completed powerhouse in operation

View down tramway

View of completed substation

Economics

The project not only received the ARRA grant and was financed with Clean Renewable Energy Bonds, but also completed construction with 19% apprentice labor thus meeting the 15% minimum apprentice labor required for a bonus Renewable Energy Credits under Washington's Renewable Energy Standard, Initiative 937. Thanks to the hard work of the team nearly every possible scenario that was possible for this project worked to its ultimate economic benefit.

We also note that the North Fork Skokomish Project is one of two finalists in the 2013 Best Hydro/Marine Project category sponsored by Power Engineering and Renewable Energy World magazines.

Energy Production

The Cushman Powerhouse No. 2 produces approximately 173,000 MWH annually. The new powerhouse is now expected to produce approximately 21,950 MWH annually, increasing the annual output by approximately 13 percent based on actual MW produced at different flow rates measured the USGS gage. This is about a 5% reduction of the grant estimate caused solely by the fact that minimum flow is dictated by the USGS gage downstream. USGS reports that flows are approximately 5% higher than the North Fork discharges. This could be due to unobserved underground flows entering the river between the plant and the gage. No surface streams enter in the reach and the distance is only 900 feet. For every one MWh saved at the North Fork Powerhouse three MWh of energy are produced at the Cushman No. 2 powerhouse. So discharging the agreed minimum flow as measured at the gage will remain the plan.

The FERC license runs through 2048 and the powerhouse began generating energy in Feb 2013. Based on these known figures, thirty-five years of operation will generate approximately 768,000 MWH. In all likelihood, the infrastructure installed as part of this project will remain in use well beyond the end of this licensing window.

Job Creation

The project resulted in approximately 71,278 hours of labor from the contractor, approximately 59,491 hours of labor from the City, and approximately 7984 hours of labor from consultants, not counting all the labor hours for material and equipment suppliers such as the factory jobs building the turbines and generators and local suppliers such as the concrete batch plant. FTE's were reported every quarter based on the hours per quarter. Thus FTE hours were divided by 520 to represent full time for one quarter. Leaving this in the same context of full time for a quarter of a year the project created 267 FTE's over the life of the project. The portion credited to the Department of Energy was a ratio of the percentage of the project the DOE paid for in that quarter. The sum of the project credited to DOE in quarterly reports was 57 FTE's.

Papers

While the project has been mentioned in a number of conference papers, three presentations were exclusively about the project.

Lisa Larson presented the Cushman No. 2 Fish Collection Facility Physical Model Study at HydroVision 2011 (Appendix D also including conference paper). The discussion focused on the hydraulic modeling performed by the Northwest Hydraulic Consultants laboratory. Also included is the conference paper.

Steven Fischer presented the North Fork Skokomish Powerhouse and Fish Facilities at the 2013 Northwest Hydro Operators Forum (Appendix E). The focus was lessons learned from design and operations.

Ozan Ferrin presented the Computer Based Flow Control Automation at the 2013 Northwest Hydro Operators Forum (Appendix F). The focus was design of an advanced control system.

VI. CONCLUSIONS

The project is an economic success as it came in just over the estimated budget but well under the plus 25% contingency number that had been used in one of the economic analyses that were run. By combining the fish collection system with the powerhouse the synergies of both constructions resulted in overall lower costs for each feature. Operation costs for fish collection will also be lower at the dam than at a separate downstream fish collector.

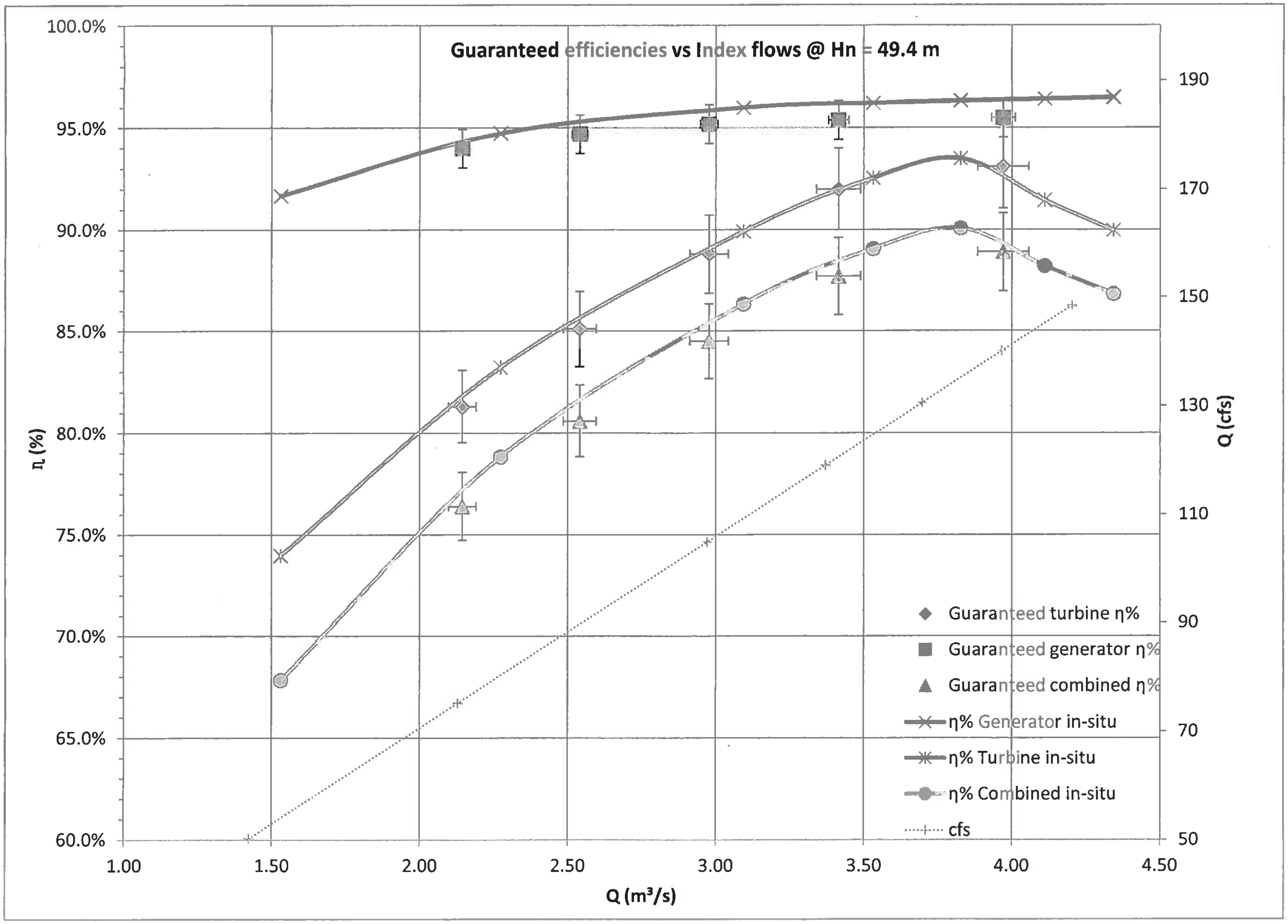
The project is operating well and has a high degree of sophistication that should limit the need for hands-on hydro operation. With this sophistication comes the demand for higher skilled labor forces and higher paying permanent jobs. Anticipated are the creation of two additional journey level jobs and the equivalent of one additional fisheries job as permanent additions to staffing the Cushman Hydroelectric Project.

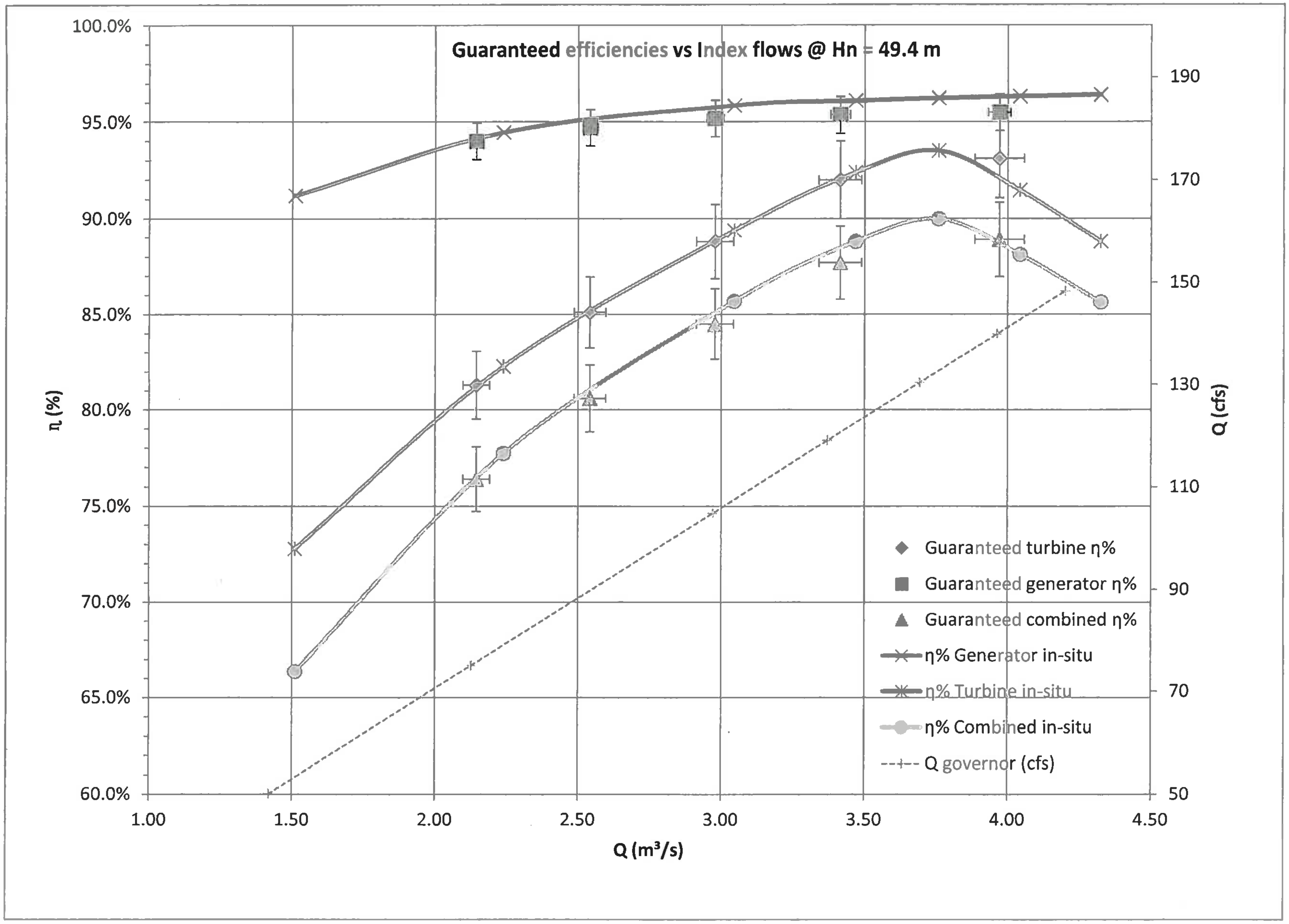
The project enjoyed a successful dedication ceremony on August 7, 2013 with attendance by Public Utility Board members, the Skokomish Tribe, local legislators, members of the Fisheries and Habitat Committee, Department of Energy and City staff. Gary Nowakowski from the Department of Energy was thanked for the work of the DOE and said a few words about the success of the project.

We also note that the North Fork Skokomish Project is one of two finalists in the 2013 Best Hydro/Marine Project category sponsored by Power Engineering and Renewable Energy World magazines.

APPENDIX A

ANDRITZ HYDRO FINAL EFFICIENCY CURVES


Guaranteed efficiencies vs Index flows @ Hn = 49.4 m
η (%)
100.0%
95.0%
90.0%
85.0%
80.0%
75.0%
70.0%
65.0%
60.0%
Q (cfs)
190
170
150
130
110
90
70
50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
Q (m³/s)
Guaranteed turbine η%
Guaranteed generator η%
Guaranteed combined η%
η% Generator in-situ
η% Turbine in-situ
η% Combined in-situ
cfs


Guaranteed efficiencies vs Index flows @ Hn = 49.4 m
100.0%
95.0%
90.0%
85.0%
80.0%
75.0%
70.0%
65.0%
60.0%
η (%)
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
Q (m³/s)
190
170
150
130
110
90
70
50
Q (cfs)
Guaranteed turbine η%
Guaranteed generator η%
Guaranteed combined η%
η% Generator in-situ
η% Turbine in-situ
η% Combined in-situ
Q governor (cfs)

APPENDIX B

SF 425, SF 428, PATENT CERTIFICATION and FINAL REPORT TABLES PRINTOUTS

FEDERAL FINANCIAL REPORT

(Follow form instructions)

1. Federal Agency and Organizational Element to Which Report is Submitted U. s. Department of Energy	2. Federal Grant or Other Identifying Number Assigned by Federal Agency (To report multiple grants, use FFR Attachment) DE-E0002669	Page 1	of 1 pages

3. Recipient Organization (Name and complete address including Zip code)
City of Tacoma, Department of Publice Utiities, Attn: Steve Fischer, 3628 So. 35th Street, Tacoma, WA 98409-3192

4a. DUNS Number	4b. EIN	5. Recipient Account Number or Identifying Number (To report multiple grants, use FFR Attachment)	6. Report Type	7. Basis of Accounting
073523297	91-600-1283	200350 customer no.	Final	Accrual

8. Project/Grant Period From: (Month, Day, Year)	To: (Month, Day, Year)	9. Reporting Period End Date (Month, Day, Year)
10/20/2009	6/30/2013	9/30/2013

10. **Transactions**	Cumulative
(Use lines a-c for single or multiple grant reporting)	
Federal Cash (To report multiple grants, also use FFR Attachment):	
a. Cash Receipts	$4,671,303.91
b. Cash Disbursements	$4,671,303.91
c. Cash on Hand (line a minus b)	$0.00
(Use lines d-o for single grant reporting)	
Federal Expenditures and Unobligated Balance:	
d. Total Federal funds authorized	$4,671,304
e. Federal share of expenditures	$4,671,304
f. Federal share of unliquidated obligations	$0
g. Total Federal share (sum of lines e and f)	$4,671,304
h. Unobligated balance of Federal funds (line d minus g)	$0
Recipient Share:	
i. Total recipient share required	$18,933,394
j. Recipient share of expenditures	$22,082,626
k. Remaining recipient share to be provided (line i minus j)	($3,149,232)
Program Income:	
l. Total Federal program income earned	$0.00
m. Program income expended in accordance with the deduction alternative	$0.00
n. Program income expended in accordance with the addition alternative	$0.00
o. Unexpended program income (line l minus line m or line n)	$0.00

11. Indirect Expense	a. Type	b. Rate	c. Period From	Period To	d. Base	e. Amount Charged	f. Federal Share
						0.00	0.00
						0.00	0.00
				g. Totals:			

12. *Remarks: Attach any explanations deemed necessary or information required by Federal sponsoring agency in compliance with governing legislation:*

13. Certification: By signing this report, I certify that it is true, complete, and accurate to the best of my knowledge. I am aware that any false, fictitious, or fraudulent information may subject me to criminal, civil, or administrative penalties. (U.S. Code, Title 218, Section 1001)

a. Typed or Printed Name and Title of Authorized Certifying Official Patrick D. McCarty, Generation Manager	c. Telephone (Area code, number and extension) 253-502-8336
	d. Email address PMCCARTY@ci.tacoma.wa.us
b. Signature of Authorized Certifying Official s/s	e. Date Report Submitted (Month, Day, Year) September 30, 2013
	14. Agency use only:

Standard Form 425
OMB Approval Number: 0348-0061
Expiration Date: 10/31/2011

TANGIBLE PERSONAL PROPERTY REPORT
SF- 428

Page	of Pages

1. Federal Agency and Organization Element to Which Report is Submitted	2. Federal Grant or Other Identifying Number Assigned by Federal Agency	3a. DUNS	3b. EIN
Department of Energy, Golden Field Office	DE-EE0002669	073523297	91-6001283

4. Recipient Organization (Name and complete address including zip code)	5. Recipient Account or Identifying Number
City of Tacoma, Department of Public Utilities, Light Division (dba Tacoma Power) 3628 S. 35th Street Tacoma, Washington 98409-3192	Customer No. 200330

6. Attachment (Check applicable)	7. Supplemental Sheet
___ Annual Report (SF-428-A) X Final (Award Closeout) Report (SF-428-B) ___ Disposition Report/Request (SF-428-C)	___ Yes X No

8. Comments

No tangible personal property was a part of this project.

9a. Typed or Printed Name and Title of Authorized Certifying Official	9c. Telephone *(area code, number, extension)* 253-502-8336
Patrick D. McCarty, Generation Manager	9d. Email address pmccarty@ci.tacoma.wa.us
9b. Signature of authorized Certifying Official	9e. Date report submitted *(Month, Day, Year)* September, 27, 2013
	10. Agency use only

TANGIBLE PERSONAL PROPERTY REPORT
Final Report SF-428- B

Federal Grant or Other Identifying Number Assigned by Federal Agency (Block 2 on SF-428).

DE-EE0002669

1. **Report** (Select all that apply)

a. ___ Federally-owned Property (List on Supplemental Sheet SF-428S or recipient equivalent and complete Section 2a below.)

b. ___ Acquired Equipment with acquisition cost of $5,000 or more for which the awarding agency has reserved the right to transfer title (List on Supplemental Sheet SF-428S or recipient equivalent and complete Section 2b below.)

c. ___ Residual Unused Supplies with total aggregate fair market value exceeding $5,000 not needed for any other Federally sponsored programs or projects. *(Complete Section 2c below)*

d. X None of the above

2. Complete relevant section(s)	**For Agency Use Only**	
2a. **Federally-owned Property** *(Select one or more.)* (i) ___ Request transfer to Award ______ (ii) ___ Request Federal Agency disposition instructions (iii) ___ Other *(Provide detail in Block 3 or attach request)*	Agency response to requested disposition of Federally owned property: (i) Recipient request approved ☐ denied ☐ (ii) Dispose in accordance with attached instructions ☐	
2b. **Acquired Equipment** *(Select one or more.)* (i) ___ Request unconditional transfer of title with no further obligation to the Federal Government. (ii) ___ Request Federal Agency disposition instructions Note: If the awarding agency does not provide disposition instructions within 120 days the recipient may continue to use the equipment for Federally supported projects or dispose in accordance with the applicable property standards.	Agency response to requested disposition of acquired equipment:: (i) Recipient request approved ☐ denied ☐ (ii) Dispose in accordance with attached instructions ☐ Authorized Awarding Agency Official Signature: Name: Title	 Date: Phone: Email

2c. **Reportable Residual Unused Supplies**

(i) __ Sale proceeds or __ Estimate of current fair market value .... $________

(ii) Percentage of Federal participation .... ________%

(iii) Federal share .... $________

(iv) Selling and handling allowance .... $________

(v) **Amount remitted to the Federal Government**.. $________

3. Comments

No tangible personal property was a part of this project

FINAL REPORT ATTACHMENT TO SF-428

Agency use only

OMB Approval Number: 3090-0289
Expiration Date: 4/30/2013

DOE F 2050.11
(2-87)
(Previous GC-792)

OMB Control No.
1910-0800

PATENT CERTIFICATION

City of Tacoma, Department of Public Utilities
Light Division (dba Tacoma Power)

Contractor

☐ Interim Certification

☒ Final Certification

DE-EE0002669
DOE Prime and/or Subcontract Nos.

Contractor hereby certifies that:

1. All procedures for identifying and disclosing subject inventions as required by the patent clause of the contract have been followed throughout the reporting period.

2. There were no subcontracts or purchase orders involving research, development, and demonstration except as follows: [State none when applicable.]

3. No inventions or discoveries were made or conceived in the course of or under this contract other than the following
(Certification includes ☐ *, does not include* ☐ *all subordinates):*
[State none when applicable.]

TITLE	INVENTOR	DATE REPORTED	DOE "S" NO.*
None			

4. The completion date of this contract is as follows: 6/30/2012

5. The following period is covered by this certification:

October	20	2009	to	June	30	2013
Month	Day	Year		Month	Day	Year

Contractor
Tacoma Power

3628 S. 35th Street
Tacoma, WA 98409
Address

Signature
[signature]

September 27, 2013
Date of Certification

* Also include Subcontract No. If available

Project Schedule & Milestones

DE-EE0002669

SOPO Task Number	Title / Task Description	Task Completion Date				Progress Notes
		Original Planned	Revised Planned	Actual	Percent Complete	
1	Turbine/Generator Procurement & Delivery	Mar-12	Jul-12	Sep-12	100%	
2	Powerhouse General Construction Contract	Sep-12	Nov-12	Mar-13	100%	
3	Transmission Design and Construction	Sep-12	May-12	Jun-12	100%	
4	Fish Facility Design and Construction	Sep-12	Oct-12	Jun-13	100%	Substantial Completion
5	Project Management and Reporting	Dec-12	Dec-12	Sep-13	100%	Final Report
6	Commence start-up testing	Jul-12	Nov-12	Jan-13	100%	
7	Begin commercial operation	Sep-12	Dec-12	Feb-13	100%	Commercial began Feb 8, 2013
8						
9						
10						
11						
12						
13						
14						
15						
16						
17						
18						
19						
20						

Spending Summary DE-EE0002669			FROM	TO
		Project Period	10/20/09	06/30/13
		Current Quarter	07/01/13	09/30/13
Object Class Categories (SF424a)	Approved Budget	Project Expenditures		
		This Quarter	Cumulative to Date	Est. Costs Next Quarter
a. Personnel	$1,560,994	$0	$2,516,364	$0
b. Fringe	$871,034	$0	$1,197,458	$0
c. Travel	$31,675	$0	$64,174	$0
d. Equipment	$6,853,132	$212,386	$5,384,064	$0
e. Supplies	$0	$0	$0	$0
f. Contractual	$13,857,132	$209,930	$17,410,077	$0
g. Construction	$430,666	$0	$181,794	$0
h. Other				
i. Total Direct Charges	$23,604,633	$422,316	$26,753,930	$0
j. Indirect Charges				
k. Totals (i+j)	$23,604,633	$422,316	$26,753,930	$0
DOE Share	$4,671,304	$0	$4,671,304	$0
Recipient Cost Share	$18,933,329	$422,316	$22,082,626	$0
Cost Share Percentage	80.2%	100.0%	82.5%	0.0%

Cost Share Contributions

DE-EE0002669

Funding Source	Approved Cost Share		This Quarter		Cumulative to Date	
	Cash	In-Kind	Cash	In-Kind	Cash	In-Kind
Bonds	$18,933,329		$422,316		$22,082,626	
TOTAL	$18,933,329	$0	$422,316	$0	$22,082,626	$0
				Total Cumulative Cost Share Contributions	**$22,082,626**	

Spend Plan Data

DE-EE0002669

Column B	Column C	Column D	Column E	Column F	Column G	Column H	Column I
Quarter	From (mm/dd/yy)	To (mm/dd/yy)	Est. Federal Share	Actual Federal Share	Est. Recipient Share	Actual Recipient Share	Actual Total (F+H)
Q1	10/20/09	03/31/10	$114,242	$114,242	$457,610	$456,967	$571,209
Q2	04/01/10	06/30/10	$418,248	$418,248	$334,469	$0	$418,248
Q3	07/01/10	09/30/10	$500,610	$500,612	$400,489	$0	$500,612
Q4	10/01/10	12/31/10	$487,838	$487,838	$810,856	$487,838	$975,676
Q5	01/01/11	03/31/11	$652,012	$652,012	$637,898	$652,012	$1,304,024
Q6	04/01/11	06/30/11	$1,028,700	$1,028,700	$1,656,390	$1,028,700	$2,057,401
Q7	07/01/11	09/30/11	$825,000	$977,235	$2,725,557	$977,235	$1,954,471
Q8	10/01/11	12/31/11	$128,931	$98,484	$2,654,331	$2,680,346	$2,778,830
Q9	01/01/12	03/31/12	$128,931	$98,484	$2,363,930	$3,321,006	$3,419,490
Q10	04/01/12	06/30/12	$128,931	$98,484	$3,688,484	$3,069,694	$3,168,178
Q11	07/01/12	09/30/12	$128,931	$98,484	$2,182,217	$3,883,366	$3,981,850
Q12	10/01/12	12/31/12	$128,930	$98,481	$1,021,163	$2,026,756	$2,125,237
Q13	01/01/13	03/31/13	$0	$0	$0	$1,403,096	$1,403,096
Q14	04/01/13	06/30/13	$0	$0	$0	$1,673,293	$1,673,293
Q15	07/01/13	09/30/13	$0	$0	$0	$422,316	$422,316
Totals			$4,671,304	$4,671,304	$18,933,394	$22,082,627	$26,753,931

Instructions:

This table should give an estimated spend plan (both DOE and Recipient Share) for the life of the project, as well as record actual outlays each quarter.

When filling out the table for the first time, Columns C, D, E, and G should be completely filled out for the life of the project and should not be updated/changed. Add rows to the table for longer projects if necessary.

Each Quarter, Columns F and H should be filled out to reflect the actual spending for the corresponding time period (should be the same as the DOE Share and Recipient Share for this Quarter in the Spending Summary Table - tab B). Column I is the sum of Columns F and H and should also be undated each Quarter.

APPENDIX C

BUSINESS CASE SCENARIO (x3 Versions)

Cushman 2 Power House Business Case (Two 1.8 MW Units, R2 Est, 9/1/12 in service)

	Total $	Levelized ($/MWh)	Raw High Constr Costs	W/ARRA	Prior W/CREB	Prior W/REC	Prior With Avd Cap
PV Costs	**$22,564,686**	**$45.90**	$48.97	$41.95	$41.95	$41.95	$34.26
PV Benefits	**21,250,336**	**$43.23**	37.64	37.64	37.64	43.23	43.23
Net	**($1,314,350)**	**($2.67)**	($11.33)	($4.31)	($4.31)	$1.28	$8.97
			Delta	$7.02	$0.00	$5.59	$7.69

AN20
AN28

Delta PV Costs	$11.64
Delta PV Benefits	$0.00
Net Delta	($11.64)

Benefit / Cost Ratio =	**0.94**
Internal Rate of Return =	**4.89%**
Payback Period =	**20**

Assumptions Table:

	Assumptions: Inputs		
Global			
1 Nominal Discount Rate	5.50%		
2 Inflation Rate	2.50%	(3.5% for O&M)	
3 Real Discout Rate	2.93%		
4 Finance Rate	5.50%		
5 Finance Term	20	Years	20
Generator:			
6 MW	2.70	Level	
8 Annual MWh	23,242	21,303	
7 Load Factor	90%		
	Trigger		
9 **Construction Cost Range**	Higher	21,622,247	
10 **Study Period (min=20, max=50)**	39	Years (39 = remaining life of license)	
	Trigger		
11 **Include "Apprenticeship REC's" (**	0	23,242 Total Annual REC'S	
	Trigger		
12 **ARRA Funds (1=Yes)?**	0	$ -	20% of CapEx (capped at $4.7M)
13 **Include Avoided Capital? (1=Yes)**	Trigger	Avoid. Cost Assumption	
14 Fish Collection	1	$3,000,000	3,000,000
15 Spill Diffusion	1	$1,000,000	1,000,000
16		Total Avoided CapEx	4,000,000

Construction Costs:

Highest	24,325,028	+ 12.5%
Higher	21,622,247	+ 12.5%
High	19,219,775	(R2 inflated)
Med	16,817,303	- 12.5%
Low	14,715,140	- 12.5%

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
17 **Market Price Adder (%)**	0%														
18 **Avoided Cost BPA/Market (adj for**	42.17	38.63	31.73	31.73	32.81	44.18	47.30	47.79	48.77	49.47	50.69	51.32	51.66	52.78	53.71
Levelized Avoided Cost	38.74														
19 **REC Starting Value Adder ($)**	$0.00		Starting Value												
20 **Value of REC's (Inflated $)**	10.00	10.00	20.00	20.50	21.01	21.54	22.08	22.63	23.19	23.77	0.00	0.00	0.00	0.00	0.00
21 **Loss Factor**	2.0%														
22 **GRT**	6.0%														
27 Jan 2010 price forecast (nominal)	45.78	41.93	44.50	45.62	45.79	47.96	51.34	51.87	52.94	53.70	55.03	55.71	56.08	57.30	58.31
28 Market Price Added	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
29 BPA Rate Forecast (nominal, 1/2 Mk	29.00	30.00	31.73	31.73	32.81	32.81	33.41	33.41	34.74	34.74	36.35	36.35	36.91	36.91	37.87
30 BPA NR headroom	-	-	21.0	15.5	3.6	0.1	-	-	-	-	0.5	0.5	-	-	-

31 Levelized Market Price	$43.21
32 Levelized BPA PF Rate	$28.05

Cushman 2 Power House Business Case (Two 1.8 MW Units, R2 Est, 9/1/12 in service)

	Total $	Levelized ($/MWh)	Raw High Constr Costs	W/ARRA	Prior W/CREB	Prior W/REC	Prior With Avd Cap
PV Costs	$18,367,742	$37.37	$48.97	$41.95	$41.95	$41.95	$34.26
PV Benefits	21,250,336	$43.23	37.64	37.64	37.64	43.23	43.23
Net	$2,882,595	$5.86	($11.33)	($4.31)	($4.31)	$1.28	$8.97
			Delta	$7.02	$0.00	$5.59	$7.69

AN20
AN28

Delta PV Costs	$3.11
Delta PV Benefits	$0.00
Net Delta	($3.11)

Benefit / Cost Ratio =	1.16
Internal Rate of Return =	7.14%
Payback Period =	15

Assumptions Table:

	Assumptions:	Inputs		
	Global			
1	Nominal Discount Rate	5.50%		
2	Inflation Rate	2.50%	(3.5% for O&M)	
3	Real Discout Rate	2.93%		
4	Finance Rate	5.50%		
5	Finance Term	20	Years	20
	Generator:			
6	MW	2.70	Level	
8	Annual MWh	23,242	21,303	
7	Load Factor	90%		
		Trigger		
9	**Construction Cost Range**	Higher	21,622,247	
10	**Study Period (min=20, max=50)**	39	Years (39 = remaining life of license)	
		Trigger		
11	**Include "Apprenticeship REC's" (**	0	23,242	Total Annual REC'S
		Trigger		
12	**ARRA Funds (1=Yes)?**	1	$ 4,671,304	20% of CapEx (capped at $4.7M)
13	**Include Avoided Capital? (1=Yes)**	Trigger	Avoid. Cost Assumption	
14	Fish Collection	1	$3,000,000	3,000,000
15	Spill Diffusion	1	$1,000,000	1,000,000
16			Total Avoided CapEx	4,000,000

Construction Costs:

Highest	24,325,028	+ 12.5%
Higher	21,622,247	+ 12.5%
High	19,219,775	(R2 inflated)
Med	16,817,303	- 12.5%
Low	14,715,140	- 12.5%

		2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
17	**Market Price Adder (%)**	0%														
18	**Avoided Cost BPA/Market (adj for**	42.17	38.63	31.73	31.73	32.81	44.18	47.30	47.79	48.77	49.47	50.69	51.32	51.66	52.78	53.71
	Levelized Avoided Cost	38.74														
19	**REC Starting Value Adder ($)**	$0.00		Starting Value												
20	**Value of REC's (Inflated $)**	10.00	10.00	20.00	20.50	21.01	21.54	22.08	22.63	23.19	23.77	0.00	0.00	0.00	0.00	0.00
21	**Loss Factor**	2.0%														
22	**GRT**	6.0%														
27	Jan 2010 price forecast (nominal)	45.78	41.93	44.50	45.62	45.79	47.96	51.34	51.87	52.94	53.70	55.03	55.71	56.08	57.30	58.31
28	Market Price Added	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
29	BPA Rate Forecast (nominal, 1/2 Mk	29.00	30.00	31.73	31.73	32.81	32.81	33.41	33.41	34.74	34.74	36.35	36.35	36.91	36.91	37.87
30	BPA NR headroom	-	-	21.0	15.5	3.6	0.1	-	-	-	-	0.5	0.5	-	-	-
31	Levelized Market Price	$43.21														
32	Levelized BPA PF Rate	$28.05														

Cushman 2 Power House Business Case (Two 1.8 MW Units, R2 Est, 9/1/12 in service)

	Total $	Levelized ($/MWh)	Raw High Constr Costs	W/ARRA	Prior LC Fin	Prior W/REC	Prior With Avd Cap
PV Costs	$13,850,717	$30.30	$54.55	$45.37	$39.53	$39.53	$30.30
PV Benefits	22,907,150	$50.10	43.86	43.86	43.86	50.10	50.10
Net	$9,056,434	$19.81	($10.68)	($1.50)	$4.34	$10.58	$19.81
			Delta	$9.18	$5.84	$6.24	$9.23

AN20
AN28

Delta PV Costs	$1.34
Delta PV Benefits	$0.00
Net Delta	($1.33)

Benefit / Cost Ratio = 1.65
Internal Rate of Return = 16.42%
Payback Period = 8 from 2012

Assumptions Table:

		Assumptions: Inputs		
	Global			
1	Nominal Discount Rate	5.50%		
2	Inflation Rate	2.50%	(3.5% for O&M)	
3	Real Discout Rate	2.93%		
4	Std Fin Rate	5.50%		
5	Low-Cost Fin Rate	3.59%	<-- Matt's DS stream below has an IRR of 3.59%	
	Finance Term	25		
6	MW	3.60	Level MWh	
8	Annual MWh	21,943	19,813	
7	Load Factor	70%		
		Trigger		
9	Construction Cost Range	High	18,580,515	
10	Study Period (min=20, max=50)	39	Years (39 = remaining life of license)	
		Trigger		
11	Include "Apprenticeship REC's" (1=Yes)?	1	26,332	Total Annual REC'S
		Trigger		
12	ARRA Funds (1=Yes)?	1	$ 4,671,304	(capped at $4.7M)
			Avoid. Cost Assumption	
13	Include Avoided Capital? (1=Yes)	Trigger		
14	Fish Collection	1	$3,000,000	3,000,000
15	Spill Diffusion	1	$1,000,000	1,000,000
16			Total Avoided CapEx	4,000,000

Construction Costs:			Net Level. All in $/MWh Cap
Highest	23,515,965	+ 12.5%	$6.92
Higher	20,903,080	+ 12.5%	$10.56
High	18,580,515	(R2 inflated)	$13.80
Med	16,257,951	- 12.5%	$17.04
Low	14,225,707	- 12.5%	$19.88

Net Capital $ 9,909,211 (After Avoid Cap and ARRA)

		2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
17																
18	Avoided Cost BPA/Market (adj for loss & GRT)	0.00	0.00	0.00	30.78	33.26	35.55	38.55	42.24	45.69	48.31	49.72	53.50	53.98	62.08	63.31
	Levelized Avoided Cost	39.60		45.38												
19	REC Starting Value Adder ($)															
20	Value of REC's (Inflated $)	2.50	2.50	2.50	2.50	2.50	2.50	7.00	7.00	7.00	7.00	13.00	13.00	13.00	13.00	13.00
21	Loss Factor	2.0%														
22	GRT	6.0%														
	Market Price Inflator past 2029	2.50%														
27	Woodmac price forecast	0.00	0.00	0.00	30.78	33.26	35.55	38.55	42.24	45.69	48.31	49.72	53.50	53.98	62.08	63.31
		0	Marginal Energy													

1	Levelized Market Price	$39.60
2	Levelized BPA PF Rate	$0.00

APPENDIX D

CUSHMAN NO. 2 FISH COLLECTION FACILITY PHYSICAL MODEL STUDY (HYDROVISION 2011)

Cushman No.2
Fish Collection Facility (FCF)
Physical Model Study

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Cushman Hydroelectric Facility
Fish Collection Facility & New Powerhouse

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Cushman Hydroelectric Project

- Cushman No.1 & No.2
- Relicensing Process
  - Original license 1924
  - License expired 1974
  - 1998 license ‘stayed
  - Settlement Agreement
  - New License 2010

Cushman No.2 New Powerhouse

- Cushman No.2
  - 230 ft high arch dam
  - 2.5 mile tunnel to penstocks
  - 81 MW capacity
- Non-capacity amendment
  - Add generating capacity on minimum flow release
  - ‘Skokomish Powerhouse’
  - Fisheris benefits

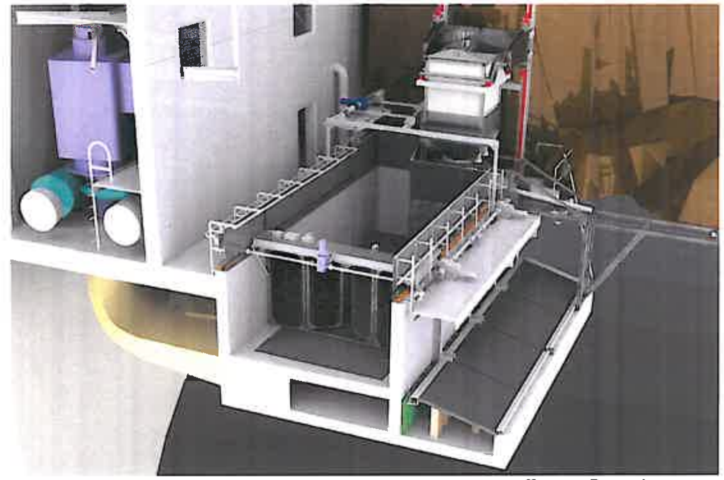
New Powerhouse and Fish Collection

- New Powerhouse
  - Normal 3.0 MW, 240 cfs
  - Peak, 3.9 MW, 320 cfs
- Fish collection facility
  - 80 cfs attraction flow system
  - Fish entrance
  - Fish pool
  - Draft tube diffuser screen

Fish Collection Facility

Tacoma Power Image

Fish Collection Facility



Tacoma Power Image

FCF Physical Model Objectives

- 1:5 scale model
- Evaluate:
  - Diffuser velocities
  - FCF entrance
  - Multiple turbine operation conditions

Fish Collection Facility Criteria

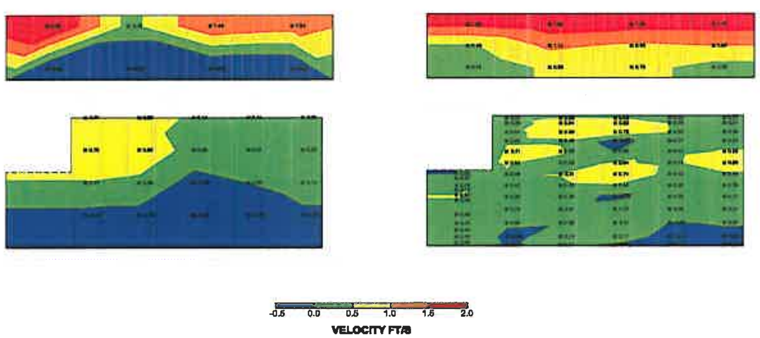
- Diffuser Velocities
  - FCF diffuser
    - max < 0.5 ft/s
  - Draft tube diffuser
    - average of 1.25 ft/s
    - max < 2.0 ft/s
- Fishway entrance
  - Target hydraulic drop of 1 ft

Model Testing – Diffusers

- Initial diffuser testing
  - Non-uniform velocities
  - High velocities at downstream end
- Modifications
  - Diffuser beams
  - Floor baffles
  - Vertical diffuser bars

Model Testing – Final Diffuser Design

Model- Diffusers



Preliminary Testing

Final Testing

Model Tetsting - Entrance

- Four modifications tested
  - Various headwall designs
  - Modeling showed left head wall required
  - Minor improvements achieved
- Final design
  - Minor modification to left head wall

Summary

- New powerhouse provides power and fish flows
- Physical modeling used to confirm fish collection facility design
- Project is currently under construction

Cushman Hydroelectric Facility Fish Collection Facility & New Powerhouse

nhc
northwest
hydraulic
consultants

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Session 21: Fish Passage Strategies and Improvements

Cushman Hydroelectric Project: Fish Collection Facility and New Powerhouse Hydraulic Modeling

Authors:
Lisa Wieland Larson, P.E., Principal, Northwest Hydraulic Consultants, USA
Andre Ball, P.E., Project Engineer, Northwest Hydraulic Consultants, USA
Steven Fischer, Assistant Generation Manager, Tacoma Power, USA

Abstract:
The Cushman Hydroelectric Project, owned and operated by Tacoma Power, is located on the North Fork of the Skokomish River in Washington State. The project consists of two dams, Cushman Dam No.1 and No. 2. The original 50-year FERC license was issued in 1924 and expired in 1974 after which the project operated under an annual license until receiving a new license in 1998. The license was immediately challenged and stayed until a Settlement Agreement (SA) was reached. The new amended license was then received in July 2010. The SA requires upstream fish passage and instream flow discharges at Cushman No. 2.

Cushman No. 2 consists of a 230 ft high concrete arch dam, a gated spillway, and two low level outlets. The intake for the existing hydroelectric facility discharges flow into a 2.5 mile long tunnel to the powerhouse, which discharges into Hood Canal. To accommodate new minimum instream flow requirements downstream of the dam, Tacoma Power installed a new jet flow gate valve in 2008. Tacoma Power also received a non-capacity amendment to construct a new powerhouse at the base of the dam. The new powerhouse will dissipate energy associated with the flow releases, provide attraction flow for the fish collection facility, and recapture some generation.

The new upstream fish collection facility (FCF) will be located directly downstream of the new powerhouse, and a portion of the turbine flow will be utilized for the new FCF attraction flow. The flow utilized for the FCF will pass through a diffuser system into the fish channel and will provide the entrance attraction flow. Due to the unique design of this system and the close proximity of the powerhouse draft tubes to the fish collection facility, a 1:5 scale physical model study was undertaken to evaluate and refine the design for the proposed FCF. The model was used to develop baffling to balance the flow in through the diffuser screens, refine the fishway entrance, and evaluate the attraction flow.

The Cushman Hydroelectric Project consists of two dams, Cushman Dam No. 1 and No. 2, on the North Fork of the Skokomish River in Washington State. Cushman Dam No. 1 is the upstream most dam and forms Lake Cushman; Cushman Dam No. 2 is located downstream and forms Lake Kokanee. The original 50 year license was issued in 1924, and the project has operated under an annual license since the expiration of the original license. In January 2009, a settlement agreement for the projects was signed between Tacoma Power, the Skokomish Tribe, and federal and state agencies. This agreement requires upstream fish passage requirements at Cushman Dam No. 2 including a new adult fish trap and haul facility and instream flow requirements

Cushman Dam No. 2 consists of a 230 ft high concrete arch dam with a gated spillway and two low level outlets. Lake Kokanee has a gross storage capacity of 8,000 acre-feet at full pool at elevation 480 ft. The intake for the existing hydroelectric facility discharges flow into a 2.5 mile long, 17 ft diameter tunnel that trifurcates into three 12 ft diameter penstocks. The existing powerhouse includes three generator units with a maximum hydraulic capacity of 3,000 cfs and a total installed capacity of 81 MW.

To accommodate new minimum instream flow requirements, Tacoma Power installed a 65-inch jet flow gate valve on one of the existing 78-inch low level outlets. Subsequently, Tacoma Power received a non-capacity amendment to construct a powerhouse at the base of Cushman Dam No. 2 to dissipate the energy associated with the minimum flow release, which will enhance habitat downstream, provide attraction flow for the adult fish passage facility, and recapture some generation lost due to the flow releases. As a result, the powerhouse and FCF will provide multiple benefits to the project. The project also received a $4.67 million dollar grant from the Department of Energy for the innovative use of power and environmental benefits.

Figure 1 shows an overall layout of the dam with the new powerhouse referred to as the North Fork Skokomish Powerhouse. The powerhouse is under construction and is located at the base of the dam and will tap into one of the existing 78-inch low level outlets. All water released into the North Fork Skokomish River up to the peak capacity of approximately 294 cfs will be discharged through the new powerhouse and the associated fish collection facility.

The proposed fish collection facility (FCF) will be constructed immediately downstream of the new powerhouse and will provide upstream fish passage by a trap and haul system. The overall footprint of the prototype FCF is 40 ft by 24 ft including the draft tube tailrace diffuser screen. The FCF requires attraction flow to meet fishway entrance requirements. This attraction flow will be provided by the draft tubes from the new North Fork Skokomish Powerhouse. Approximately 80 cfs of the powerhouse flow will be passed through upwell diffuser screens to be used for fish attraction flow, and the excess flow will be discharged through a draft tube tailrace diffuser screen directly into the downstream river channel since the excess flow is not required in the fish collection facility. The FCF upwell diffuser and the draft tube tailrace diffuser chambers are separated by four 78 inch wide by 36 inch tall knife gate openings. These knife gates can be adjusted to control the flow distribution. The fish collection facility also includes an entrance weir, V-trap/crowder, and a hopper where the fish are collected and transported to the sorting facility above the dam. Figure 2 general model arangement.

Physical Model Description

Due to the close proximity of the powerhouse draft tubes and the FCF diffuser screens, physical modeling was used to evaluate and modify FCF attraction flow system. The draft tubes provide a focused jet of flow that needed to be dissipated and spread out uniformly to prevent non-uniform velocities along the diffuser screens. The objectives of the physical model included:

- Test FCF upwell diffuser and tailrace diffuser arrangements and make modifications as required to meet NMFS diffuser guidelines

- Test fishway entrance and attraction flow jet and make modifications as required to improve entrance attraction

- Test one and two turbine unit operations, as well as a maximum turbine flow

The physical hydraulic model was built at an undistorted scale of 1:5 and included the turbine draft tubes, FCF diffuser chamber, FCF upwell diffuser screen, hopper approach, hopper blockout, FCF entrance, knife gates, draft tube tailrace diffuser chamber, tailrace diffuser screens and approximately 100 ft of the downstream river channel. The model represented the full-width of the river and reproduced the topography from El. 300 ft to El. 315 ft. The river bathymetry was represented with a rough concrete surface. The powerhouse draft tubes were made out of acrylic, and the FCF was made out of acrylic and wood.

For the diffuser screens, the scale was modified to achieve an acceptable Reynolds number through the bars. The size of the diffuser screen bars (3/8 inch wide) and spacing (1/2 inch clear spacing) in the prototype design of the screens approaches turbulent/laminar flow regime, $\mathbf{R}_c \approx 1{,}000$. A strict geometric scaling of the diffuser screens based on the Froude number similitude would drop the Reynolds number well into the laminar flow regime. The only way to maintain a Reynolds number near the critical range ($R_c \approx 1,000$) is to alter the fluid properties or adjust the spacing of the diffuser screen geometry. Since altering the fluid properties is not possible, the bar spacing geometry had to be modeled closer to the prototype scale. The diffuser bar width and spacing was increased to a 1:3 geometric scale; however, the depth of the bar maintained the 1:5 scale. The porosity was unaffected because the bar widths and openings both increased proportionally. As a result, the headloss through the screens and the impact the screens have on the distribution of flow within the FCF are accurately simulated in the model.

Testing

Model testing initially focused on the FCF upwell diffuser and the tailrace diffuser screen. After the diffuser screen tests were completed, the testing focused on the fish entrance. The modification testing for both of these components of the FCF are summarized below.

Diffuser Screens:

The initial design exhibited non-uniform floor screen velocities with the highest velocities at the downstream end of the FCF upwell diffuser screen (near the draft tube knife gates) and negative velocities (indicating re-entrainment of flow) at the upstream end of the upwell diffuser screen. The tailrace diffuser screen also showed high velocities at the downstream end (toe) of the screen and negative velocities at the upstream end (top) of the screen. Figure 3 shows the velocity data collected for the preliminary design testing. Although the flow distribution needed improvement, modifications to the diffuser chamber to better distribute the flow were considered to be feasible.

Following the preliminary design testing, it was determined that the initial design did not distribute the flow evenly through both the upwell diffuser and the tailrace diffuser to meet their respective velocity guidelines; however, baffling on the floor and beneath the screens was considered to be a viable approach to improving the flow conditions within the footprint of the facility. A series of modifications were tested to improve the performance including:

- Modification 1: Floor Baffles
- Modification 2: Diffuser Beams Version 1
- Modification 3: Diffuser Beams Version 2
- Modification 4: Diffuser beams, vertical diffuser bars, and baffle blocks.

Beneath the upwell diffuser screen, a series of lateral diffuser beams were installed. These diffuser beams reduced the porosity at the downstream end to 25%, and the beams transitioned to a spacing that provided 40% and then 50% open area at the upstream end of the diffuser screen. The varied baffle spacing in the model showed significant promise in providing more distribution of the discharge through the FCF upwell diffuser.

The diffuser bars reduced the porosity of the knife gate openings to 40%. It was demonstrated that installation of the diffuser bars improved the vertical distribution of flow through the tailrace diffuser screen. The knife gates were still able to control the attraction flow at 80 cfs for a range of turbine operating conditions between 147 cfs and 294 cfs discharge. Figure 4 shows the diffuser screen velocities measured following Modification 4.

Fish Entrance

After optimizing the upwell and tailrace diffuser screen designs, the focus of the testing shifted back to the FCF entrance design. Previous testing indicated that the initial entrance design resulted in a non-uniform water surface across the width of the entrance weir and that the flow jet downstream of the entrance was directed along the right bank of the tailrace channel. Design development testing was undertaken to develop a modification that would make the water surface more uniform and possibly redirect the discharge jet closer to the center of the tailrace.

As shown in Figure 2, the initial entrance weir design included a 23 degree offset wall on the left approach (looking downstream in the FCF) and a 90 degree wall located on the right approach. This design resulted in a water surface elevation that was higher on the left side of the entrance weir. Four modifications to the left approach were investigated:

- Entrance Modification 1: Mirror image of right approach with 90 degree headwall on left side
- Entrance Modification 2: Angled left approach wall and 90 degree headwall.
- Entrance Modification 3: Same as Entrance Modification 2 with the addition of rounded face on the protrusion.
- Entrance Modification 4: Similar to the initial design tested in the Preliminary tests but with the addition of a small, 4 inch section of headwall on the left side of the entrance weir

After testing the first three modifications, it was apparent that basic modifications to the left wall geometry were not likely to create a uniform flow surface over the weir. The existence of the abutment is necessary to turn the flow and discharge it into the center of the tailrace, but this also cause a slightly higher concentration of flow along the left side of the entrance weir. As shown in Figure 5, a design very similar to the initial design with only a small (4 inch) portion of headwall on the left side of the FCF entrance weir was selected for the final design.

Selected Design Modifications

The selected configuration used for the final documentation testing consisted of the following modifications:

- diffuser beams placed beneath the upwell diffuser screen,
- vertical diffuser bars in the knife gate slots,
- baffle blocks below the tailrace diffuser screen, and
- small portion of headwall added on the left side of the entrance weir.

Conclusion:

In summary, a physical model study was undertaken to evaluate and refine the design for the proposed fish collection facility (FCF) below Cushman Dam No. 2. The FCF will be located directly downstream of two new turbine units which will provide the auxiliary water supply for the FCF. This project is an example of a fish collection facility that serves multiple functions: collecting adult fish, providing instream flows for downstream habitat, and producing power.

Since the FCF diffusers were located immediately downstream of the turbine draft tubes, design attention associated with dissipating the energy and providing a uniform flow distribution across the FCF diffuser screens was required. Physical modeling was selected as a design tool to evaluate the initial design and make improvements. The model was also used as a demonstration tool for stakeholders involved in the project.

The physical modeling was used to evaluate the FCF upwell diffuser, draft tube tailrace diffuser, and the fish entrance. Modifications were made to the diffuser chambers located below the upwell and draft tube tailrace diffuser screens to achieve more uniform flow distributions and to meet NMFS diffuser screen guidelines. The results from the preliminary design testing showed that the flow distribution through the upwell diffuser screens and the powerhouse diffuser screens was not sufficiently uniform to meet the required NMFS velocity guidelines for horizontal AWS screens and horizontal draft tube diffusers. During the modification testing phase, different methods of baffling were incorporated into the FCF design to provide a more uniform distribution of flow though the diffuser screens. Some additional fine tuning will be conducted in the prototype to account for effects of the turbines which were not represented in the model.

For the tailrace diffuser, two methods of baffling were implemented. First, in the knife gate slots, vertical diffuser bars were added to reduce the amount of knife gate closure needed to achieve 80 cfs attraction flow. The second method of baffling was comprised of installing two rows of baffle blocks spaced beneath the tailrace diffuser screen. The row of baffle blocks located closest to the knife gates consisted of 36-inch tall baffle blocks which were designed to deflect a portion of the flow up through the top of the tailrace diffuser screen and reduce the flow concentration at the bottom of the screen. Minor modifications were made to the headwall located in the FCF upstream of the entrance gate to help provide a more uniform flow distribution across the entrance weir.

The Cushman FCF design provides a facility that will meet multiple goals at the project including collecting adult fish for transport and providing instream flows downstream of the facility.

Authors:

Lisa Larson, P.E.

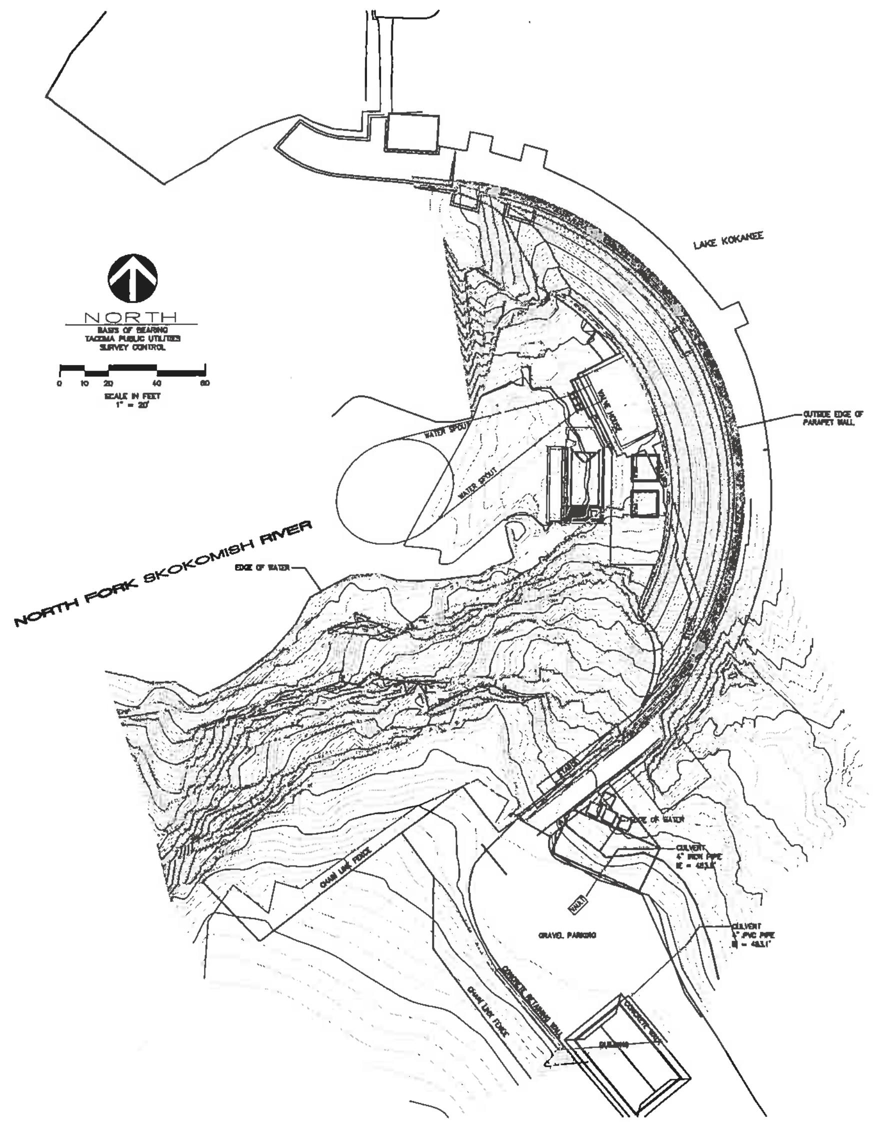
Lisa is a principal with NHC and manages NHC's Seattle physical modeling laboratory. She has a bachelor's and master's degree in Civil Engineering from Oregon State University and 16 years of experience in hydraulic engineering. Her background includes hydraulic design and modeling, with an emphasis on hydroelectric projects. Many of her projects have been associated with fish passage and water quality issues. She is a Washington Director for the Northwest Hydroelectric Association.

Andre Ball, P.E.

André Ball is a project engineer with NHC and works in the Seattle office's physical modeling laboratory. He has his bachelor's and master's degrees in Civil Engineering from the University of Washington and has 6 years of experience practicing hydraulic engineering. His background includes hydrology and hydraulic modeling. His has been involved with numerous physical modeling projects particularly related to fish passage and hydraulic structures.

Steven Fischer, P.E.

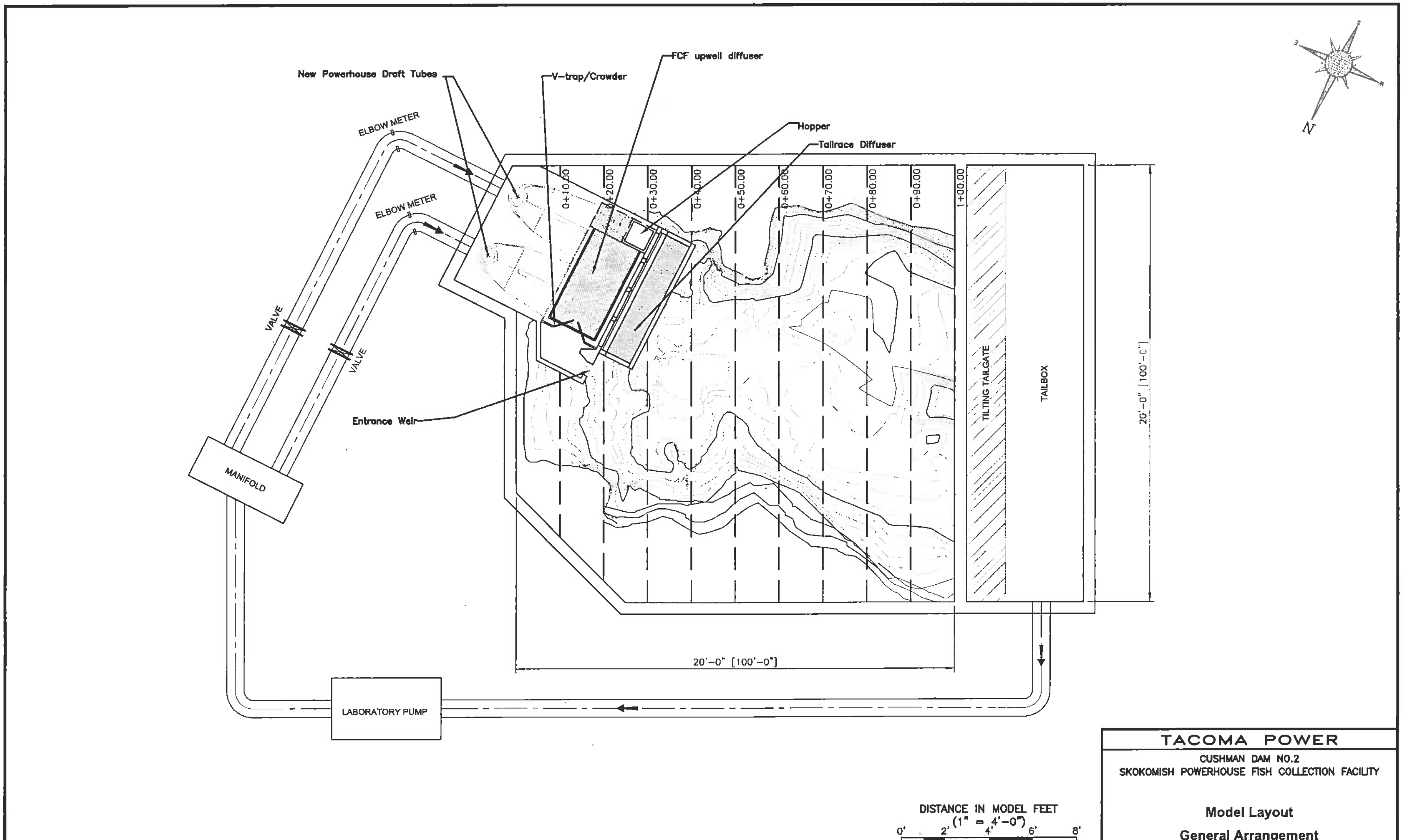
Steve is an Assistant Generation Manager with Tacoma Power and has 34 years experience in Civil/Structural work for the City. He graduated from Washington State University. His current assignment is the project manager for up and downstream fish passage facilities at the Cushman Project, two small hatcheries also at the Cushman Project, and a downstream fish passage facility at the Cowlitz Project.



TACOMA POWER			
CUSHMAN DAM NO.2 SKOKOMISH POWERHOUSE FISH COLLECTION FACILITY			
Overview of Cushman Dam No. 2			
21642-000	REV. NO.: 0	DRN. BY: JAB	APR 14-10
northwest hydraulic consultants			

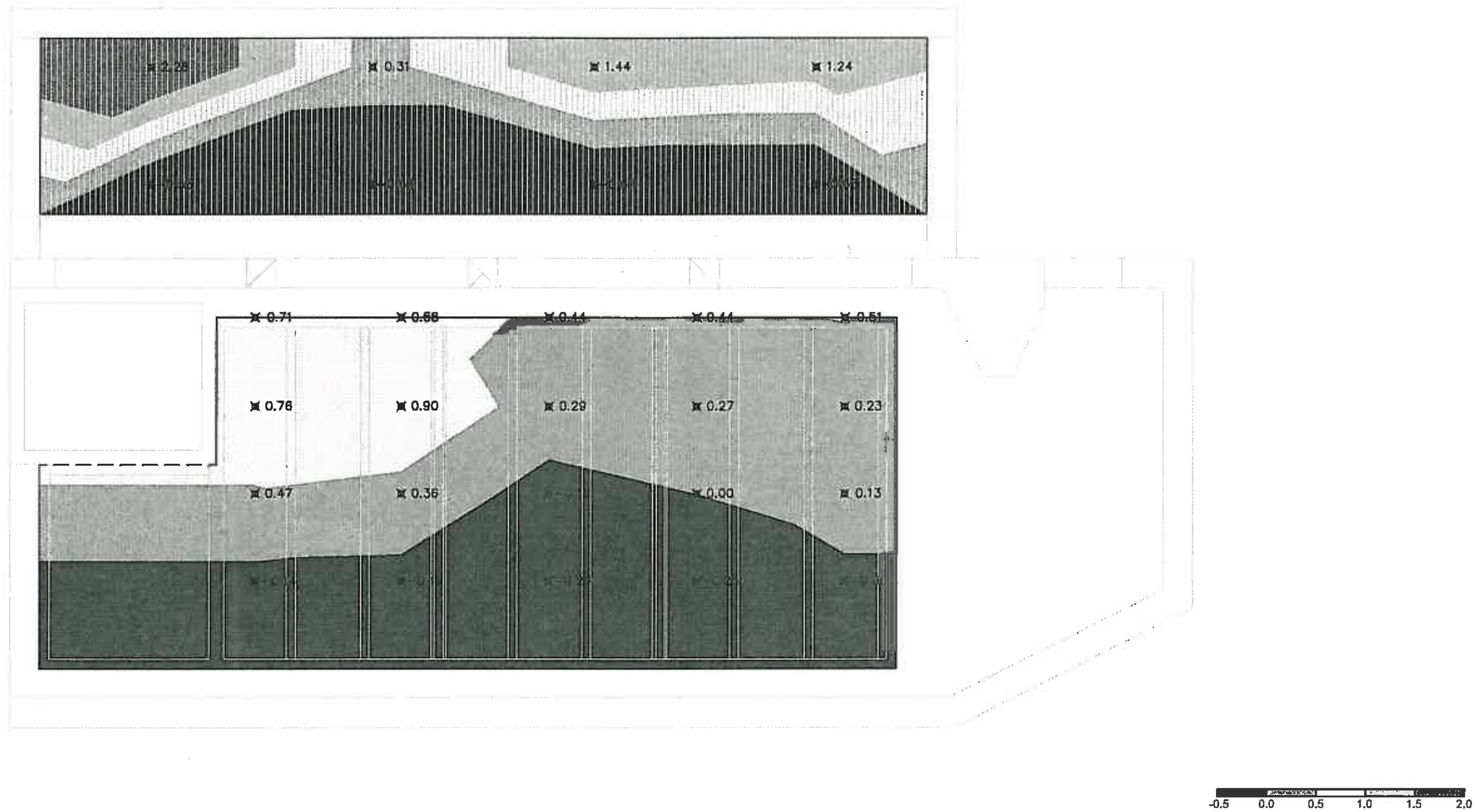
NOTES:
1. DRAWING IS BASED ON TACOMA POWER DWG, 2007 Cushman 2 Overall Plan with contours.dwg. (7/15/09)

FIGURE 1



NOTES:
1. PRIMARY DIMENSIONS ARE GIVEN IN MODEL FEET AND INCHES.
2. SECONDARY [BRACKETED] DIMENSIONS ARE GIVEN IN PROTOTYPE FEET AND INCHES.
3. MODEL SCALE: 1 MODEL = 5 PROTOTYPE.

FIGURE 2



OPERATING CONDITIONS

DISCHARGE	240 cfs
UNITS OPERATING	2
ATTRACTION FLOW	80 cfs
TAILWATER EL.	312 ft.

LEGEND:

ADV MEASUREMENT LOCATIONS

NOTES:
1. THE COLOR CONTOUR PLOTS INDICATE THE VELOCITY PERPENDICULAR TO THE DIFFUSER SCREEN SURFACES.
2. ALL VELOCITY DATA POINTS WERE 6" (PROTOTYPE) ABOVE THE DIFFUSER SCREENS.
3. THE PROTRUSION NEAR THE FCF ENTRANCE WEIR PREVENTED ADV MEASUREMENTS IN THE UPPER RIGHT-HAND CORNER OF THE FLOOR DIFFUSER SCREEN.

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CUSHMAN DAM NO. 2
SKOKOMISH POWERHOUSE FISH COLLECTION FACILITY

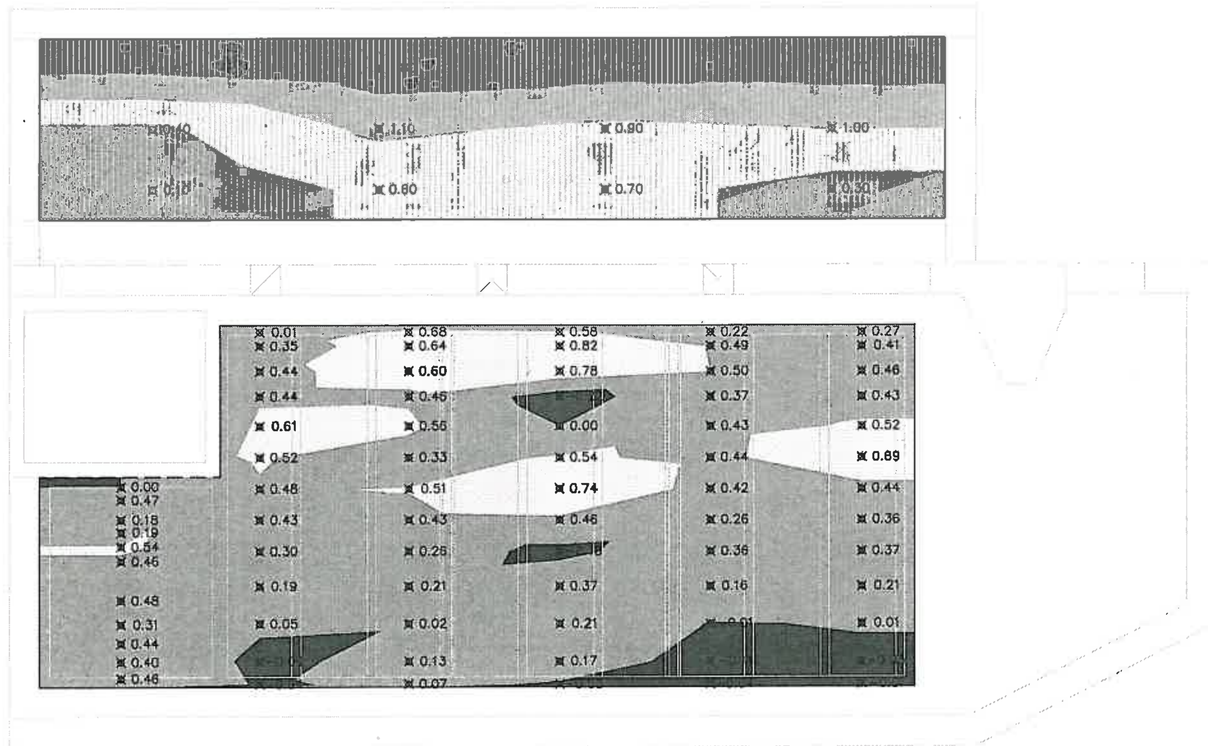
Diffuser Screen Surface Velocities

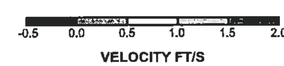
Preliminary Design

21642-100	REV. NO.: 1	DRN. BY: JAB	MAY 5-10

northwest hydraulic consultants

FIGURE 3





OPERATING CONDITIONS

DISCHARGE	240 cfs
UNITS OPERATING	2
ATTRACTION FLOW	80 cfs
TAILWATER EL.	312 ft.

LEGEND:

⌘ ADV MEASUREMENT LOCATIONS

NOTES:
1. THE COLOR CONTOUR PLOTS INDICATE THE VELOCITY PERPENDICULAR TO THE DIFFUSER SCREEN SURFACES.
2. ALL VELOCITY DATA POINTS WERE 6" (PROTOTYPE) ABOVE THE DIFFUSER SCREENS.
3. THE PROTRUSION NEAR THE FCF ENTRANCE WEIR PREVENTED ADV MEASUREMENTS IN THE UPPER RIGHT-HAND CORNER OF THE FLOOR DIFFUSER SCREEN.

TACOMA POWER

CUSHMAN DAM NO. 2
SKOKOMISH POWERHOUSE FISH COLLECTION FACILITY

Diffuser Screen Surface Velocities

Modification 4

21642-100	REV. NO.: 1	DRN. BY: JAB	MAY 5-10

northwest hydraulic consultants

FIGURE 4

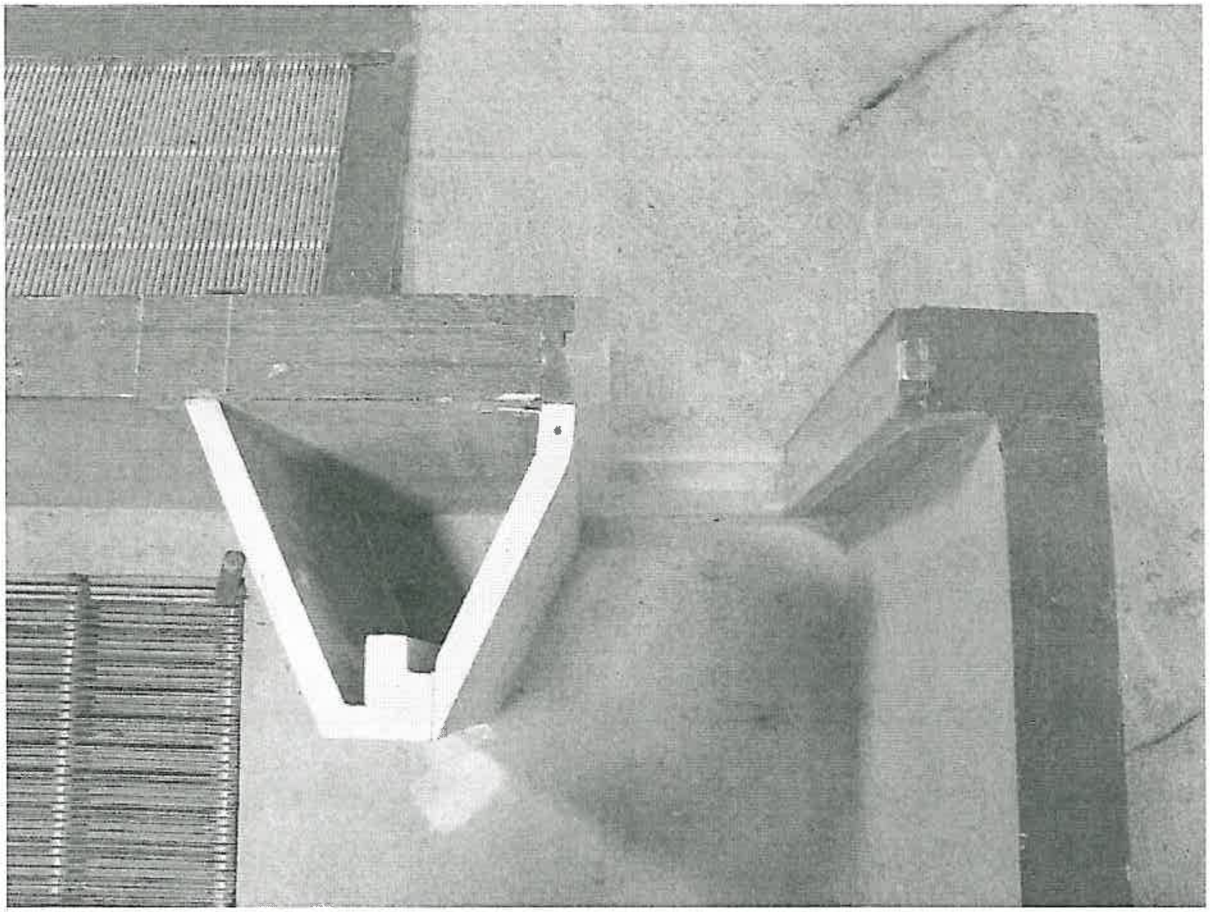


Figure 5: Overhead photo showing final fish collection facility entrance configuration.

APPENDIX E

NORTH FORK SKOKOMISH POWERHOUSE and FISH FACILITIES
(2013 NORTHWEST HYDRO OPERATORS FORUM)

NORTH FORK SKOKOMISH POWERHOUSE & FISH FACILITIES

2013 NORTHWEST HYDRO OPERATORS FORUM

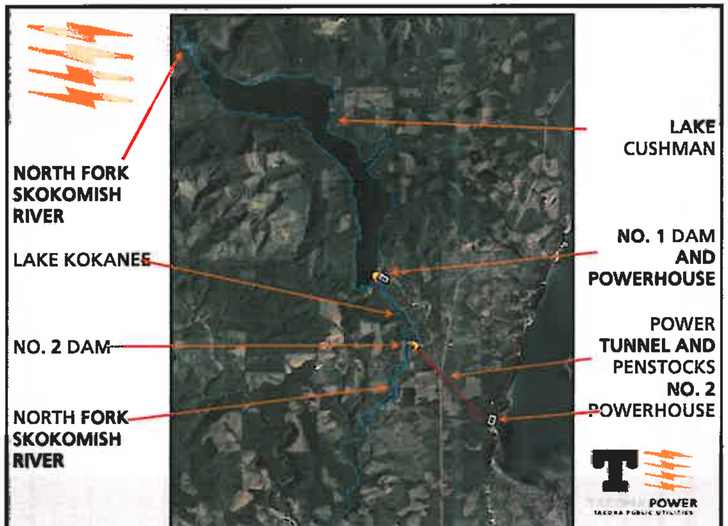
STEVEN FISCHER, P.E.

TACOMA POWER
TACOMA PUBLIC UTILITIES

NORTH FORK SKOKOMISH POWERHOUSE & FISH FACILITIES

2013 NORTHWEST HYDRO OPERATORS FORUM
STEVEN FISCHER, P.E.

CUSHMAN HYDROELECTRIC PROJECT



AGENDA

- Background
  - Cushman Settlement Agreement 2009
  - Future Floating Surface Collector
  - Future Fish Hatcheries
- North Fork Skokomish Powerhouse and Fish Facilities Overview
  - Powerhouse
  - Fish Collection Pool
  - Fish Tram
  - Jib Crane
  - Fish Sorting and Handling Facility
- Lessons Learned Design
- Lessons Learned Operations

2009 SETTLEMENT AGREEMENT

- Upstream Fish Passage
- Downstream Fish Passage
- Sockeye Hatchery
- Spring Chinook, Coho & Steelhead Hatchery
- Recreation Improvements
- Allowed Powerhouse at Cushman #2 Dam

CUSHMAN NO. 1 DAM & DOWNSTREAM FISH COLLECTOR

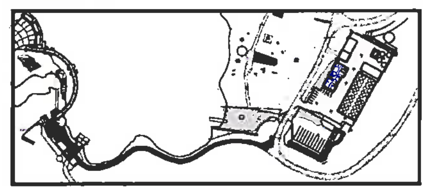
SALTWATER PARK HATCHERY

OPERATIONAL 2015

- Raise 2,000,000 Sockeye fry per year to plant in Lake Cushman
- Uses spring water from hillside

NORTH FORK SALMON HATCHERY

OPERATIONAL 2015

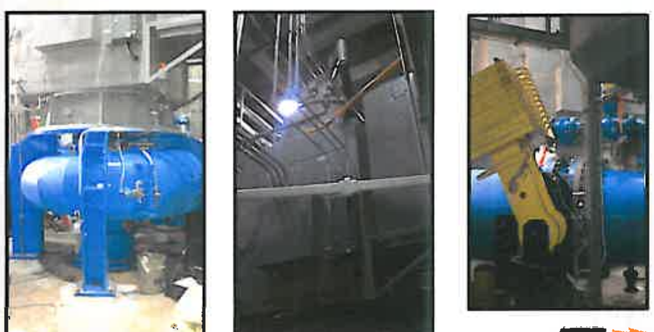


- Raise over 400,000 Chinook, Steelhead and Coho smolts to plant in the North Fork below the dam
- Uses water from Lake Kokanee

NORTH FORK SKOKOMISH POWERHOUSE & FISH FACILITIES

POWERHOUSE CONTROL FLOOR

POWERHOUSE TURBINE/GENERATOR FLOOR

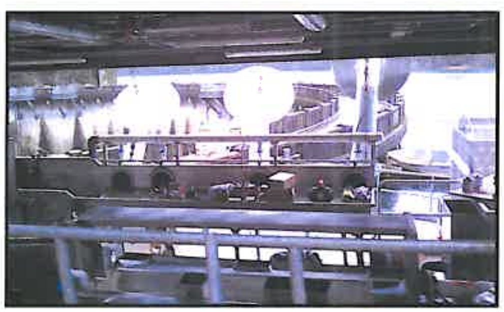


FISH COLLECTION FACILITY

FISH COLLECTION FACILITY

FISH TRAMWAY

FISH SORTING FACILITY



FISH SORTING FACILITY

FISH SORTING FACILITY

POWER
TACOMA PUBLIC UTILITIES

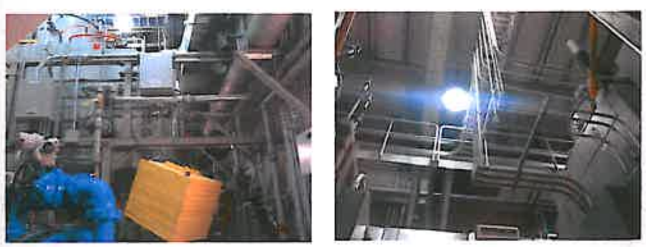
LESSONS LEARNED DESIGN

- Planning Space

POWER
TACOMA PUBLIC UTILITIES

LESSONS LEARNED DESIGN

- Planning Space



POWER
TACOMA PUBLIC UTILITIES

LESSONS LEARNED DESIGN

- Engineering Design vs. Contractor Design

POWER
TACOMA PUBLIC UTILITIES

LESSONS LEARNED DESIGN

- Don't Over Design – Simple is Good

TACOMA POWER
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LESSONS LEARNED OPERATIONS

- Think About Maintenance

TACOMA POWER
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LESSONS LEARNED OPERATIONS

- Think About Operator Location

TACOMA POWER
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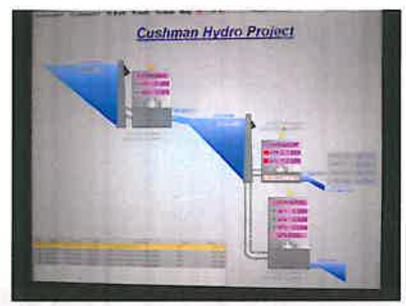
LESSONS LEARNED OPERATIONS

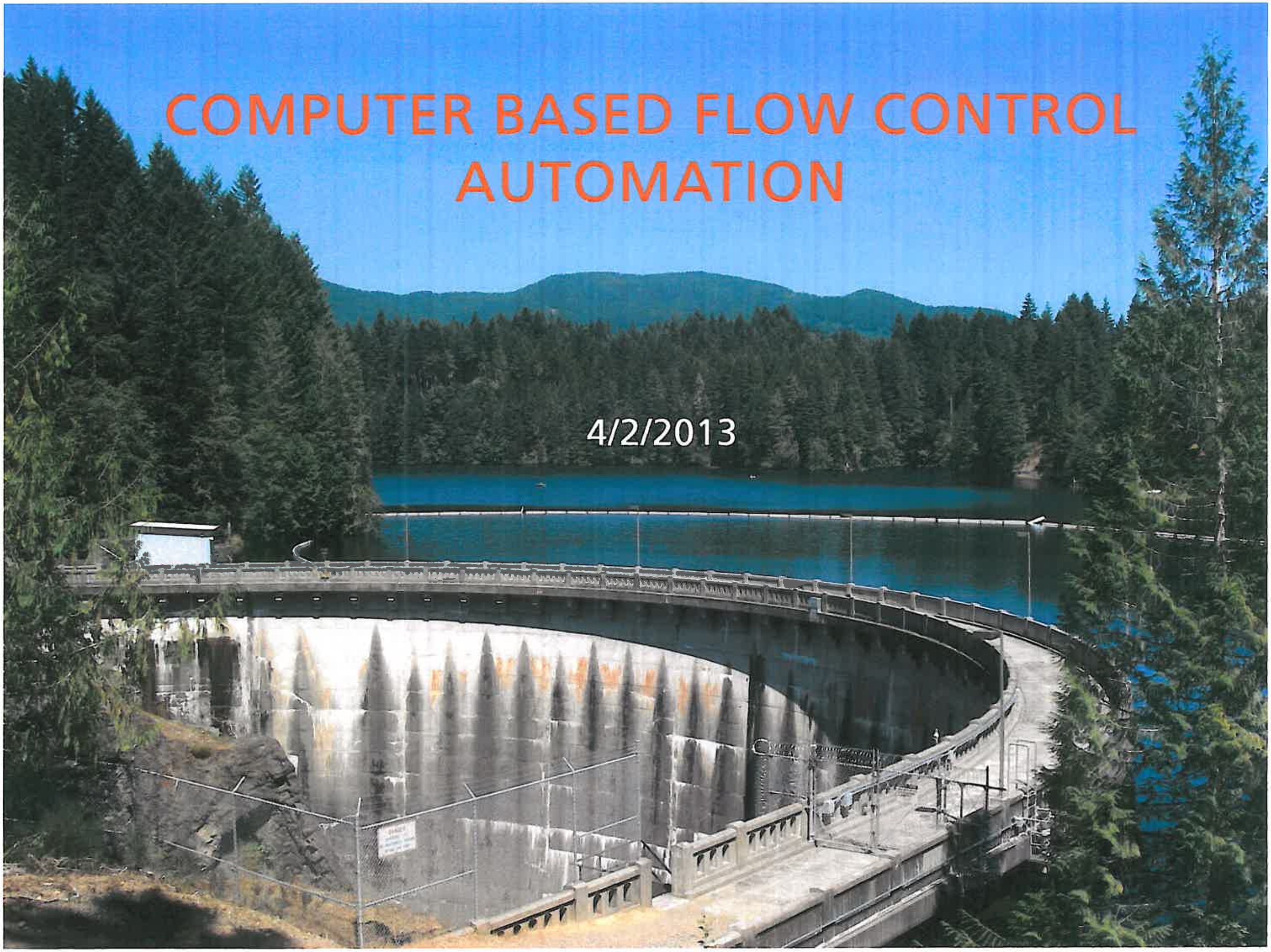
- Think About The Operator



TACOMA POWER
TACOMA PUBLIC UTILITIES

APPENDIX F

COMPUTER BASED FLOW CONTROL AUTOMATION
(2013 NORTHWEST HYDRO OPERATORS FORUM)


COMPUTER BASED FLOW CONTROL
AUTOMATION
4/2/2013

FLOW CONTROL AUTOMATION

- CUSHMAN HYDROPROJECT OVERVIEW
- APPLICATION 1: NORTHFORK
- CONSIDERATIONS
- CHALLENGES
- COMPLEXITY, FLEXIBILITY, & OPERABILITY
- APPLICATION 2: MAYFIELD
- APPLICATION 3: LAGRANDE

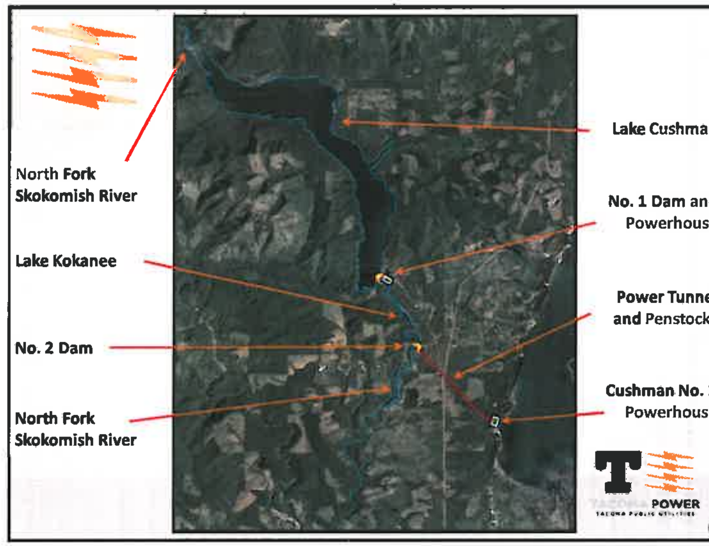
POWER

1

CUSHMAN HYDROELECTRIC PROJECT

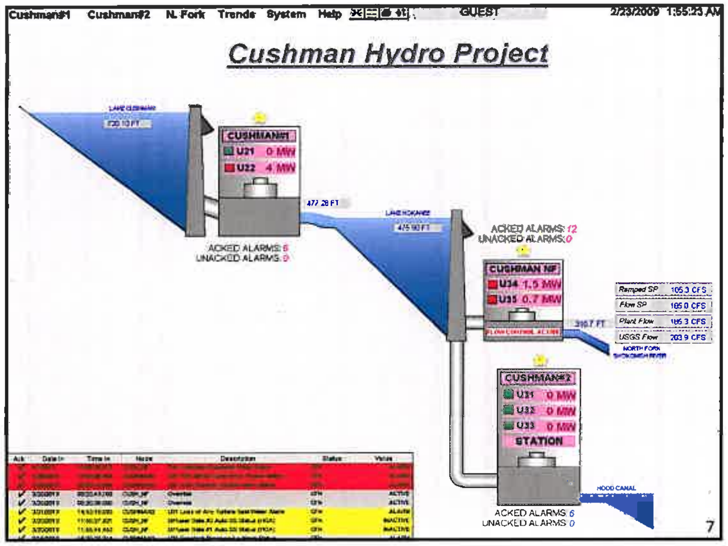
POWER

5



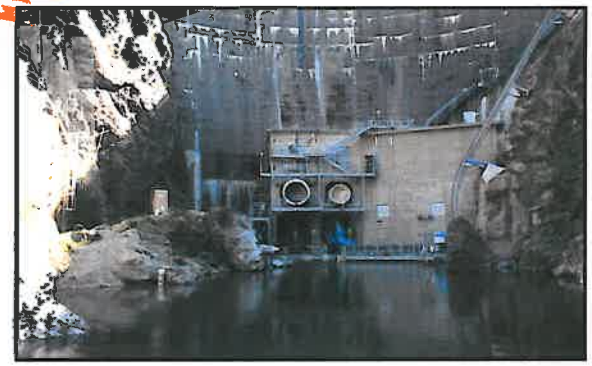
POWER

6



7

CUSHMAN #2 DAM



- Completed in 1930
- 175 feet tall
- 575 feet long
- Retains two-mile long Lake Kokanee

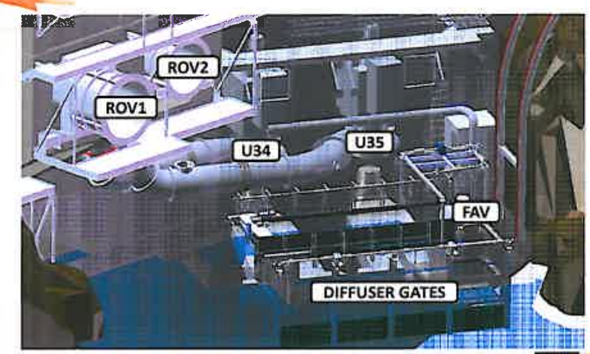
TACOMA POWER
TACOMA PUBLIC UTILITIES
8

NORTHFORK SITE OVERVIEW

- The Fish Collection Facility provides fish passage over the Cushman No. 2 dam
- Includes two 1.8 MW turbine-generator units to pass the required flows into the North Fork while generating approximately 24 million kW-hours of Clean, Renewable Energy each year

TACOMA POWER
TACOMA PUBLIC UTILITIES
9

POWERHOUSE LAYOUT



TACOMA POWER
TACOMA PUBLIC UTILITIES
10

FERC LICENSING REQUIREMENTS
RAMPING RATES

Up Ramping
➤Limit to 12"/hour

Down Ramping (Below Critical Flow)

Time of Year	Daylight Rates	Night Rates
Feb 16 – Jun 15	No Ramping	2"/hr
Jun 16 – Oct 31	1"/hr	1"/hr
Nov 1 – Feb 15	2"/hr	2"/hr

Critical Flow = 500 CFS

Down Ramping (Above Critical Flow)
➤Limit to 6"/hr

Steady State Operations
➤Allowed +/5% variation in steady-state river stage/flow

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TACOMA PUBLIC UTILITIES

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LICENSING REQUIREMENTS
Component 1 Flow Requirements (2013)

"The licensee shall release 115,835 acre-feet of the annual 160,000 acre-foot water budget as instantaneous minimum flows from the Cushman Project, into the Lower North Fork of the Skokomish River."

Instantaneous Minimum Flow Schedule
(changes yearly)

Month	Base Flow
July	160->120 CFS
August	120 CFS
September	170->235 CFS
October	270->290 CFS
November	290 CFS
December	290 CFS
January	290 CFS
February	280 CFS
March	280->200CFS
April	190->180 CFS
May	180 CFS
June	170 CFS

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TACOMA PUBLIC UTILITIES

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FLOW EQUIPMENT
FISH ATTRACTION VALVE (FAV)

1. Max flow of 5 CFS with a nominal flow of 2 CFS.
2. Used for fish attraction when collecting fish
3. Not used for flow regulation
4. Will open during load rejection to provide fresh water to the fish in the collection pool.

TACOMA POWER
TACOMA PUBLIC UTILITIES

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FLOW EQUIPMENT
GENERATOR UNITS 3

1. Maximum Turbine Output is approximately 148CFS
2. Unit Plant Capacity is about 290 CFS
3. Turbine Contract called for minimum operation of a unit at 70 CFS
4. Units will each have gate setpoint control
5. There will be no load control for these units

POWER

15

FLOW EQUIPMENT
RIVER OUTLET VALVE #1 (ROV1)

1. ROV1 takes lower priority than units to accomplish flow setpoints
2. Used to provide flow continuation if units trip and to provide for flows above full plant output
3. Max flow at 477ft lake elevation is approximately 1900 CFS
4. ROV1 will have position setpoint control

POWER

16

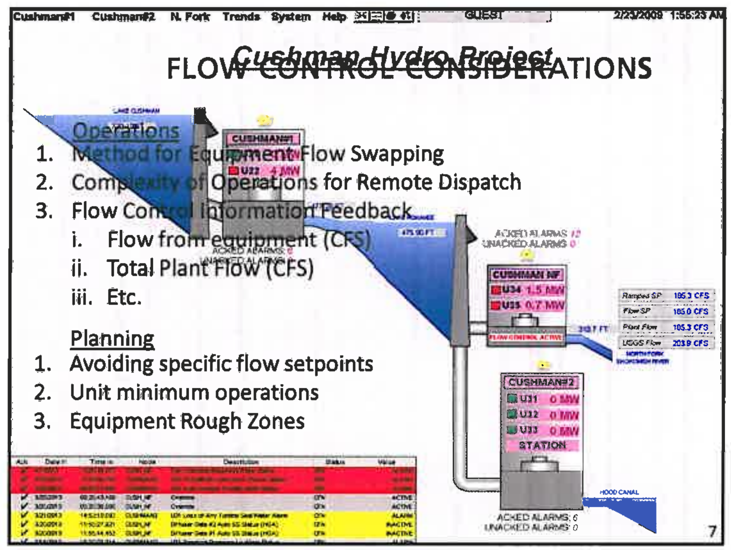
FLOW EQUIPMENT
RIVER OUTLET VALVE #2 (ROV2)

1. ROV2 takes last priority
2. ROV2 will only be controlled manually (no PCS control)
3. Both units must be stopped before opening ROV2 manually
4. ROV2 will be used only for spill events higher than about 2150 CFS. A component 3 flow may require the use of ROV2.

POWER

17

FLOW CONTROL CONSIDERATIONS



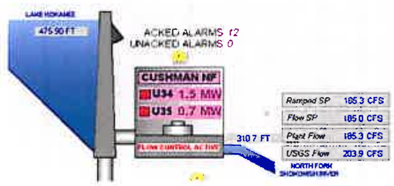
Operations
1. Method for Equipment Flow Swapping
2. Complexity of Operations for Remote Dispatch
3. Flow Control Information Feedback
   i. Flow from equipment (CFS)
   ii. Total Plant Flow (CFS)
   iii. Etc.

Planning
1. Avoiding specific flow setpoints
2. Unit minimum operations
3. Equipment Rough Zones

7

FLOW CONTROL CHALLENGES

1. Flow Continuation
2. Maintaining Ramping Profile
3. Load Swapping Without Violating Flow Restrictions
4. Avoiding Rough Zones (or Running Unequal Loads)
5. Predicting Failure Modes
6. Prioritization
7. Synchronizing Flow Calculations



TACOMA POWER 3

PROGRAM COMPLEXITY

Complexity

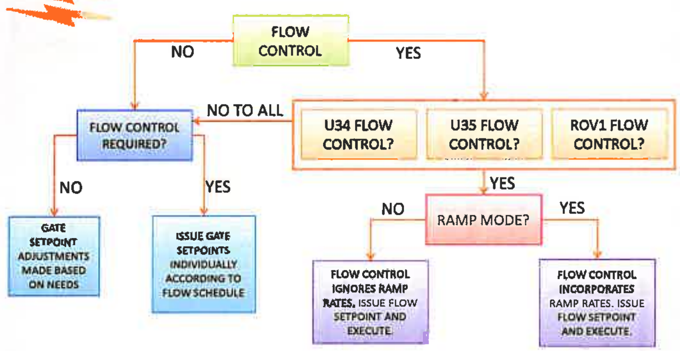
LOW

1. Add independent gate control to units and valve/spillgates. Gate control with full flexibility.
2. Add independent flow control for each piece of equipment. Flow control with full flexibility.
3. Add integrated joint flow control.
4. Add automatic start/stop to units

HIGH

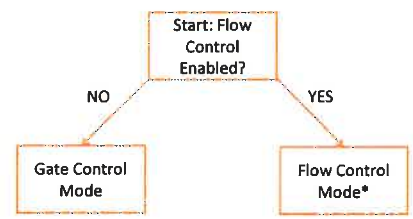
TACOMA POWER 4

FLOW CONTROL PROCESS CHART



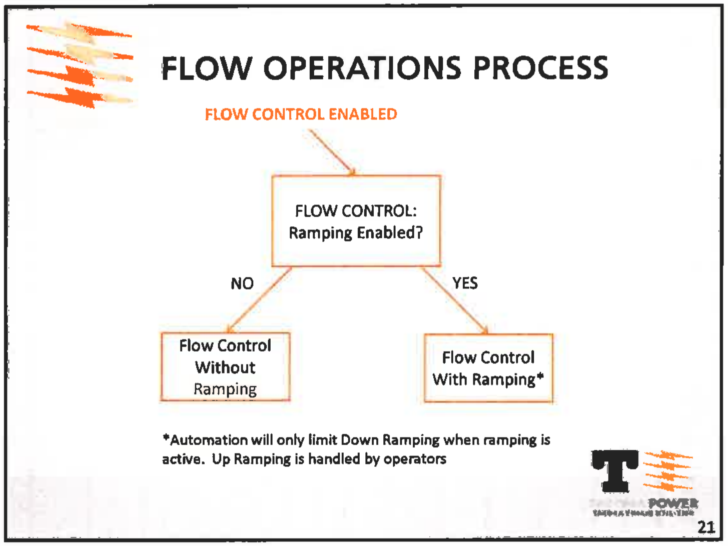
TACOMA POWER 19

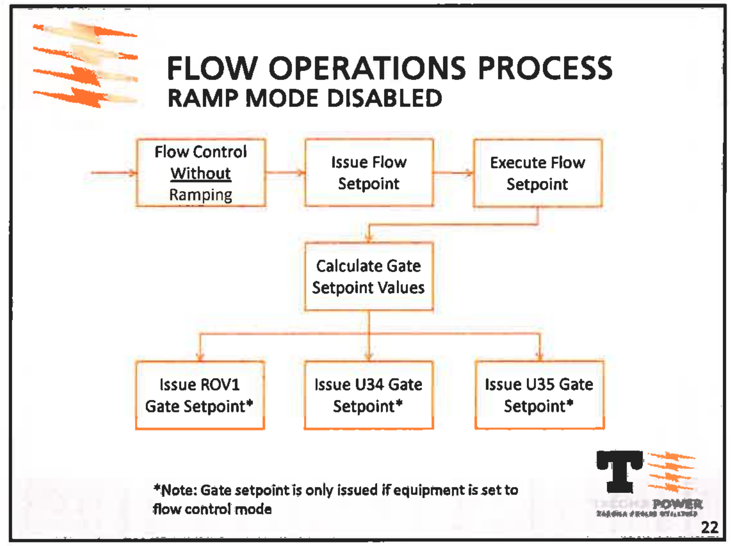
FLOW OPERATIONS PROCESS

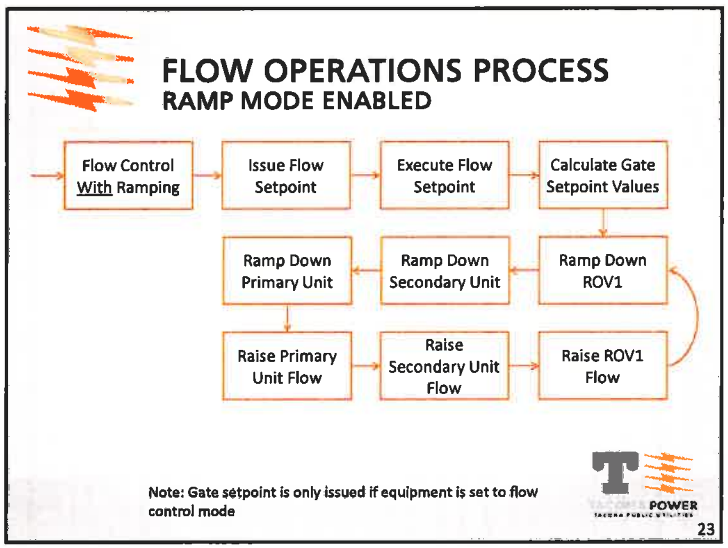


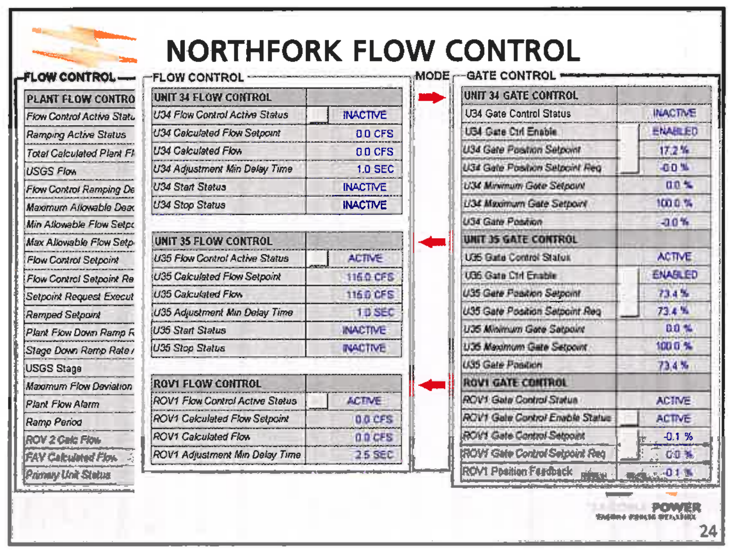
*Each Unit has a Flow Control Mode/Gate Control Mode In Addition to Flow Control Enable/Disable

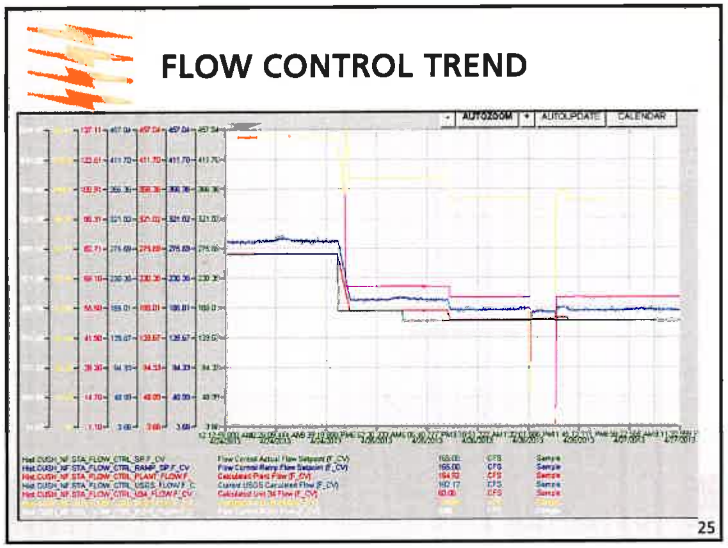
TACOMA POWER 20

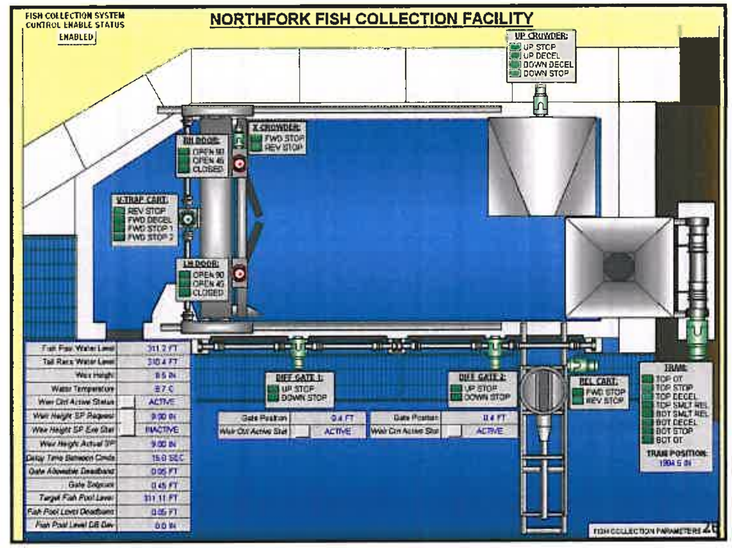

FLOW OPERATIONS PROCESS
FLOW CONTROL ENABLED
FLOW CONTROL: Ramping Enabled?
NO
YES
Flow Control Without Ramping
Flow Control With Ramping*
*Automation will only limit Down Ramping when ramping is active. Up Ramping is handled by operators
POWER
21

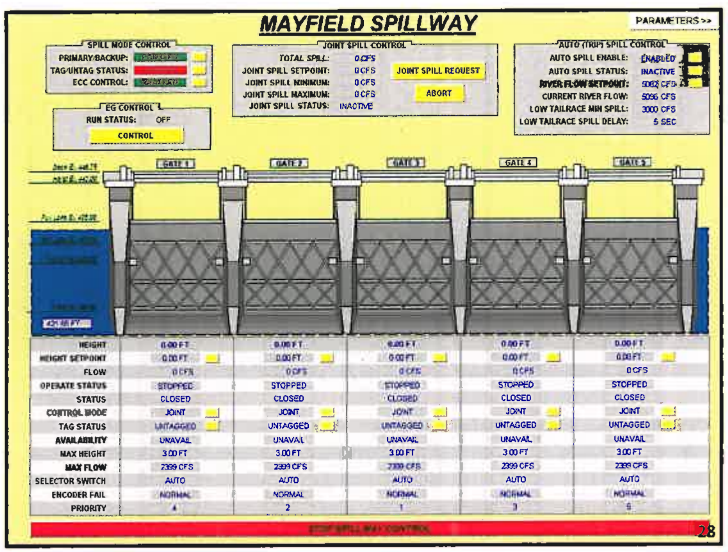

FLOW OPERATIONS PROCESS
RAMP MODE DISABLED
Flow Control Without Ramping
Issue Flow Setpoint
Execute Flow Setpoint
Calculate Gate Setpoint Values
Issue ROV1 Gate Setpoint*
Issue U34 Gate Setpoint*
Issue U35 Gate Setpoint*
*Note: Gate setpoint is only issued if equipment is set to flow control mode
POWER
22

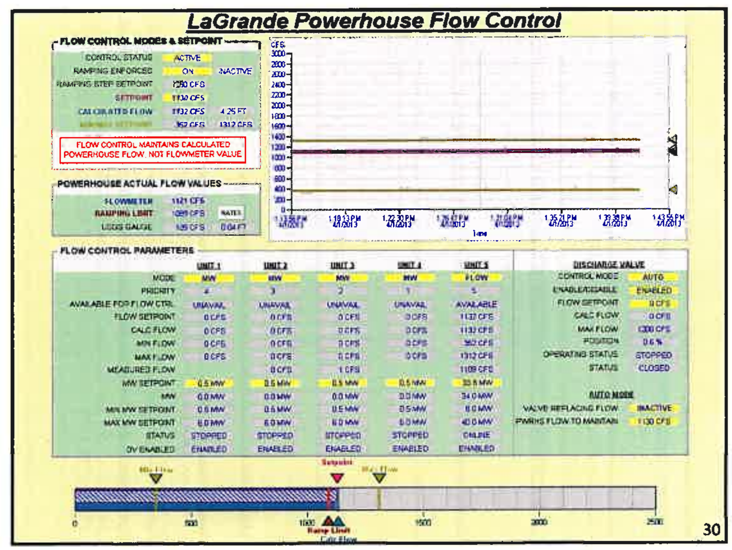

FLOW OPERATIONS PROCESS
RAMP MODE ENABLED
Flow Control With Ramping
Issue Flow Setpoint
Execute Flow Setpoint
Calculate Gate Setpoint Values
Ramp Down Primary Unit
Ramp Down Secondary Unit
Ramp Down ROV1
Raise Primary Unit Flow
Raise Secondary Unit Flow
Raise ROV1 Flow
Note: Gate setpoint is only issued if equipment is set to flow control mode
POWER
23

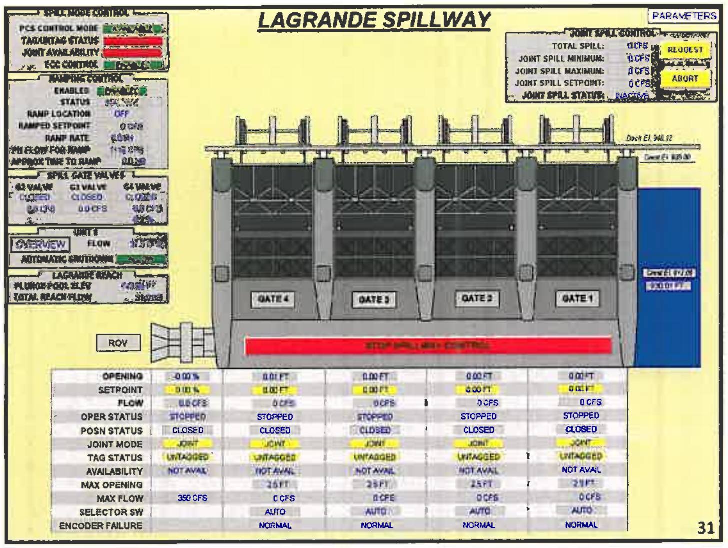

NORTHFORK FLOW CONTROL
FLOW CONTROL
FLOW CONTROL
MODE
GATE CONTROL
UNIT 34 FLOW CONTROL
U34 Flow Control Active Status INACTIVE
U34 Calculated Flow Setpoint 0.0 CFS
U34 Calculated Flow 0.0 CFS
U34 Adjustment Min Delay Time 1.0 SEC
U34 Start Status INACTIVE
U34 Stop Status INACTIVE
UNIT 35 FLOW CONTROL
U35 Flow Control Active Status ACTIVE
U35 Calculated Flow Setpoint 116.0 CFS
U35 Calculated Flow 116.0 CFS
U35 Adjustment Min Delay Time 1.0 SEC
U35 Start Status INACTIVE
U35 Stop Status INACTIVE
ROV1 FLOW CONTROL
ROV1 Flow Control Active Status ACTIVE
ROV1 Calculated Flow Setpoint 0.0 CFS
ROV1 Calculated Flow 0.0 CFS
ROV1 Adjustment Min Delay Time 2.5 SEC
UNIT 34 GATE CONTROL
U34 Gate Control Status INACTIVE
U34 Gate Ctrl Enable ENABLED
U34 Gate Position Setpoint 17.2 %
U34 Gate Position Setpoint Req -0.0 %
U34 Minimum Gate Setpoint 0.0 %
U34 Maximum Gate Setpoint 100.0 %
U34 Gate Position -0.0 %
UNIT 35 GATE CONTROL
U35 Gate Control Status ACTIVE
U35 Gate Ctrl Enable ENABLED
U35 Gate Position Setpoint 73.4 %
U35 Gate Position Setpoint Req 73.4 %
U35 Minimum Gate Setpoint 0.0 %
U35 Maximum Gate Setpoint 100.0 %
U35 Gate Position 73.4 %
ROV1 GATE CONTROL
ROV1 Gate Control Status ACTIVE
ROV1 Gate Control Enable Status ACTIVE
ROV1 Gate Control Setpoint -0.1 %
ROV1 Gate Control Setpoint Req 0.0 %
ROV1 Position Feedback -0.1 %
PLANT FLOW CONTRO
Flow Control Active Statu
Ramping Active Status
Total Calculated Plant Fl
USGS Flow
Flow Control Ramping De
Maximum Allowable Dea
Min Allowable Flow Setp
Max Allowable Flow Setp
Flow Control Setpoint
Flow Control Setpoint Re
Setpoint Request Execut
Ramped Setpoint
Plant Flow Down Ramp R
Stage Down Ramp Rate
USGS Stage
Maximum Flow Deviation
Plant Flow Alarm
Ramp Period
ROV 2 Calc Flow
FAV Calculated Flow
Primary Unit Status
POWER
24

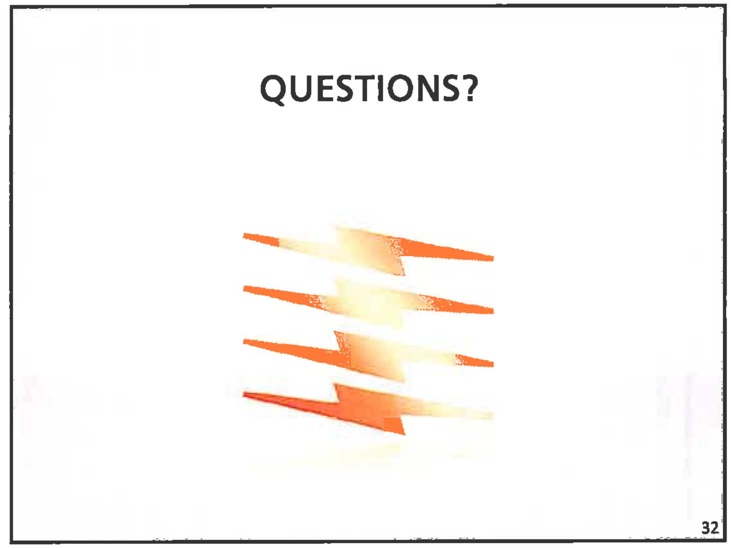

FLOW CONTROL TREND
AUTOZOOM
AUTOUPDATE
CALENDAR
25


NORTHFORK FISH COLLECTION FACILITY
FISH COLLECTION SYSTEM CONTROL ENABLE STATUS
ENABLED
FISH COLLECTION PARAMETERS
26


MAYFIELD SPILLWAY
PARAMETERS>>
SPILL MODE CONTROL
JOINT SPILL CONTROL
AUTO (TRIP) SPILL CONTROL
JOINT SPILL REQUEST
ABORT
EG CONTROL
CONTROL
GATE 1
GATE 2
GATE 3
GATE 4
GATE 5
28


LaGrande Powerhouse Flow Control
FLOW CONTROL MODES & SETPOINT
POWERHOUSE ACTUAL FLOW VALUES
FLOW CONTROL PARAMETERS
FLOW CONTROL MAINTAINS CALCULATED POWERHOUSE FLOW, NOT FLOWMETER VALUE
UNIT 1
UNIT 2
UNIT 3
UNIT 4
UNIT 5
DISCHARGE VALVE
AUTO MODE
30


LAGRANDE SPILLWAY
PARAMETERS
JOINT SPILL CONTROL
TOTAL SPILL:
JOINT SPILL MINIMUM:
JOINT SPILL MAXIMUM:
JOINT SPILL SETPOINT:
JOINT SPILL STATUS:
REQUEST
ABORT
SPILL MODE CONTROL
PCS CONTROL MODE
TAGOUT/TAG STATUS
JOINT AVAILABILITY
ECC CONTROL
RAMPING CONTROL
ENABLED
STATUS
RAMP LOCATION
OFF
RAMPED SETPOINT
RAMP RATE
APPROX TIME TO RAMP
SPILL GATE VALVES
G2 VALVE
G3 VALVE
G4 VALVE
CLOSED
UNIT 6
OVERVIEW
FLOW
AUTOMATIC SHUTDOWN
LAGRANDE REACH
PLUNGE POOL ELEV
TOTAL REACH FLOW
ROV
GATE 4
GATE 3
GATE 2
GATE 1
STOP SPILLWAY CONTROL
OPENING
SETPOINT
FLOW
OPER STATUS
POSN STATUS
JOINT MODE
TAG STATUS
AVAILABILITY
MAX OPENING
MAX FLOW
SELECTOR SW
ENCODER FAILURE
STOPPED
CLOSED
JOINT
UNTAGGED
NOT AVAIL
350 CFS
AUTO
NORMAL
31


QUESTIONS?
32