Annex A

Turbine Passage Modification Plan

Annex A: Turbine Passage Modification Plan

A.1 General

This annex describes the plans for modifying and operating the turbines to conduct a controlled drawdown of the reservoirs below spillway crest elevation.

Preliminary evaluations considered a wide range of outlet configurations to control the discharge of up to 60,000 cfs under decreasing head conditions. These options included an embankment tunnel and intake, an intake and conduit through the non-overflow concrete dam, and a modification to a turbine passage to convert it to a controlled discharge conduit. All these options were very costly, risky, and required significant time for implementation. The use of the turbines and turbine passages was then considered.

Three alternatives for using the turbine passages to draft the reservoir were considered: 1) operate the existing turbines below the normal operating range, 2) remove the turbine blades, but leave the hub in place, and 3) remove the turbine entirely. As part of this Feasibility Study, Voest-Alpine MCE Corporation in Linz, Austria, was contracted to evaluate intermediate- and low-head turbine operation using a 1:25-scale model for a Lower Granite Dam turbine. At the same time, the Corps' Waterways Experiment Station (WES) in Vicksburg, Mississippi, also conducted tests using a bladeless runner in a 1:25-scale sectional model of a Lower Granite Dam turbine. The Corps' Hydroelectric Design Center (HDC) in Portland, Oregon, provided assistance interpreting the model test data and recommending actions necessary to prepare for a reservoir drawdown using the turbine passages to draft the reservoir.

The spillways can be used to lower the reservoir water surfaces to near the spillway crest elevation at each dam. Below the spillway crest, there are no low-level outlets except the turbine passages through the powerhouse (see Figure A1). The four lower Snake River dams were designed as run-of-river projects, meaning the turbines were designed to operate over a narrow range of forebay water surface elevations, with typically only a 0.9 meter to 1.5 meter (3-to 5-foot) difference between the minimum and maximum operating pool. A report prepared by Raytheon Infrastructure Services in 1996, entitled *Lower Granite Dam, Turbine Passage Evaluation*, indicated that it may be feasible to use the turbine passages to draft the reservoirs far below normal operating range (Raytheon, 1996). However, that report recommended further studies to evaluate the issues involved in such an action.

As part of this Feasibility Study, Voest-Alpine MCE Corporation in Linz, Austria, was contracted to evaluate intermediate- and low-head turbine operation using a 1:25-scale model for a Lower Granite Dam turbine. At the same time, the Corps's Waterways Experiment Station (WES) in Vicksburg, Mississippi, also conducted tests using a bladeless runner in a 1:25-scale sectional model of a Lower Granite Dam turbine. The Corps' Hydroelectric Design Center (HDC) in Portland, Oregon, provided assistance interpreting the model test data and recommending actions necessary to prepare for a reservoir drawdown using the turbine passages to draft the reservoir.

A.2 Voest-Alpine MCE Operating Turbine Model Testing

Voest-Alpine MCE performed hydraulic turbine model testing using a 1:25 scale model of the Unit 4 turbine at Lower Granite Dam. The turbine modeling was performed using Froudian methods of similitude to predict turbine operating characteristics and limits for anticipated drawdown conditions. These conditions consisted of turbine operation at and below the existing spillway crest elevation of 208 meters (681 feet) mean sea level (msl) and tailwater elevations of 193 meters (633 feet) msl and

190 meters (624 feet) msl. The turbine model operated over head ranges of 15 meters to 2 meters (48 feet to 8 feet) for the tailwater of 193 meters (633 feet) msl and 17 meters to 5 meters (57 feet to 17 feet) for the tailwater of 190 meters (624 feet) msl. The testing investigated four wicket gate openings (100 percent, 75 percent, 50 percent, and 25 percent) and two runner blade angles (minimum opening of 20 degrees and maximum opening of 32 degrees). In all, approximately 160 test conditions were performed. The lower bound for the testing was established as the point where the actual turbine produces no electrical power, which is referred to as speed no load (SNL).

A.2.1 Assumptions

The study team made the following assumptions in using the turbine model results to predict actual turbine performance:

- Modeling using Froude techniques provides quantitative information regarding turbine performance.
- Model performance represents performance of actual turbine units.
- The operation of the turbine during drawdown will be a one-time operation. Operation may continue until structural safety of the unit is compromised.
- The modeling was performed on a model of Lower Granite Unit 4. Units 1-3 (Baldwin-Lima-Hamilton design) operate similarly to Units 4-6 (Allis-Chalmers design).

A.2.2 Results

Tables A1 through A4 contain data from the turbine model testing. Figures A2 through A5 present this data graphically. The model testing results, brought to actual conditions through hydraulic affinity laws, indicate the limits of actual turbine operation to be as follows:

- Pool elevation range is from 207.6 meters (681.0 feet) to 196.4 meters (644.2 feet) msl.
- Gross head range is from 17.4 meters to 6.2 meters (57.0 feet to 20.2 feet).
- Flow range is from 587 m^3/s to 218 m^3/s (20,750 cfs to 7,700 cfs).
- Wicket gate operating range is 100 percent to 38 percent, depending on the specific site hydraulic conditions.

Table A1. Model Turbine Performance at Minimum Runner Blade Angle (20 degrees) and Tailwater Elevation of 633 feet msl

Pool Elevation (feet msl)	Gross Head (feet)	Flow (cfs)	Wicket Gate Opening (%)	Power (horsepower)	Operational Feasibility
681.0	48.0	14,550	100	56,600	Yes
681.0	48.0	12,500	75	44,500	Yes
681.0	48.0	9,150	50	10,000	Yes
681.0	48.0	8,400	43	0	Yes (SNL at Minimum Gate)
675.5	42.5	8,850	50	0	Yes (SNL)
670.0	37.0	14,000	100	37,000	Yes
670.0	37.0	11,850	75	21,700	Yes
660.0	27.0	13,350	100	14,000	Yes
660.0	27.0	11,200	75	200	Yes
659.4	26.4	11,150	75	0	Yes (SNL)
653.2	20.2	12,850	100	0	Yes (SNL)

Table A2. Model Turbine Performance at Minimum Runner Blade Angle (20 degrees) and Tailwater Elevation of 624 feet msl

Pool Elevation (feet msl)	Gross Head (feet)	Flow (cfs)	Wicket Gate Opening (%)	Power (horsepower)	Operational Feasibility
681.0	57.0	15,000	100	74,300	Yes
681.0	57.0	13,000	75	64,000	Yes
681.0	57.0	9,650	50	27150	Yes
681.0	57.0	7,700	38	0	Yes (SNL a Minimum. Gate)
670.0	46.0	14,450	100	52,700	Yes (SNL)
670.0	46.0	12,400	75	41,150	Yes
670.0	46.0	9,100	50	6,900	Yes
666.5	42.5	8,850	50	0	Yes (SNL)
660.0	36.0	13,800	100	34,550	Yes
660.0	36.0	11,700	75	20,300	Yes (SNL)
650.5	26.5	11,150	75	0	Marginal (SNL)
650.0	26.0	13,200	100	11,200	Marginal
644.2	20.2	12,850	100	0	Marginal (SNL)

Table A3. Model Turbine Performance at Maximum Runner Blade Angle (32 degrees) and Tailwater Elevation of 633 feet msl

Pool Elevation (feet msl)	Gross Head (feet)	Flow (cfs)	Wicket Gate Opening (%)	Power (horsepower)	Operational Feasibility
681.0	48.0	20,750	100	69,200	Yes
681.0	48.0	16,000	75	21,000	Yes
681.0	48.0	14,200	65	0	Yes (SNL at Minimum Gate)
674.2	41.2	15,400	75	0	Marginal (SNL)
670.0	37.0	19,650	100	30,400	Marginal
660.9	27.9	18,800	100	0	Marginal (SNL)

Table A4. Model Turbine Performance at Maximum Runner Blade Angle (32 degrees) and Tailwater Elevation of 624 feet msl

Pool Elevation (feet msl)	Gross Head (feet)	Flow (cfs)	Wicket Gate Opening (%)	Power (horsepower)	Operational Feasibility
681.0	57.0	21,500	100	99,425	Yes
681.0	57.0	16,800	75	47,850	Yes
681.0	57.0	12,700	57	0	Yes (SNL a Minimum Gate)
670.0	46.0	20,500	100	61,650	Yes
670.0	46.0	15,850	75	15,500	Yes
665.2	41.2	15,400	75	0	Marginal (SNL)
660.0	36.0	19,550	100	26,750	Marginal
652.2	28.2	18,650	100	0	Marginal (SNL)

In addition to the above measured data, qualitative information was obtained through direct observation to identify effects on stability of operation. These observations indicated that a vortex was formed on the runner for various conditions measured above (see Figure A6). The vortex is an indication of undesirable and possibly unsafe zones of turbine operation. The development of a vortex normally corresponds with severe unstable conditions. The vortex forming and collapsing creates pressure pulsations and causes severe vibrations from unstable flow distribution to the runner.

Froude modeling techniques do not allow investigation of cavitation phenomena. However, significant cavitation can be expected to occur, increasing the tendencies for unstable operation at high flows and low tailwater conditions. Severe cavitation could also cause damage to the machinery and structures.

At head ranges far outside the design operating range, the turbines operate at reduced efficiencies. The poor performance of the turbine (low efficiency) indicates the equipment and structure must absorb substantial energy. For example, at the minimum gate SNL condition (zero turbine efficiency) with the minimum blade angle of 20 degrees and a flow of 218 m^3/s (7,700 cfs), 37 megawatts of potential energy must be dissipated through the turbine and powerhouse structure.

The observations indicated that the worst conditions of unstable operation and vortex formation occurred with a blade angle of 32 degrees, wicket gate openings from 100 percent to 75 percent, and heads of 14 meters (46 feet) and below. The worst condition noted during the observational testing was for 100 percent wicket gate opening, 32 degrees blade angle, tailwater of 190 meters (624 feet) msl, and gross head of 8.6 meters (28.2 feet) (SNL condition). As head on the turbine is reduced with a blade angle of 20 degrees (for either tailwater), the model testing indicates acceptable to marginal operating conditions.

The effect of lowering the pool elevation on the turbine intake velocity was noted during the observational testing. As the pool elevation was lowered and intake flow area decreased, the velocity increased. The study team also noted that higher intake velocities may cause higher loading on the trash racks from debris accumulation, which may affect the turbine discharge capacity.

A.2.3 Recommendations for Using Existing Turbines

Turbine Operation

Tables A1 through A4 show which operating conditions are operationally feasible. The turbine discharge capabilities for those operating conditions are used to evaluate various drawdown alternatives. However, unstable or unacceptable operation may occur at many of the conditions identified in the tables, which may preclude actual operation at those conditions. The magnitude of the response of the actual turbine to the hydraulic conditions is difficult to quantify for zones of turbine operation far below accepted design practice.

Because the actual response to operation far below the design range is uncertain, operation to the SNL condition should be restricted to low blade angles and should be carefully monitored prior to incremental increases in discharge.

Operation below SNL is possible, but would require direct manual operation of each turbine. The turbine generators must be disconnected from the power grid by opening the breakers. Operation below SNL would require an operator at each turbine to adjust the wicket gates and monitor the turbine speed and other unit parameters. More critical evaluation of this option is necessary to establish the operating methods and constraints.

Performance Instrumentation

The turbines and plant should be appropriately instrumented to detect structurally dangerous conditions. Instrumentation should measure acceleration, shaft run out, increased leakage, bearing temperatures, structural and mechanical vertical displacement, and pressures at the head cover, intake, and draft tube man doors. There should also be instrumentation to detect runner blade impact on the discharge ring.

The study team recommends installing instrumentation for one turbine unit and conducting several tests to make sure the instrumentation setup is sufficient and working properly before the instrumentation is installed on the remainder of the units. Less instrumentation would be required for bladeless runner units, but some instrumentation would still be necessary.

Emergency Closure Devices

Existing emergency closure devices should be in operating condition. Currently, the intake gates at each project are either raised (with the hydraulic operators disconnected) or removed for improved fish passage purposes. During a reservoir drawdown, the fish screens would be removed. The intake gates should be connected to the hydraulic operators and stored in the normal position, ready for emergency use.

Cooling Water System

Additional cooling water for turbines and generators would be required to supplement the existing gravity-fed system as the head drops. There are two broad categories of water that need to be provided, depending on absolute pool level and whether generation is necessary. The first category is the water required for thrust- and guide-bearing cooling, gland water, air compressors, station service transformers, and heat pumps for cooling the control and computer rooms. This water is required as long as the units are turning, whether they are generating or not. The bearing cooling water can be shut off if the units are stationary. The second category is for cooling water for the main unit. This cooling water is required only if the units are generating. The main unit transformers are air-cooled.

The following modifications would be typical to adapt the existing turbine cooling water system for drawdown conditions:

- Provide a piping header from an external source providing 57 m^3 (15,000 gallons) per minute to supply cooling water pumps.
- Install six generator-cooling water pumps, motors, and pump bases to replace the existing gravity-feed system.
- Install six thrust- and guide-bearing cooling water pumps, motors, and pump bases to replace the existing gravity-feed system.
- Install electric power supply for the pump motors.
- Provide remote annunciation and operation in the powerhouse control room.

Trash Rack Modifications

Investigation is necessary to assure that the trash rack structures are adequate for the wide range of static and dynamic loads anticipated. Some strengthening has been assumed to be necessary for drawdown conditions. The trash racks should be inspected and modifications made as necessary prior to drawdown. A significant effort will be required to keep the trash racks clear of debris during drawdown.

Draft Tube Bulkheads

If more than one project is drawn down at once, the tailwater of the upstream project will drop significantly. For example, normal minimum tailwater at Lower Granite is 193 meters (633 feet). If

Little Goose Reservoir is also drawn down, the tailwater at Lower Granite will fall to about 190 meters (624 feet). This drop in tailwater may cause serious cavitation problems for the turbines. One solution is to minimize cavitation conditions by partially lowering the draft tube bulkheads to create an orifice in the draft tube. This would increase head losses and create an artificial tailwater for the turbines. More specific model studies are necessary to establish the parameters to best prevent potential problems. It is not intended that extraordinary measures be implemented to prevent all damage. The intention is to control the rate of damage progression during the critical periods of operation.

The loading on the bulkheads and supporting structures would be in the opposite direction from how they were designed, and the forces would no longer be just static loading. Figure A13 shows existing draft tube bulkheads. A more complete structural analysis that would include a vibration analysis and a review of hydraulic pull-down forces on the bulkheads would need to be completed before implementing this action. Each project has only one set of draft tube bulkheads, so additional bulkheads for the remaining five units would need to be fabricated.

A.3 Waterways Experiment Station Model Testing

WES performed hydraulic turbine model testing using a 1:25 scale sectional model of the Lower Granite Dam turbine units. Both of these model tests were performed with the blades removed and the entire turbine removed. Only a few tests were conducted with the turbine removed entirely. This was because it quickly became apparent that extremely high velocities and unpredictable flow conditions through the turbine passages could potentially lead to structural failures and uncontrolled discharge. This alternative was dropped from further consideration. Numerous experiments were performed with the bladeless runner at tailwater elevations of 190 meters (624 feet) and 193 meters (633 feet). These experiments helped to determine how to operate the unit to achieve the desired drawdown rates. These curves are straightforward and were repeatable.

A total of 10 velocity experiments were performed to document what flow conditions might exist at various operation points that might occur during the drawdown process. Velocities were measured in the intake structure upstream of the wicket gates in Bays A and B, in the vicinity of the bladeless runner, and in both barrels of the draft tube.

A.3.1 Results

Velocities Upstream of the Turbine

See Figure A7 for typical velocity measurement locations upstream of the turbine. The velocity experiments indicated that no problems would be anticipated for flow conditions upstream of the wicket gates. This is true for all heads and discharges, as long as the trash racks and wicket gates are free of debris. As the reservoir is drawn down, debris loading may increase. Velocities and flow conditions in the turbine intakes will be affected if debris accumulates on the trash racks. Care must be taken to keep the trash racks clean for the information presented here to be valid.

Velocities measured 1.2 meters (4 feet) upstream of the upstream edge of the wicket varied between 4.0 meters (13.2 feet) per second for a turbine discharge of 600 m^3/s (20,000 cfs) to 1.5 meters (5 feet) per second for a turbine discharge of 200 m^3/s (7,000 cfs). Since the flow is accelerating downstream, it can be expected to reach a velocity of 15.5 meters (50.7 feet) per second for a turbine discharge of 600 m^3/s (20,000 cfs) to 4.5 meters (14.8 feet) per second for a turbine discharge of 200 m^3/s (7,000 cfs) with an upper pool of 195 meters (640 feet) at the controlling point of the wicket gate opening. Although high velocities would be expected in this area with a bladed runner, the velocities between the wicket gates are even higher than what would be expected. The measured velocities upstream of the wicket gates indicated no instabilities in the approaching flow field.

Velocities Near the Bladeless Runner

See Figure A8 for typical velocity measurement locations near the bladeless runner. Velocities measured in the vicinity of the runner indicated that high velocities could be expected at this location for discharges of 600 m^3/s (20,000 cfs) and 400 m^3/s (15,000 cfs). Measured velocities for a turbine loading of 600 m^3/s (20,000 cfs) were as high as 28.5 meters (93.4 feet) per second near the runner. This was much higher than expected. At this measurement section, the average velocity based on the available area would be approximately 14 meters (46 feet) per second. Measured velocities for lower discharges were as high as 17 meters (57 feet) per second. This is also a high velocity but is close to what would be expected at some of the normal turbine operations with a bladed runner.

Unstable flow conditions are likely to occur when there are extremely high velocities due to cavitation and severe turbulence. Large vibrations occurred in the model for discharges of 600 m^3/s (20,000 cfs). While these vibrations are not scaleable, they indicate operating conditions that would not be good for the unit, even for short durations.

Velocities in the Draft Tube

See Figures A9 and A10 for typical velocity measurement locations in the draft tube. Velocities measured in the draft tube indicated a very non-uniform flow field. This was true for all 10 experimental conditions. These conditions should not prohibit the use of the bladeless runner for the natural river drawdown process. However, for all 10 conditions, the boil that occurs downstream in the tailrace area occurred much further downstream than was expected. The boil in the Voest-Alpine MCE bladed runner model occurred much closer to the structure than it did in the WES model. The bladed runner removes much of the energy in the flow to produce power with the generator. With a bladeless runner, most of this energy remains in the flow, so the boil occurs much further downstream. This may have an effect on scour in the tailrace area downstream of the draft tube exits, depending on how well the bed is armored.

Pressure Experiments

Pressures were measured at five locations in the vicinity of the bladeless runner as shown in Figure A11. Four of these locations were on the discharge ring, and one was located on the bladeless runner itself. These experiments indicated that cavitation will occur on the bladeless runner for discharges of 600 m^3/s (20,000 cfs). The tests also indicated that there is potential for cavitation on the runner for discharges of 440 m^3/s (15,600 cfs) and 400 m^3/s (15,000 cfs). These pressure readings are consistent with the extremely high velocity measurements noted for these discharges. The cavitation associated with the 400 m^3/s (15,000 cfs) range is probably not of the magnitude to prohibit operating the bladeless unit for the length of time it would take to draft the reservoir down to elevation 195 meters (640 feet) msl.

A.3.2 Recommendations for Using Bladeless Turbines

The bladeless runner can be used to draw down the river to the lowest possible river levels. Approximately 4 meters to 7 meters (12 to 22 feet) of head is required to yield the required discharge through the turbine units. Curves generated from the hydraulic model studies show that the potential hydraulic capacity of a unit with a bladeless runner is higher than that of a unit with a normal bladed runner. However, at discharges above approximately 400 m^3/s (15,000 cfs), there would be problems with extremely high velocities, cavitation, vibrations, and unstable flow conditions. Potential cavitation problems may be encountered at discharges in the range of 400 m^3/s (15,000 cfs). These problems are most pronounced at high heads. It is recommended that the maximum discharges of the unit not exceed 400 m^3/s (15,000 cfs). If possible, the maximum unit discharge should be closer to 300 m^3/s (10,000 cfs). Limiting the discharge may also reduce the likelihood of scour problems in the tailrace area downstream of the draft tube exits.

With the turbine and generator units in place, there is not enough clearance to remove the blades intact. The blades must be cut off at the hub and removed through the draft tubes. The cut surface should be made smooth with the surface of the hub to minimize cavitation.

The high velocities and associated turbulence through the bladeless runner area would not be conducive to safe fish passage. The bladeless runner should not be used if migrating juvenile fish are in the river.

The recommendations noted earlier for the existing turbines regarding emergency closure systems and trash rack cleaning are also applicable for the bladeless runner units.

A.4 Proposed Configuration

The maximum drawdown rate has been established at 0.6 meter (2 feet) per day. To achieve this drawdown rate, the turbines must pass a flow amount equal to the discharge necessary to draft the reservoir plus the inflow into the reservoir. Figure B5, in Annex B, shows summary hydrographs for Ice Harbor Dam, which is representative of all four lower Snake River dams for the purposes of this report. The graph shows that the average mean daily flow for the period from August through November is 850 m^3/s (30,000 cfs) or less. The maximum mean daily discharge for most of this period (up through about mid-November) is 1,400 m^3/s (50,000 cfs) or less.

Tables A5 and A6 show the required discharge for various heads at Lower Granite Dam as the reservoir is drafted for inflows of 850 m^3/s (30,000 cfs) and 1,400 m^3/s (50,000 cfs). The tables also show the hydraulic capacity of an existing turbine and a bladeless runner unit for each head, along with a possible combination of the two types of units to satisfy the required total discharge.

Several combinations of existing turbines and bladeless runners were considered with a goal of providing the necessary discharge capacity over the entire range of pool elevation. The best combination appears to be three existing turbines and three units with bladeless runners. At high and intermediate heads (above the spillway crest), the entire discharge can pass through either the three existing turbines or a combination of the three existing turbines and the spillway. It is best to avoid using the bladeless runner units at high heads, even with restricted discharge. The existing turbines reach the SNL condition with the wicket gates 100 percent open at a head of about 6.2 meters (20.2 feet). It is possible to operate the turbines below the SNL level, as described in Section A.2.3 for the existing turbines, allowing the reservoir to be drafted lower than 6 meters (20 feet) of head. However, operation below the SNL is not recommended unless necessary. In most years, depending on river inflow, the three bladeless runner units would be sufficient to draft the reservoir below the 6-meter (20-foot) level, and possibly as low as

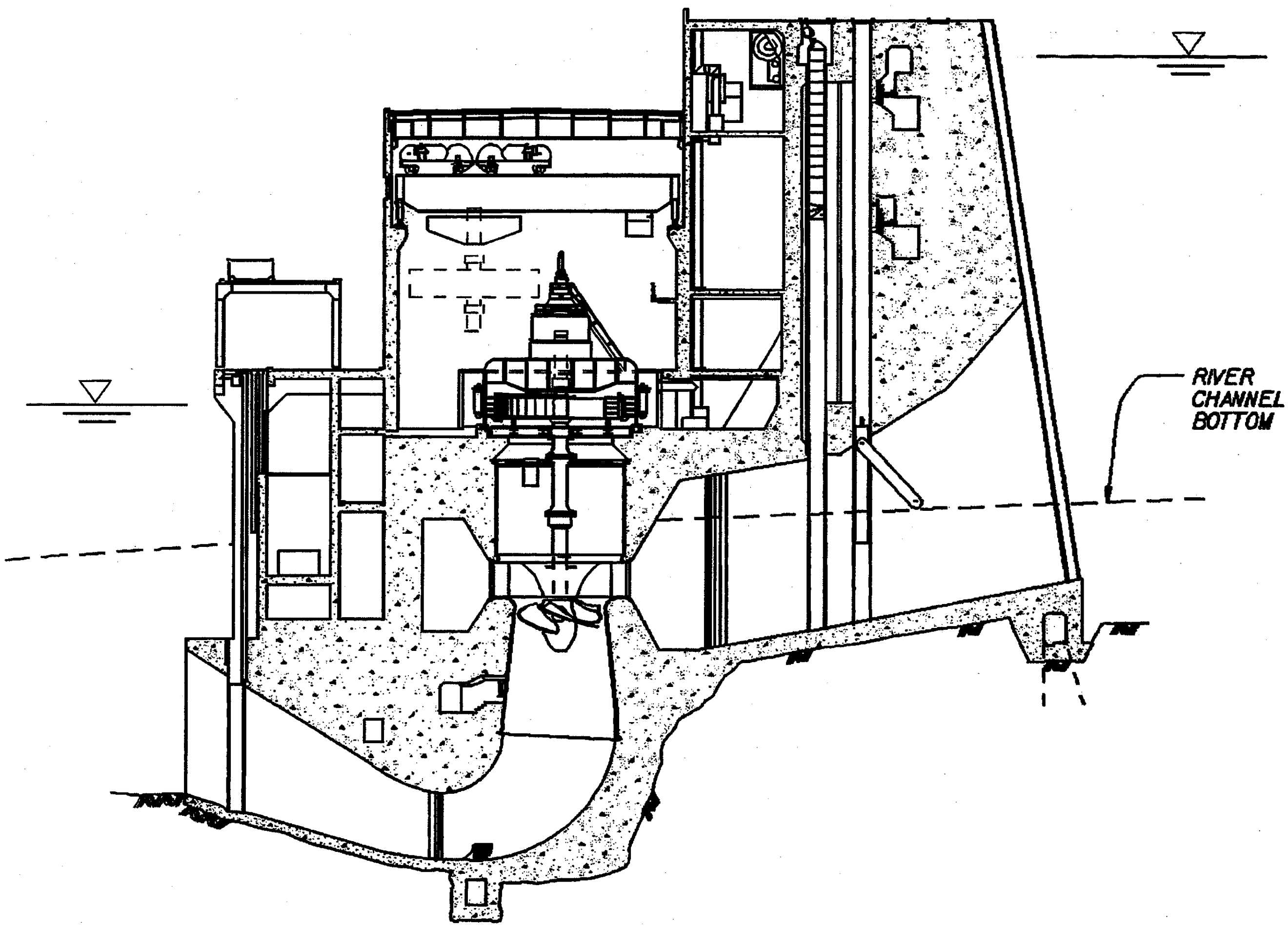
3 meters (10 feet), without exceeding the 280 m^3/s (10,000 cfs) limit per unit. More bladeless runner units would ensure the ability to draft the reservoir to the very low heads, but would also make it necessary to start using the bladeless runner units at higher heads while reducing the benefits derived by using the existing turbines. Using fewer bladeless runner units would reduce the ability to lower the final drawdown head below the SNL level (about 3 meters [20 feet]).

Table A5. Required Discharges and Proposed Turbine Configurations for Lower Granite with Inflow of 30,000 cfs and Tailwater Elevation of 624 feet

Forebay Elevation (feet msl)	Head (feet)	Reservoir Volume (AF)	Drawdown Discharge (cfs)	Total Required Discharge (cfs)	Maximum Discharge for Existing Turbine (cfs)	Minimum Discharge for Existing Turbine (cfs)	Target Maximum Discharge for Bladeless Runner Turbine (cfs)	Proposed Operating Configuration
733	109	442,900	8,067	38,067			10,000	2EX, 0BL
730	106	418,900	8,067	38,067	19,400	15,700	10,000	2EX, 0BL
725	101	380,900	7,663	37,663	19,686	15,744	10,000	2EX, 0BL
720	96	345,200	7,200	37,200	20,231	15,460	10,000	2EX, 0BL
715	91	312,000	6,695	36,695	20,279	15,370	10,000	2EX, 0BL
710	86	281,000	6,252	36,252	19,968	15,410	10,000	2EX, 0BL
705	81	252,100	5,828	35,828	18,875	13,350	10,000	2EX, 0BL
700	76	225,100	5,445	35,445	18,350	13,475	10,000	2EX, 0BL
695	71	200,200	5,022	35,022	17,900	13,700	10,000	2EX, 0BL
690	66	177,100	4,659	34,659	17,400	13,750	10,000	2EX, 0BL
685	61	155,800	4,296	34,296	17,200	13,850	10,000	2EX, 0BL
681	57	140,200	3,933	33,933	15,000	7,700	10,000	3EX, 0BL
680	56	136,500	3,731	33,731	14,950	7,800	10,000	3EX, 0BL
675	51	119,000	3,529	33,529	14,700	8,150	10,000	3EX, 0BL
670	46	103,400	3,146	33,146	14,450	8,550	10,000	3EX, 0BL
665	41	89,700	2,763	32,763	14,150	9,000	10,000	3EX, 0BL
660	36	77,800	2,400	32,400	13,850	9,550	10,000	3EX, 0BL
655	31	67,900	1,997	31,997	13,500	10,300	10,000	3EX, 0BL
650	26	59,800	1,634	31,634	13,200	11,100	10,000	2EX, 1BL
645	21	53,200	1,331	31,331	12,900	12,700	10,000	2EX, 1BL
640	16	46,600	1,331	31,331	NA	NA	10,000	0EX, 3BL
635	11	42,900	746	30,746	NA	NA	10,000	0EX, 3BL

Table A6. Required Discharges and Proposed Turbine Configurations for Lower Granite with Inflow of 50,000 cfs and Tailwater Elevation of 624 feet

Forebay Elevation (feet msl)	Head (feet)	Reservoir Volume (AF)	Drawdown Discharge (cfs)	Total Required Discharge (cfs)	Maximum Discharge for Existing Turbine (cfs)	Minimum Discharge for Existing Turbine (cfs)	Target Maximum Discharge for Bladeless Runner Turbine (cfs)	Proposed Operating Configuration
733	109	444,100	8,067	58,067			10,000	3EX, 0BL
730	106	420,200	8,033	58,033	19,400	15,700	10,000	3EX, 0BL
725	101	382,300	7,643	57,643	19,686	15,744	10,000	3EX, 0BL
720	96	346,900	7,139	57,139	20,231	15,460	10,000	3EX, 0BL
715	91	313,900	6,655	56,655	20,279	15,370	10,000	3EX, 0BL
710	86	283,100	6,211	56,211	19,968	15,410	10,000	3EX, 0BL
705	81	254,500	5,768	55,768	18,875	13,350	10,000	3EX, 0BL
700	76	228,000	5,344	55,344	18,350	13,475	10,000	3EX, 0BL
695	71	203,500	4,941	54,941	17,900	13,700	10,000	3EX, 0BL
690	66	181,000	4,538	54,538	17,400	13,750	10,000	3EX, 0BL
685	61	160,300	4,175	54,175	17,200	13,850	10,000	3EX, 0BL
681	57	145,100	3,832	53,832	15,000	7,700	10,000	3EX, 1BL
680	56	141,500	3,630	53,630	14,950	7,800	10,000	3EX, 1BL
675	51	124,500	3,428	53,428	14,700	8,150	10,000	3EX, 1BL
670	46	109,400	3,045	53,045	14,450	8,550	10,000	3EX, 1BL
665	41	96,100	2,682	52,682	14,150	9,000	10,000	3EX, 1BL
660	36	84,500	2,339	52,339	13,850	9,550	10,000	3EX, 2BL
655	31	74,700	1,976	51,976	13,500	10,300	10,000	3EX, 2BL
650	26	66,700	1,613	51,613	13,200	11,100	10,000	3EX, 2BL
645	21	60,200	1,311	51,311	12,900	12,700	10,000	3EX, 2BL
640	16	53,600	1,331	51,331	NA	NA	10,000	
635	11	49,900	746	50,746	NA	NA	10,000	



SHEET MAIN SCALE:

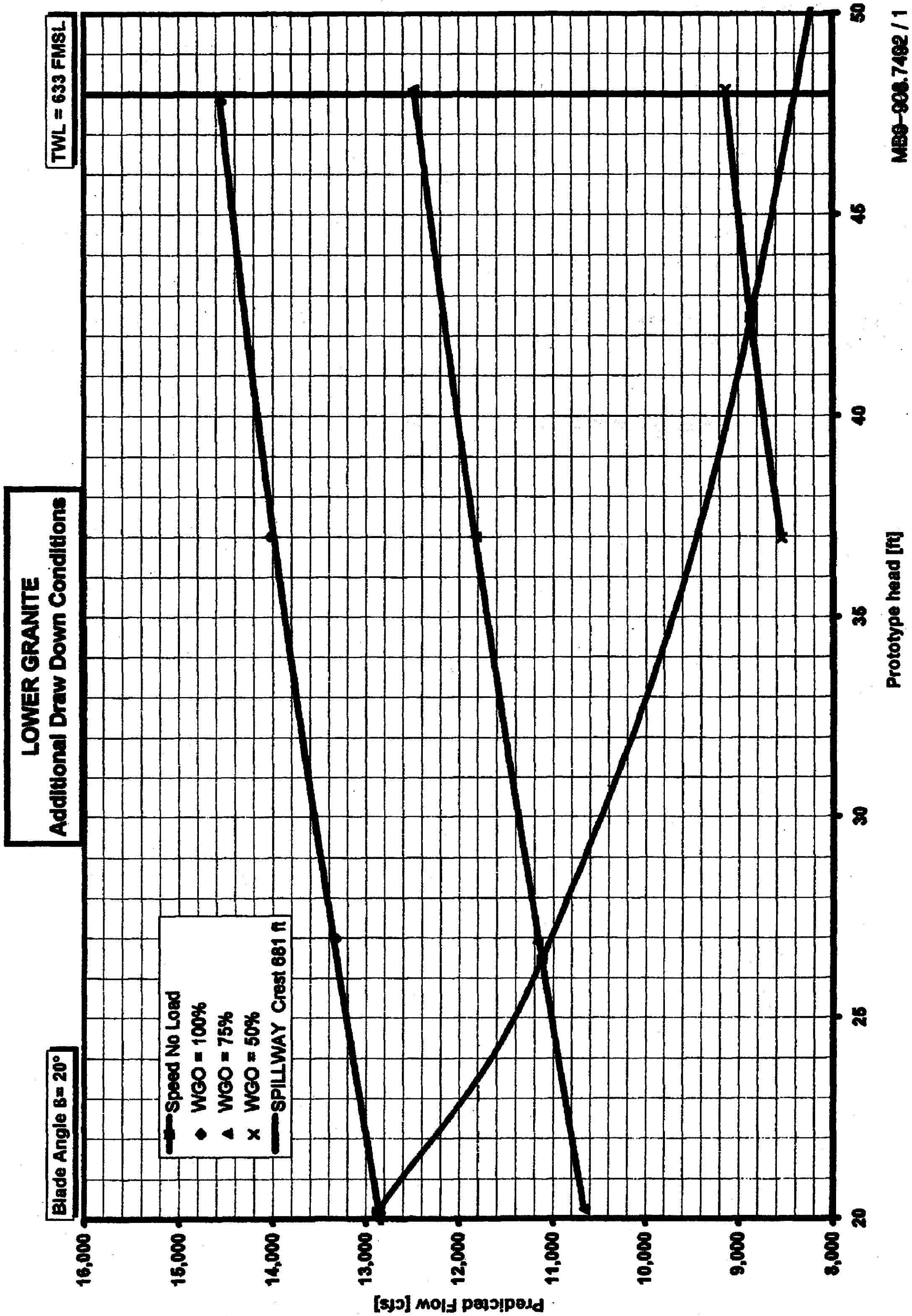
US Army Corps of Engineers
Walla Walla District

LOWER SNAKE RIVER JUVENILE SALMON MIGRATION FEASIBILITY STUDY

LOWER GRANITE POWERHOUSE SECTION

Figure: A1

CADD FILENAME: E:\drawdown\plates\a\pltal.dgn PLOT TIME: 16-SEP-1999 14:36



US Army Corps of Engineers
Walla Walla District

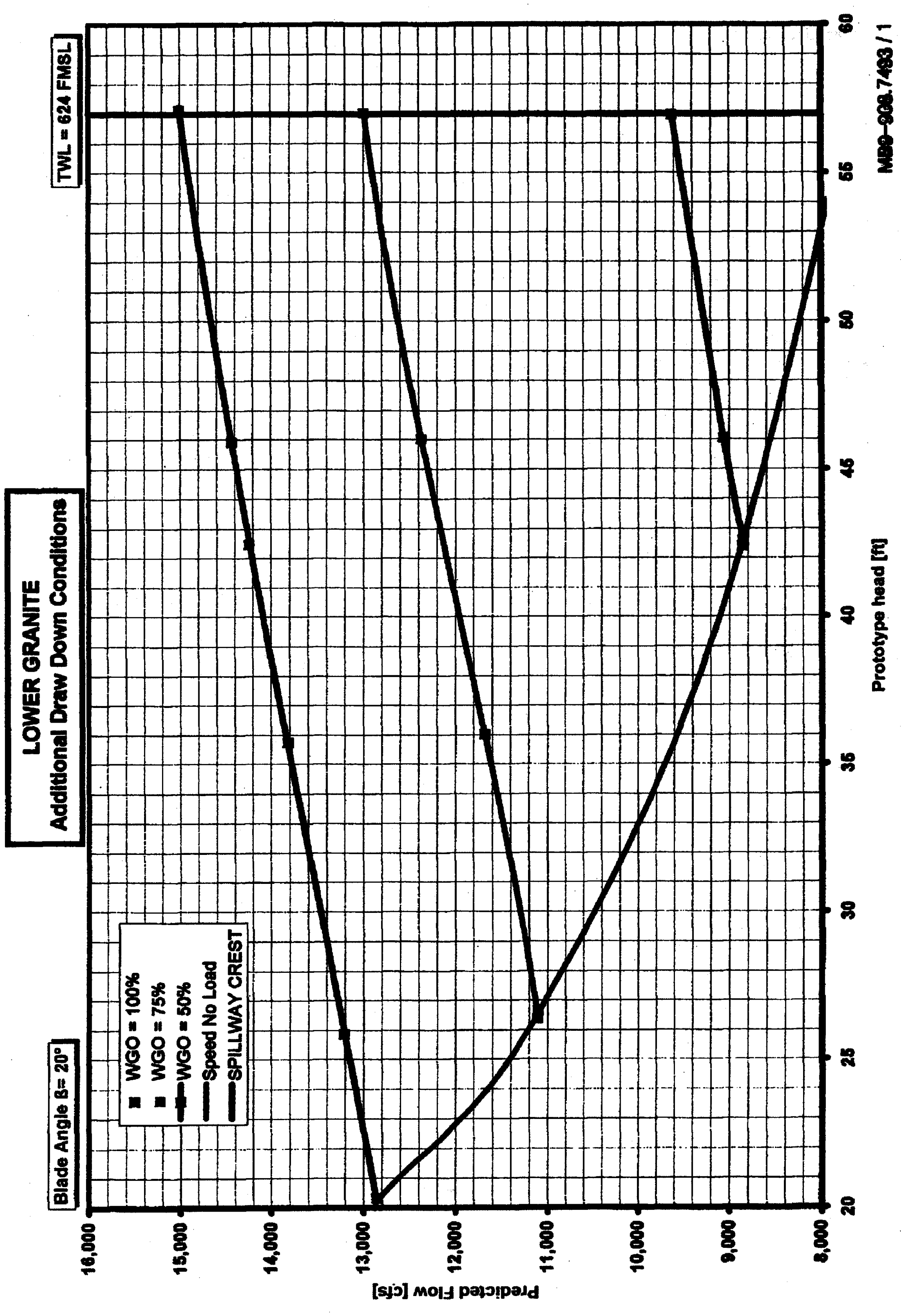
LOWER SNAKE RIVER JUVENILE SALMON MIGRATION FEASIBILITY STUDY

TURBINE PERFORMANCE CURVES FOR LOWER GRANITE
BLADE ANGLE=20, TW=633'

Figure: A2

CADD FILENAME:E:\drawdown\plates\a\plta2.dgn PLOT TIME:16-SEP-1999 14:12

SHEET MAIN SCALE:



SHEET MAIN SCALE:

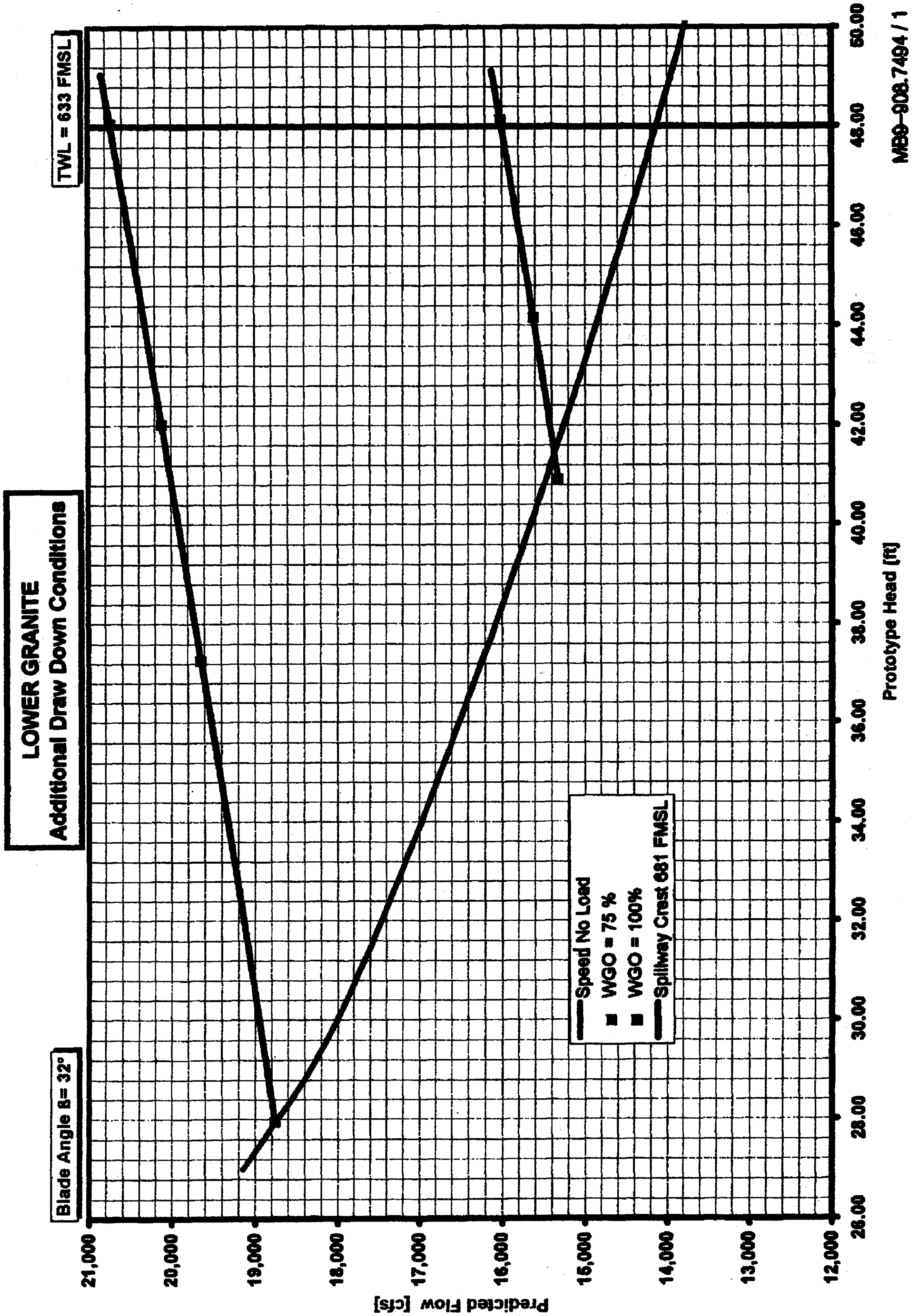
US Army Corps of Engineers
Walla Walla District

LOWER SNAKE RIVER JUVENILE SALMON MIGRATION FEASIBILITY STUDY

TURBINE PERFORMANCE CURVES FOR LOWER GRANITE
BLADE ANGLE=20, TW=624'

Figure:
A3

CADD FILENAME:E:\drawdown\plates\a\plta3.dgn PLOT TIME:16-SEP-1999 14:14



US Army Corps of Engineers
Walla Walla District

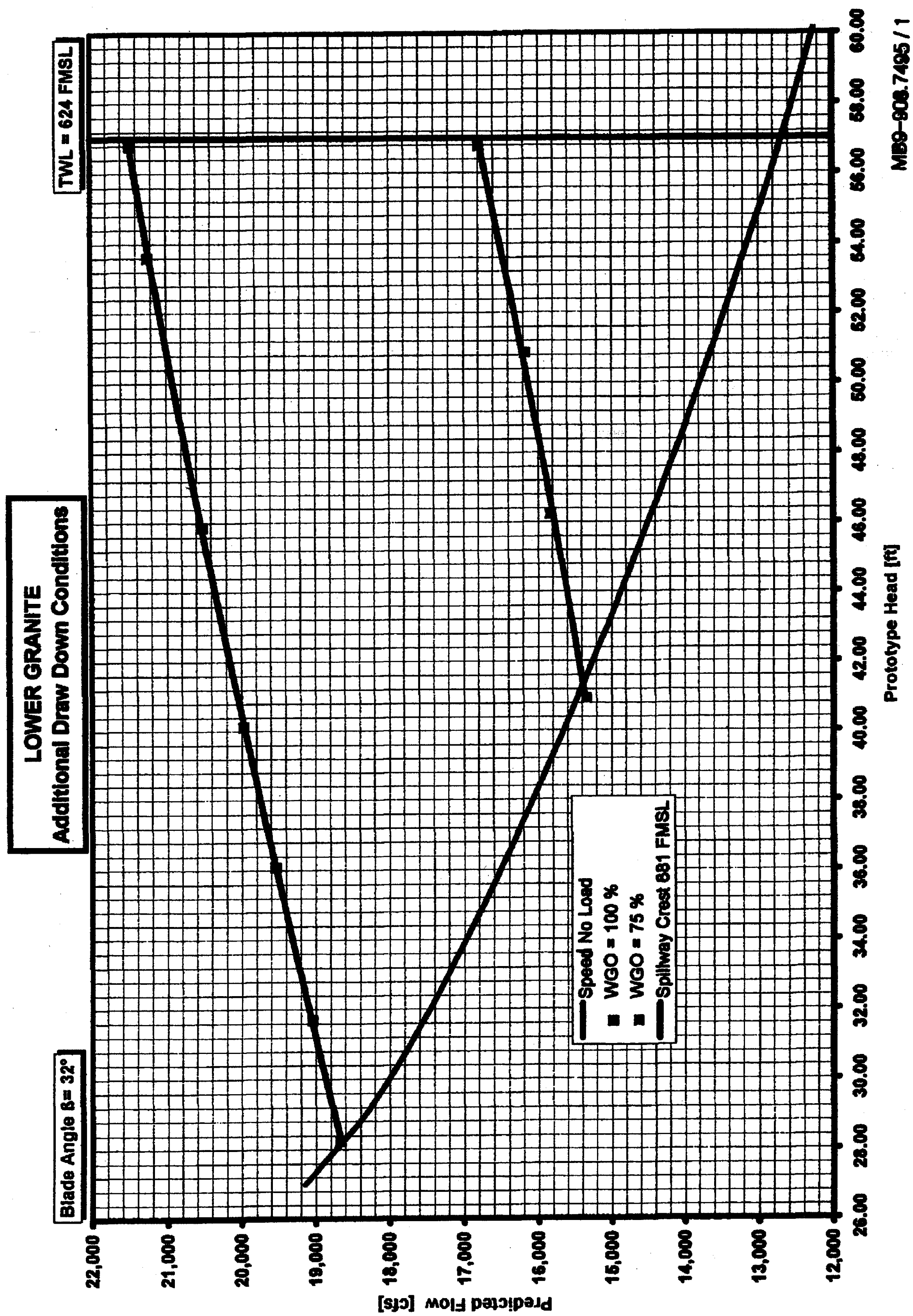
LOWER SNAKE RIVER JUVENILE SALMON MIGRATION FEASIBILITY STUDY

TURBINE PERFORMANCE CURVES FOR LOWER GRANITE
BLADE ANGLE=32, TW=633'

Figure:
A4

CADD FILENAME:E:\drawdown\plates\a\plta4.dgn PLOT TIME:16-SEP-1999 14:16

SHEET MAIN SCALE:



SHEET MAIN SCALE:

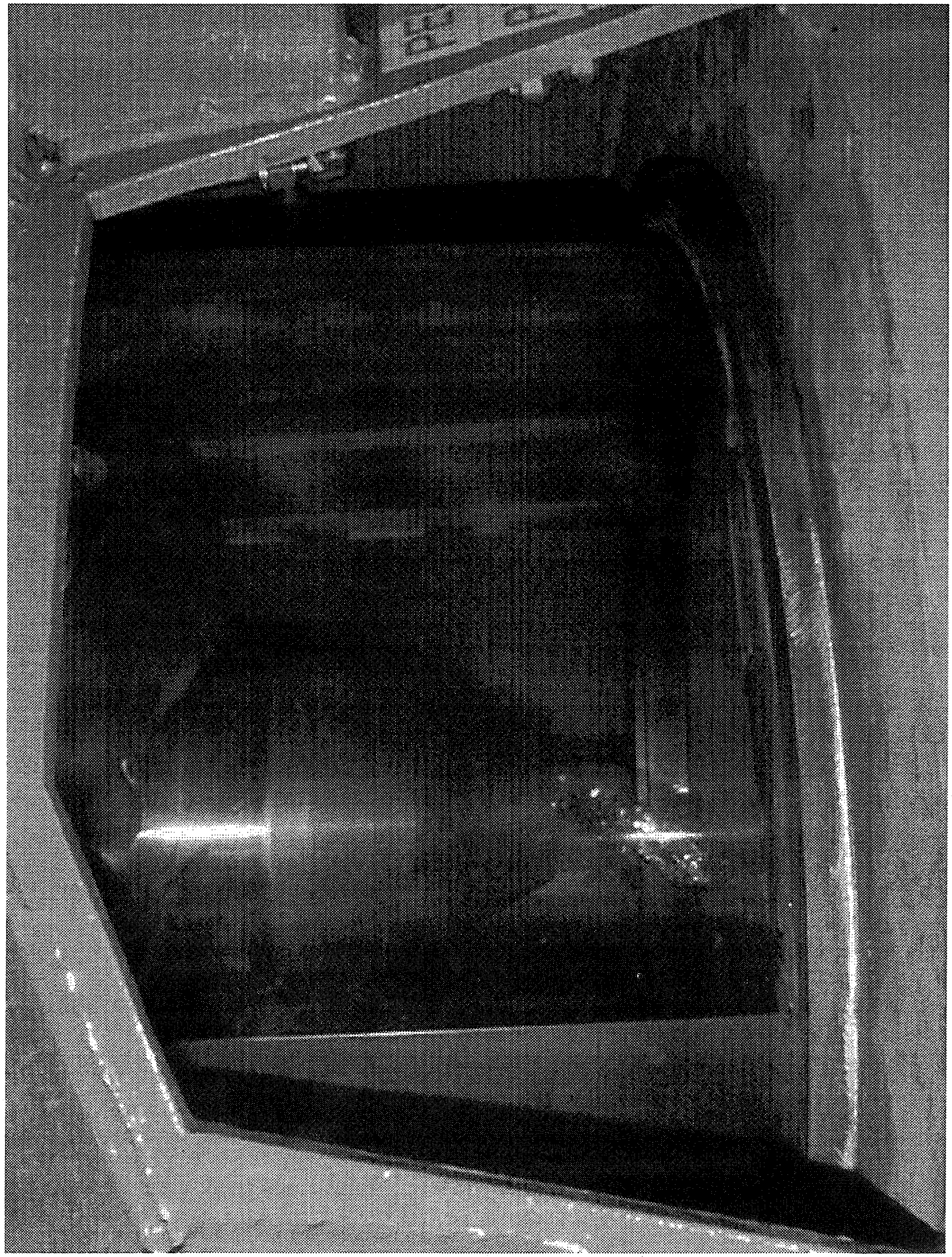
US Army Corps of Engineers
Walla Walla District

LOWER SNAKE RIVER JUVENILE SALMON MIGRATION FEASIBILITY STUDY

TURBINE PERFORMANCE CURVES FOR LOWER GRANITE
BLADE ANGLE=32, TW=624'

Figure:
A5

CADD FILENAME:E:\drawdown\plates\a\plta5.dgn PLOT TIME:16-SEP-1999 14:18



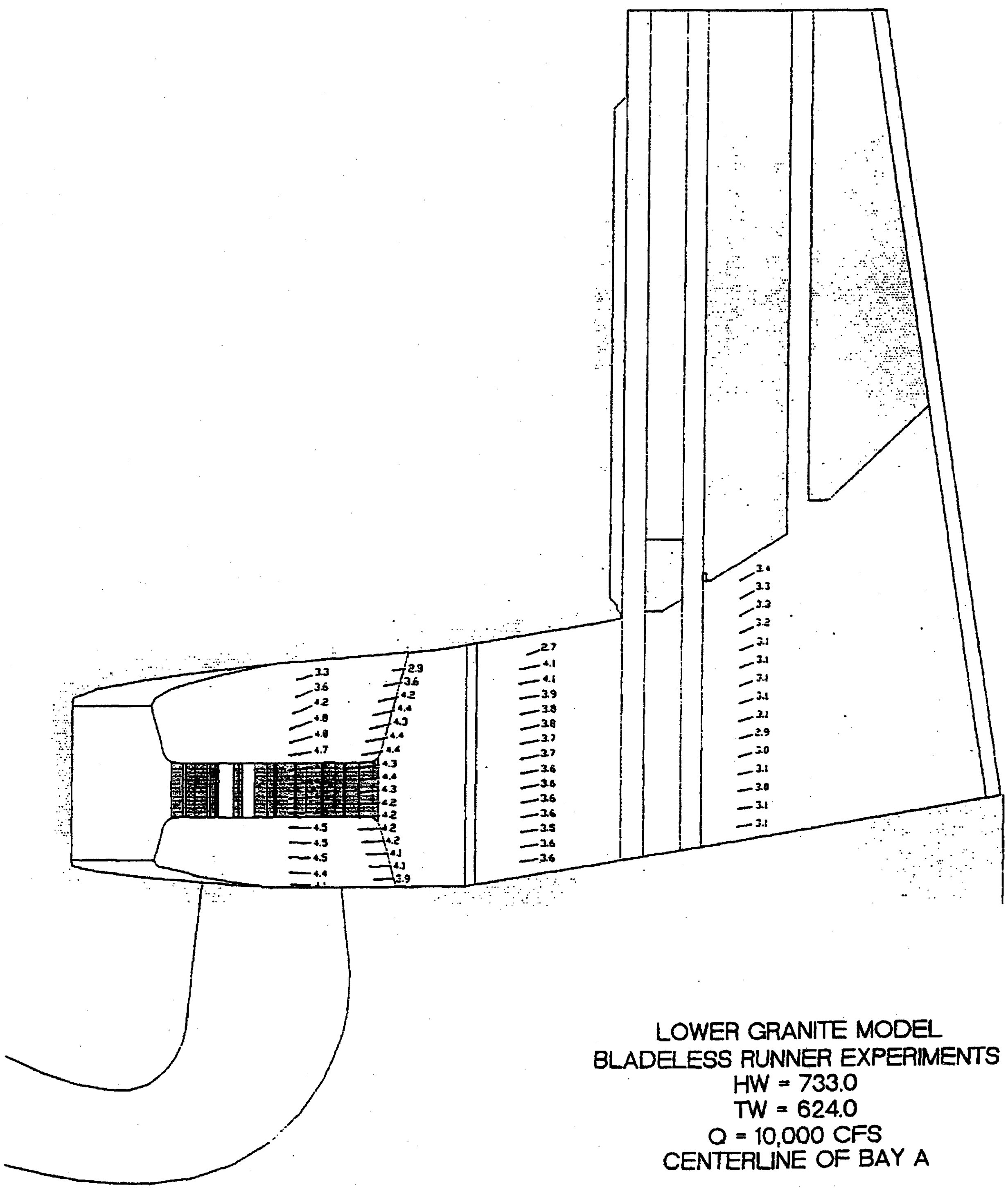
SHEET MAIN SCALE:

US Army Corps of Engineers
Walla Walla District

LOWER SNAKE RIVER JUVENILE SALMON MIGRATION FEASIBILITY STUDY
VORTEX IN THE LOWER GRANITE TURBINE MODEL
AT VOEST ALPINE MCE

Figure:
A6

CADD FILENAME: E:\drawdown\plates\a\plta6.dgn PLOT TIME: 16-SEP-1999 14:22



SHEET MAIN SCALE:

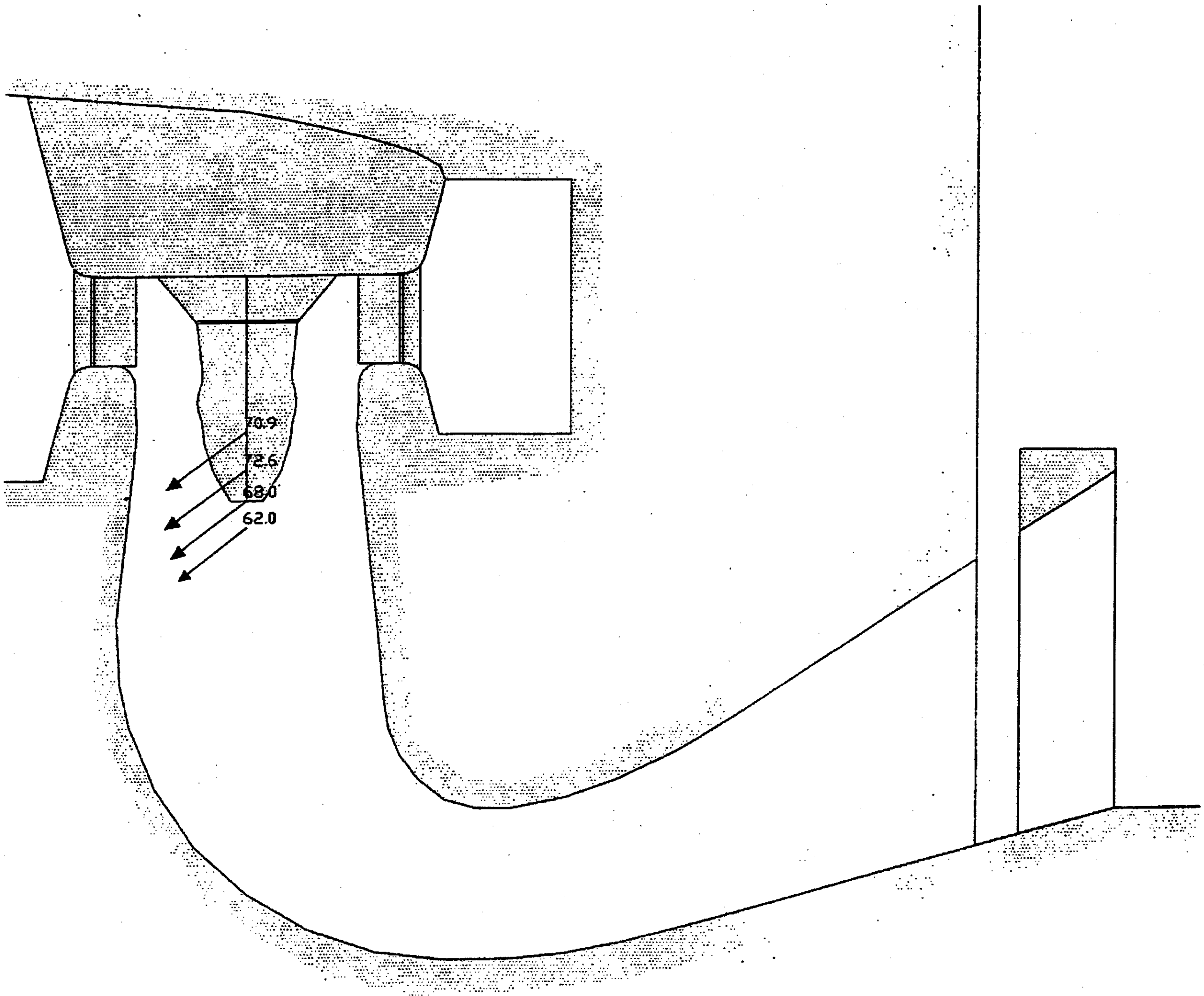
US Army Corps of Engineers
Walla Walla District

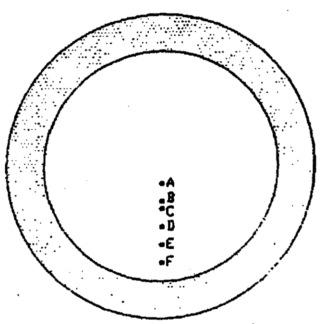
LOWER SNAKE RIVER JUVENILE SALMON MIGRATION FEASIBILITY STUDY

TURBINE INTAKE VELOCITIES WITH A BLADELESS RUNNER AT LOWER GRANITE

Figure: A7

CADD FILENAME: E:\drawdown\plates\a\plta7.dgn PLOT TIME: 16-SEP-1999 14:24





LOCATION OF VEL MEASUREMENTS
RUNNER NOT SHOWN

LOWER GRANITE MODEL
BLADELESS RUNNER EXPERIMENTS

HW = 733.0
TW = 624.0
Q = 10,000 CFS
LOCATION F

SHEET MAIN SCALE:

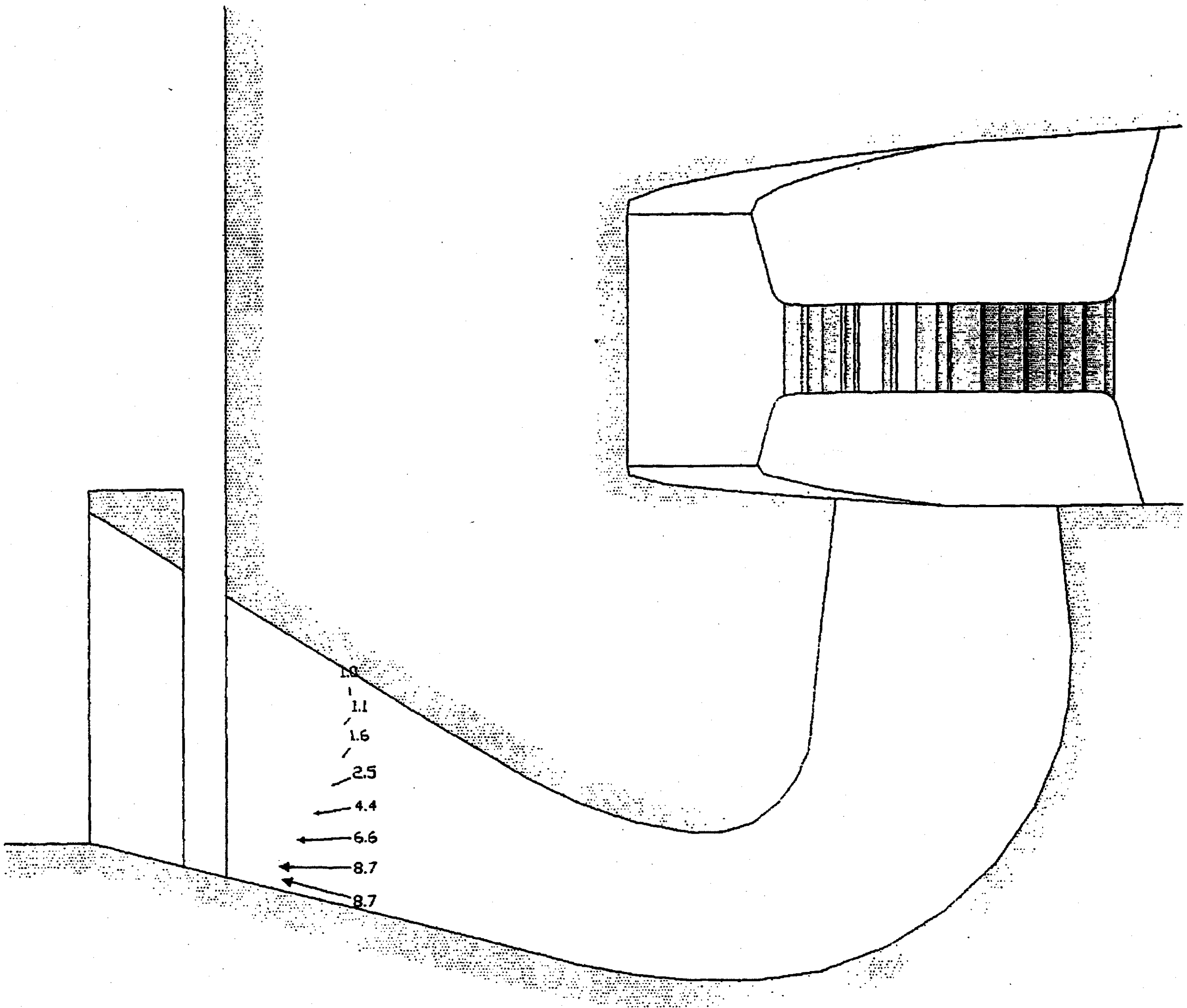
US Army Corps of Engineers
Walla Walla District

LOWER SNAKE RIVER JUVENILE SALMON MIGRATION FEASIBILITY STUDY

VELOCITIES IN THE VICINITY OF THE BLADELESS
RUNNER AT LOWER GRANITE

Figure:
A8

CADD FILENAME: E:\drawdown\plates\a\plta8.dgn   PLOT TIME: 16-SEP-1999 14:26



LOWER GRANITE MODEL
BLADELESS RUNNER EXPERIMENTS
HW = 733.0
TW = 624.0
Q = 10,000 CFS
Z = 17.75 FT
BARREL A

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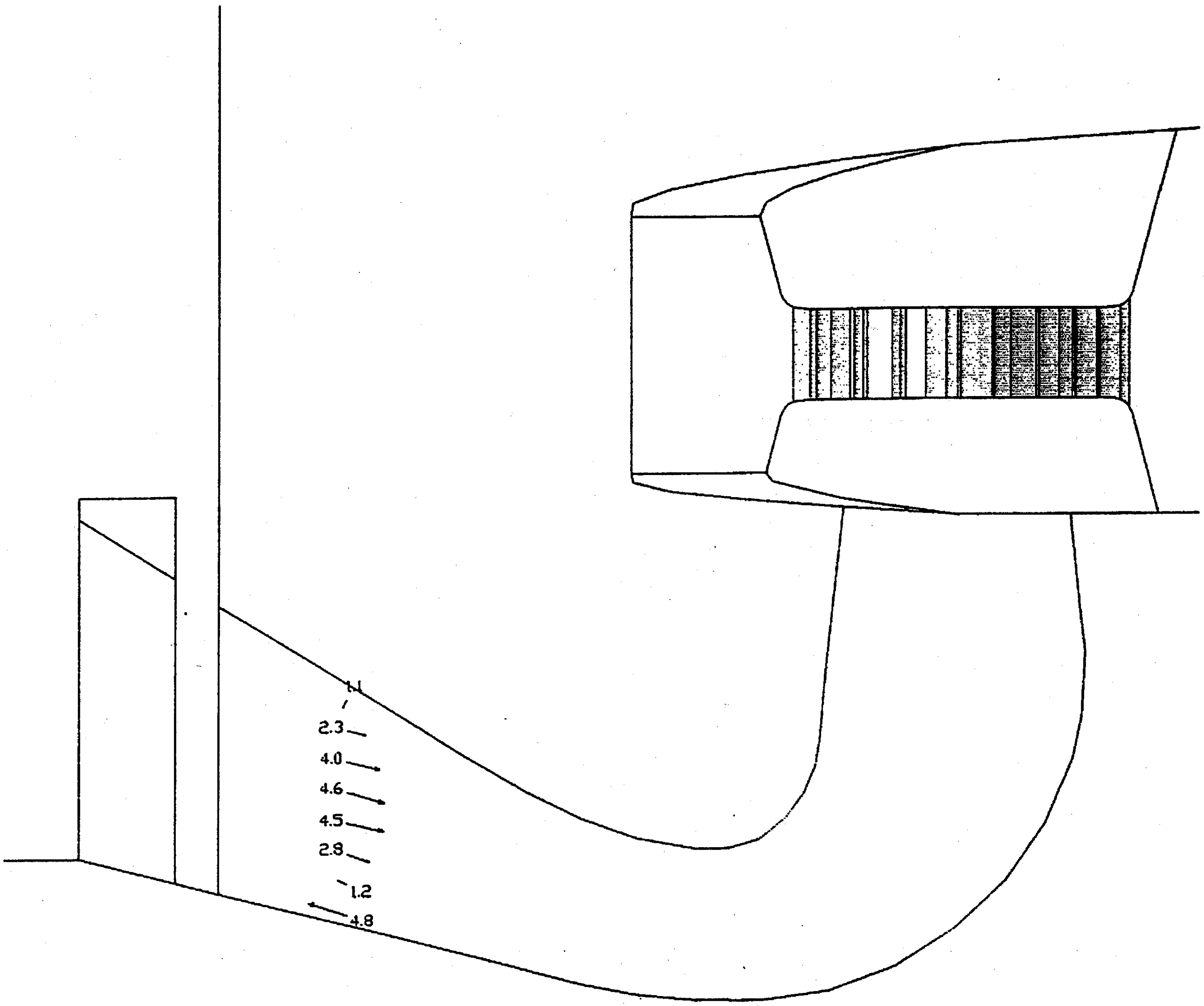
LOWER SNAKE RIVER JUVENILE SALMON MIGRATION FEASIBILITY STUDY

VELOCITIES IN BARREL A OF THE DRAFT TUBE AT LOWER GRANITE

Figure: A9

CADD FILENAME: E:\drawdown\plates\a\plta9.dgn PLOT TIME: 16-SEP-1999 14:27

SHEET MAIN SCALE:



LOWER GRANITE MODEL
BLADELESS RUNNER EXPERIMENTS
HW = 733.0
TW = 624.0
Q = 10,000 CFS
Z = 59.25 FT
BARREL B

SHEET MAIN SCALE:

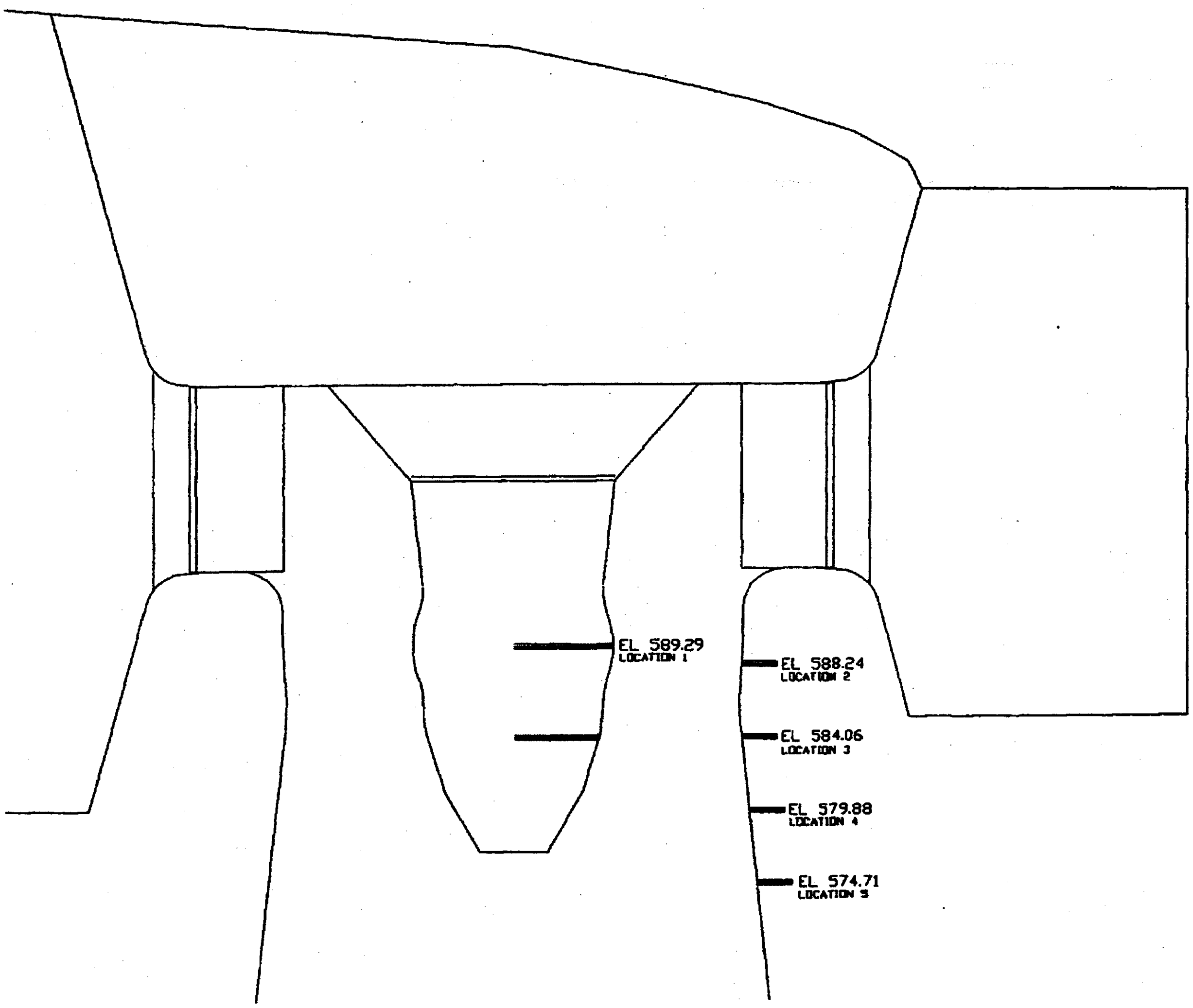
US Army Corps of Engineers
Walla Walla District

LOWER SNAKE RIVER JUVENILE SALMON MIGRATION FEASIBILITY STUDY

VELOCITIES IN BARREL B OF THE DRAFT TUBE
AT LOWER GRANITE

Figure:
A10

CADD FILENAME: E:\drawdown\plates\a\plta10.dgn PLOT TIME: 16-SEP-1999 14:29



SHEET MAIN SCALE:

US Army Corps of Engineers
Walla Walla District

LOWER SNAKE RIVER JUVENILE SALMON MIGRATION FEASIBILITY STUDY

LOWER GRANITE MODEL BLADELESS RUNNER EXPERIMENTS
PRESSURE MEASUREMENT LOCATIONS

Figure:
A11

CADD FILENAME: E:\drawdown\plates\a\plta11.dgn   PLOT TIME: 16-SEP-1999 14:30