



**Lac Courte Oreilles Band of
Lake Superior Ojibwe**

Lac Courte Oreilles Hydro Dam Assessment

March 2015



Final Report

Presented to:

U.S. Department of Energy
Tribal Energy Program
Contract # DE-EE0002514

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Project Data

Awardee: Lac Courte Oreilles Band of Lake Superior Ojibwe

Location: Town of Winter

Project Title: Hydro-dam Assessment

Type of Award: First Steps Grant

DOE Grant Number: DE-EE002514

Project Amounts: DOE:
Awardee:
Total:

Project Period: Start: June 30, 2010
End: December 31, 2014

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TURBINE ANALYSIS FINAL REPORT

For

LAC COURTE OREILLES BAND of LAKE SUPERIOR CHIPPEWA

Winter, WI



PREPARED BY:
Kiser Hydro, LLC
April 2014



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EXECUTIVE SUMMARY

Kiser Hydro was contracted by the Lac Courte Oreilles Band of Lake Superior Chippewa to perform a complete Computational Fluid Dynamics (CFD) Analysis for the Winter Dam Hydroelectric plant. The purpose of the study is to observe efficiencies with the existing mechanical equipment and historical Annual Energy Production (AEP) to determine whether a mechanical upgrade would be feasible in terms of cost effectiveness and return on investment.

Swiderski Engineering, Inc was subcontracted by Kiser Hydro to perform the CFD Analysis. It was determined that on average, with the existing mechanical and electrical systems, the annual energy produced between all three units is 10.9 GWh (Gigawatt-hour) with an overall hydraulic efficiency of approximately 84%. The lower efficiency can be contributed to Units #2 and #3 being oversized and not being operable at lower flows, 350 cfs (cubic feet per second) and lower.

Kiser Hydro recommends upgrading one of the large units, either Unit #2 or Unit #3. The upgraded runner would be designed to operate over a wider range of flows, including flows less than 350 cfs. This in turn, would increase the overall efficiency of the plant. The projected annual energy production is 11.7 GWh, an increase of AEP of 7.3% (797,513 kWh)

The rough order of magnitude estimate to complete this proposed upgrade is \$700,000. This includes design of a new runner, fabrication of the runner, as well as removal and installation of the existing and new runners respectively.



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INTRODUCTION

The following report details the findings of the Computational Fluid Dynamics Analysis performed by Swiderski Engineering, along with recommendations and estimates from Kiser Hydro for future upgrades that would result in increased Annual Energy Production (AEP). The report is organized in chronological order per the original proposal, beginning with a flow duration curve and existing site specifications.

The flow duration curve is based on historical data recorded from 1993 through present time. The flows during these years are the most accurate representation of the flows that the hydroelectric facility currently experiences, given the origin date of the powerhouse as well as the requirement to pass a minimum of 250 cubic feet per second (cfs). The CFD analysis was performed with these historical data points.

Recommendations of a proposed runner upgrade along with the corresponding cost estimate and projected annual energy production conclude this report.



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1 – Flow Duration Curve

2 – Site Specifications

3 – Site Inspection Reports

4 – Computational Fluid Dynamics Analysis
Report

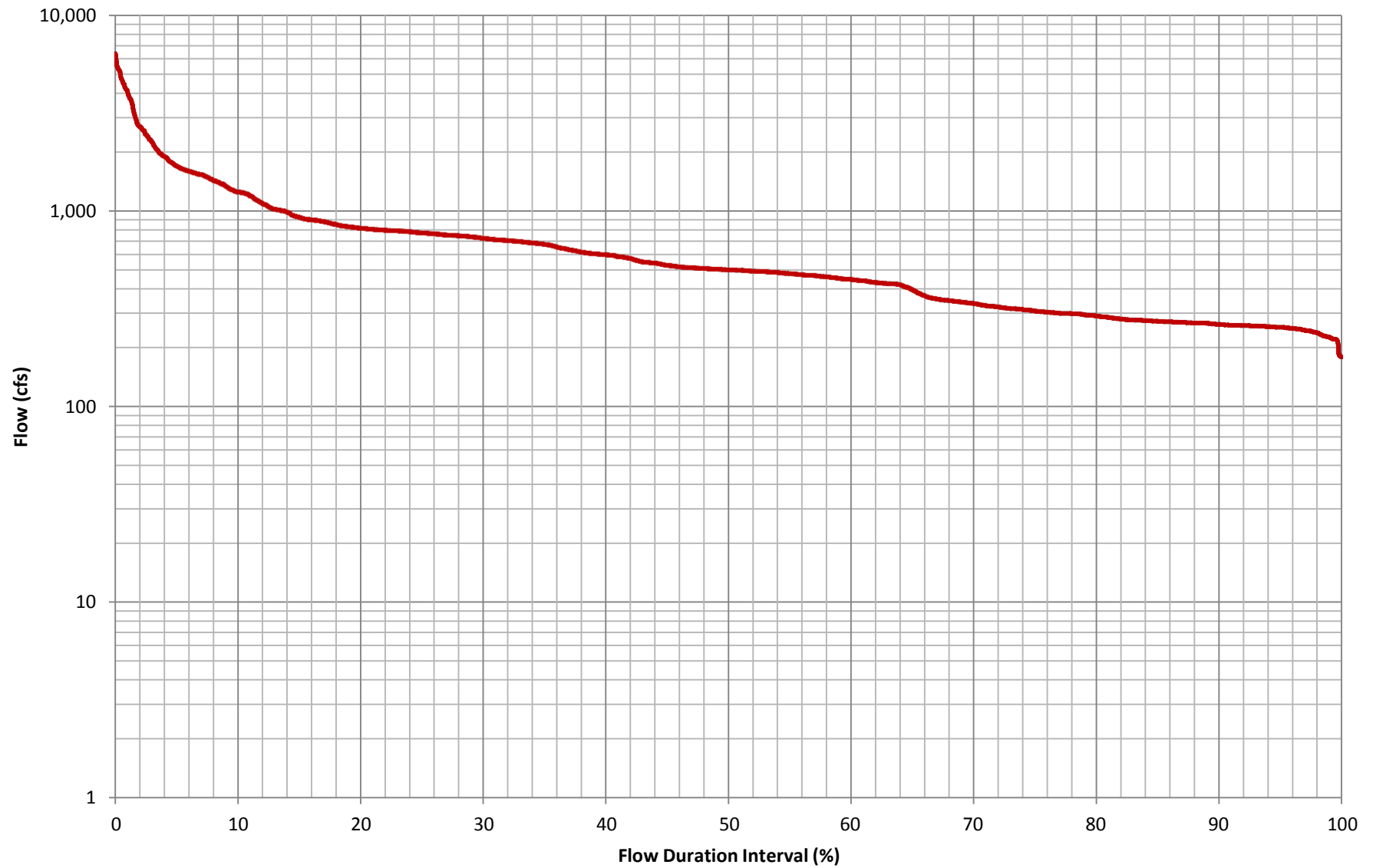
5 – Proposed Upgrade Estimates

6 – Proposed Upgrade Summary Table

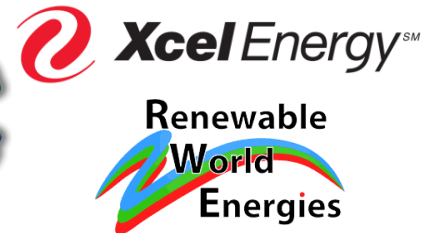
7 – Final Report

8 – Turbine Analysis Presentation

LCO Flow Duration Curve



— Flow(cfs) 1993 - 2013 (250 cfs Minimum Flow)



CHIPPEWA RESERVOIR FERC PROJECT: P-8286

CONSTRUCTION & KEY DATES

Owner Xcel Energy (Dam)
Owner Lac Corte Oreilles Band of Lake
Superior Chippewa (Powerhouse)
Date Originally Built 1923 (Dam)

HYDROLOGIC DATA

River Chippewa
County Sawyer
Nearest City Winter
Drainage Area Square Miles 787
Storage Volume Acre Feet 230,000
Average Flow 775 CFS
Minimum Flow 250 CFS
Flood of Record 7520 CFS
Probable Maximum Flood 72,000 CFS

OPERATIONAL DATA

Normal Headwater Elevation 1311.7 FT
Minimum Headwater Elevation 1295.7 FT
Normal Operating Head 45 FT
Number of Units 3
Maximum Generating Capacity 3100 kW
Maximum Turbine Discharge (Total) 1,490 CFS
Hazard Rating High

STRUCTURAL DATA

Dam Type Spillway Gates w/ Embankments
Overall Length & Height 1290'L x 26'H
Penstock Two Steel - $\phi 9'$ x 300' Long Siphon-Type

Spillway Description:

.....Three spillway gates ... 20'W x 26'H (ea)

PLANT DATA

Turbine Manufacturer W.J. Bauer Inc.

Turbine Identification:

Unit #1 40" Francis Type
Unit #2 93" Francis Type
Unit #3 93" Francis Type

Turbine CFS @ 100% Gate:

Unit #1 90 CFS
Unit #2 700 CFS
Unit #3 700 CFS

Generator Identification:

Unit #1 Siemens-Allis
Unit #2 Siemens-Allis
Unit #3 Siemens-Allis

Generator Nameplate Rating kW:

Unit #1 250 kW
Unit #2 1800 kW
Unit #3 1800 kW

Generator Speed RPM:

Unit #1 1215 RPM
Unit #2 905 RPM
Unit #3 905 RPM

Generator Voltage:

Unit #1 4160 V
Unit #2 4160 V
Unit #3 4160 V



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TRIP REPORT

DATE: August 6th, 2013

CUSTOMER : Lac Courte Oreilles Band of Lake Superior Chippewa
13394 West Trepania Road
Hayward, WI 54843

PROJECT: Turbine Analysis

JOB NUMBER: 13-33

SUMMARY OF PROJECT

Kiser Hydro has been contracted to evaluate the existing turbines at the Winter Dam Hydro facility. Existing geometry will be used with historical flows and power production to evaluate the efficiency of the plant and its power producing capabilities. Through use of Computational Fluid Dynamics (CFD) Analysis, Kiser Hydro will be better able to determine possible turbine improvements that would benefit overall plant efficiency and annual power production.

FIELD SERVICES

Project Manager, Amy Pitcher, along with Project Engineer Tim Olson performed a site visit on August 6th, 2013. The purpose of the visit was to verify geometry of the units with the prints that were being used to complete the CFD analysis. Aside from visual verification, a few general measurements were documented to confirm that the prints were reflecting the existing geometry.

By entering the shared pit of Units #1 & #2, a visual inspection was completed, verifying that the unit layout and general machine prints correlated to the existing machinery and infrastructure. It was also confirmed that Units #2 & #3 share the same geometry, an inspection was completed on Unit #2 only. Further inspection/verification was documented by recording the following measurements:



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Table 1: Unit #1 Inspection

REFERENCE DRAWING	MEASUREMENT & OBSERVATIONS
CH-108	Right Hand Oriented Machine
	14 Buckets on Unit
	Runner Height ... 13-3/4 inches
CH-105	Wicket Gate Height ... 13-1/2 inches
	16 Wicket Gates
	Wicket Gate Opening ... Approx. 3 inches (@ 68% Open)
	Step from Headcover to Runner Crown ... 1/16 inch
	Step from Bottom Ring to Runner Skirt ... 1/8 inch

Table 2: Unit #2 Inspection

REFERENCE DRAWING	MEASUREMENT & OBSERVATIONS
CH-104	Wicket Gate Height ... 35 inches
	20 Wicket Gates
	Wicket Gate Opening ... Approx. 9-1/2 - 9-7/16 inches (@ 100% Open)
	ø1-1/2 inch Bars every 2 Gates - Extend Through Gate Casing
	Discharge Ring - ID to OD ... 11-1/4 inches
	No Visible Wear Ring
	Step from Headcover to Runner Crown ... 1/8 inch
	Step from Bottom Ring to Runner Skirt ... 3/8 inch
	Top, Bottom & Sides of Pit are Flat
CH-107	Right Hand Oriented Machine
	15 Buckets on Unit
	Runner Height ... 59-1/4 inches

Based on the verifications made during this site inspection, Kiser Hydro felt comfortable moving forward by performing the CFD Analysis based on the geometry found on the existing print set.



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TRIP REPORT

DATE: September 24th, 2013

CUSTOMER: Lac Courte Oreilles Band of Lake Superior Chippewa
13394 West Trepania Road
Hayward, WI 54843

PROJECT: Turbine Analysis

JOB NUMBER: 13-33

SUMMARY OF PROJECT

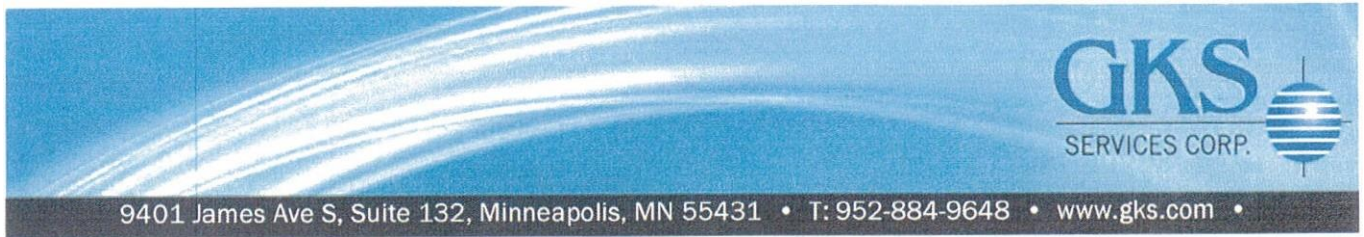
Kiser Hydro has been contracted to evaluate the existing turbines at the Winter Dam Hydro facility. Existing geometry will be used with historical flows and power production to evaluate the efficiency of the plant and its power producing capabilities. Through use of Computational Fluid Dynamics (CFD) Analysis, Kiser Hydro will be better able to determine possible turbine improvements that would benefit overall plant efficiency and annual power production.

FIELD SERVICES

Project Engineer Tim Olson performed a site visit on September 24th, 2013 to meet and assist GKS Services with the 3D scanning of blades from Units #1 & #2 for use in the CFD Analysis.

Due to the tight space constraints of the accessibility of Unit #1, GKS deemed it impossible to perform an accurate scan of the blades. Since geometry was previously visually verified in a separate site visit, and because Unit #1 accounts for less than 10% of the power production, Kiser Hydro did not pursue this issue any further. GKS submitted a written statement to Kiser Hydro explaining why the scan was not completed (see attached).

A blade from Unit #2 was successfully scanned by GKS. GKS submitted a CAD model of the scan to Kiser Hydro. This model was used to accurately model Units #2 & #3 for the CFD Analysis.



October 21st, 2013

Kiser Hydro, LLC
Amy (Meyers) Pitcher
1001 Stephenson Street
Norway, MI49870

Amy,

As you have seen from the completion of the 3 D laser scanning/CAD modeling work we did for Kiser at the hydro dam at Winter, WI. It was not possible to gain access to the smaller of the two units. We could physically reach the turbine, although the height of the conduit was around 3 feet. However, the spacing between the wicket gates was too narrow for the arm (portable CMM ...Faro arm) to be effective. The spacing between the blades themselves would have prevented us from gathering useful data even if the wicket gates were removed due to the stand-off distance of the laser probe. We have two criteria to meet to be able to gain scan data. One is for the articulated arm to have enough room to get positioned in several different attitudes. The other is to have the scanning head within the maximum depth of field of the scanner. That is typically in the 4 – 12 inch distance from the surface being scanned. In this case both criteria could not be achieved. Let me know if you have any further questions, and Thank you for thinking of us for your scanning project.

Best regards,

W

Jeff Sieber

Account Manager
GKS Services Corp.
9401 James Avenue South #132
Bloomington, MN 55431
Direct ph. number: 952-252-3418
Fax: 952-516-5189

Lac Courte Oreilles Project – CFD-based upgrade analysis - final report -

Swiderski Engineering Inc.

for

Kiser Hydro LLP

December/2013

Table of contents

Preamble.....	3
Conclusions and Observations	3
Plant modernization - recommendation summary.....	4
Numerical model of units 2&3 – general information.....	5
Flow analysis results.....	6
Annual Energy Production.....	10
Turbine characteristics units 1 and 2, 3.....	10
Flow duration curve and Annual Energy Production (AEP).....	14
Proposed upgrade	20
Proposed partial upgrade: Unit #2 only.....	25

Preamble

This report presents results of work undertaken based on the PO 13-33-2068 issued by Kiser Hydro LLP. Based on information provided on the equipment and the statistical data of the available flows, an analysis was conducted to determine turbine characteristics and their operation under available flows. Final stage of the analysis resulted in a proposed modernization scheme to increase Annual Energy Production (AEP) by the plant.

Conclusions and Observations

Following verified calculation results of the CFD model of existing turbines, consultation with plant's operators, inclusion of head losses calculation for the penstock as tuning-up the range of turbines operation the following are major observations and conclusions:

- 1) Turbines of units #2 and #3 are oversized by approx. 30 to 40%. This is a reason?: the majority of their operation falls into so-called "part load", where turbine efficiency is low and operation of the Francis turbine becomes rough. This also makes it impossible to operate those turbines at flows below approx. 350 cfs (Fig. 16) causing extra loss generation
- 2) Due to the fact that turbines of units #2 and #3 are oversized, overall hydraulic efficiency is low, reaching maximum value of approx. 84%, while normally expected should be 87 – 92%.
- 3) Unit #1 performances are verified based on general knowledge on this type of machine, as well as data obtained from the plant's operators. This unit is undersized, as the gap between lowest flow operating range of large units (2&3) and the maximum flow capacity of unit 1 is too large causing unnecessary spilling of water over the dam (Fig. 6)
- 4) Generators for units #2 and #3 are sized properly; the only information which should be verified is their achievable output and efficiency characteristic.
- 5) Generator of Unit #1 is sized accordingly to capacity of the existing turbine, however, if turbine capacity is to be increased, the generators would have to be rewound or replaced to facilitate higher output

Plant modernization - recommendation summary

It is possible to increase AEP under existing hydrological circumstances by approx. 8.7% (951,423 kWh) (Table 1 vs. Table 3). In order to achieve this all units should be upgraded:

Units 2 & 3:

New, modern design runners shifting peak efficiency of the turbine up by 3% to 5% and lowering flow at peak efficiency by approx. 12% (Fig. 3. page 7). The turbine will still have capacity to go up to the limits of existing generators, while extending it's operating range down to approx. 250 cfs (turbine aeration system may have to be provided)

Unit 1:

New, modern design runner to maximize turbine capacity and increase it's operating range to go above 100 cfs (possibly 150 cfs). This will require examination of the existing generator to determine whether it will be capable of handling higher turbine output: generator rewind, or replacement may be required.

AEP calculations for a partial upgrade scenario (only Unit #2 or #3 upgraded) show also promising results: calculated incremental revenue is higher by approx. 7.3% (797,513 kWh).

Numerical model of units 2&3 – general information

A numerical model was created using SolidWorks commercial structural analysis software and the Computational Fluid Dynamics (CFD) software called CFX. All flow passages were modeled based on provided 2D manufacturing drawings of details and 3D scanned shape of the runner blade. The overall similarity to the existing turbine should be within IEC code recommended manufacturing tolerances. The level of accuracy of the calculation results determining turbine performances should be within ± 1.5 to $\pm 2\%$, which would be within site-measurements admissible error.

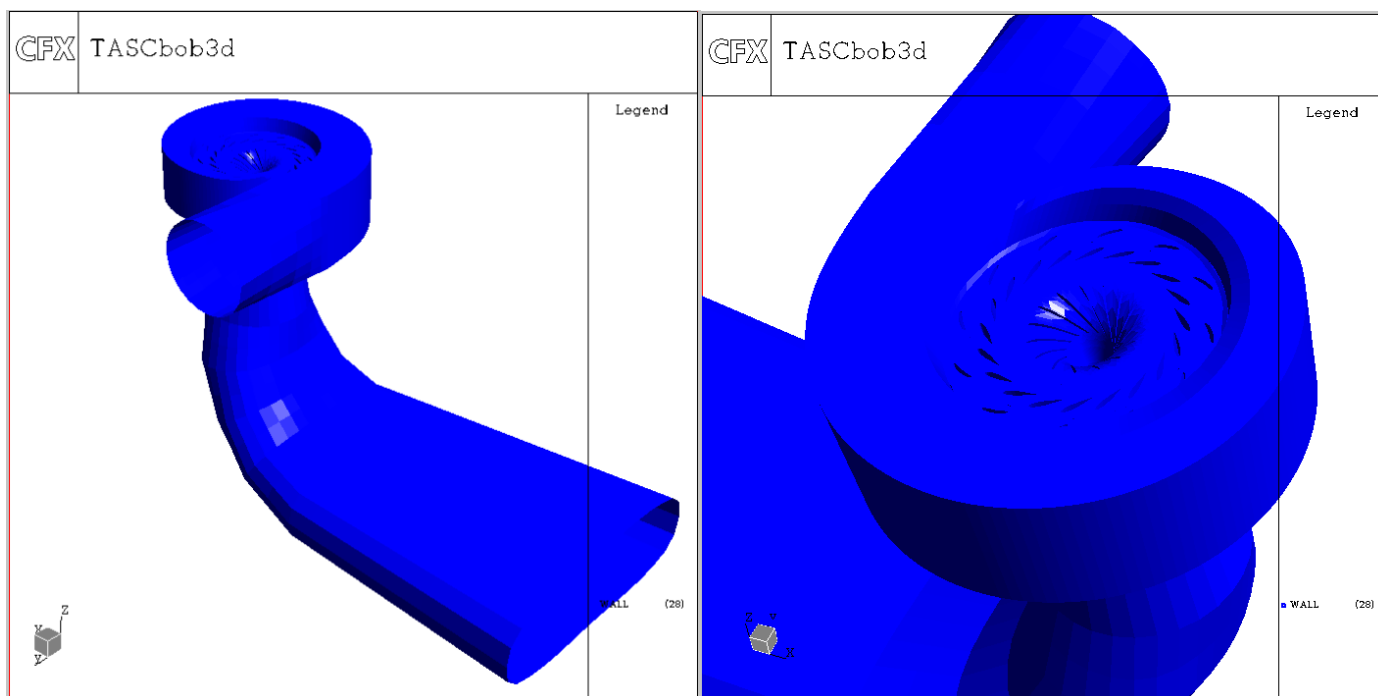


Fig. 1 General views of the computational domain

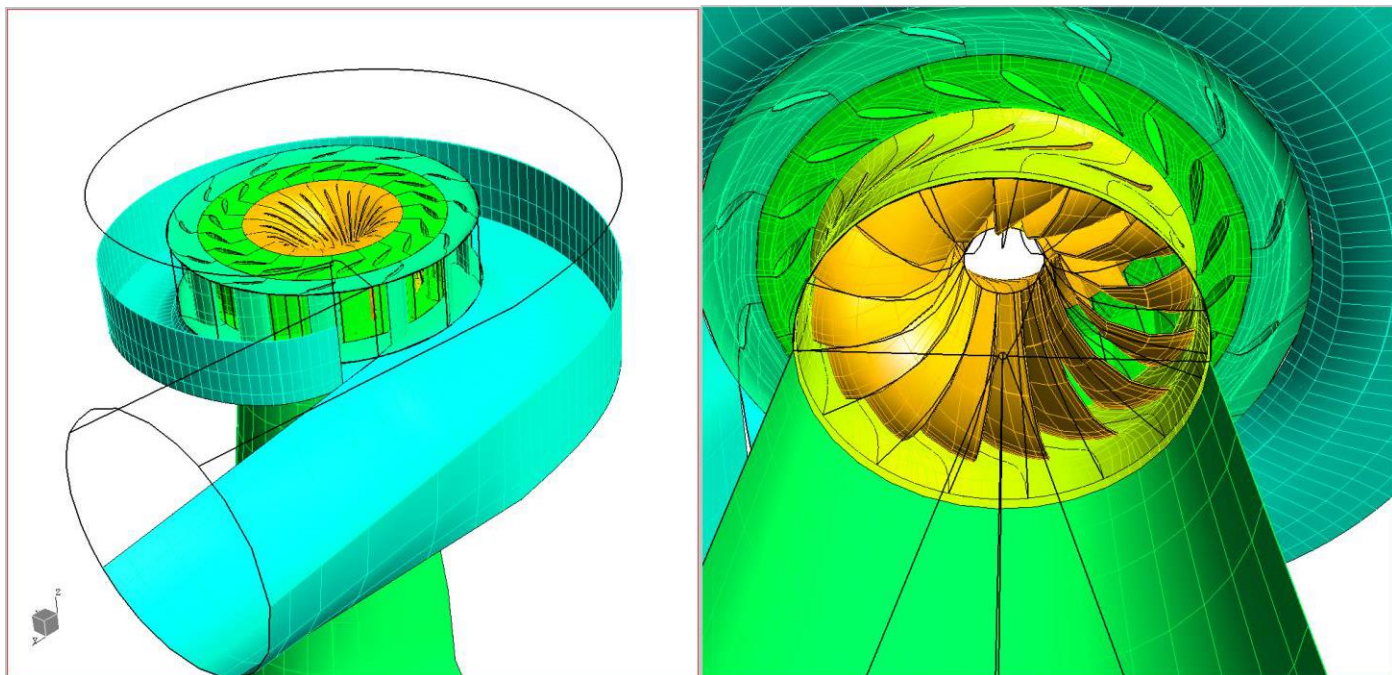


Fig. 2 General views of the computational domain – close-up on the runner and distributor

Flow analysis results

Flow analysis was conducted through the CFX commercial software. All results presented here were completed for medium-size grids at the preliminary stage and for the fine grid (highest accuracy of flow modeling). Overall conversions of the solver were very good in the operating range between 350cfs and 900 cfs (beyond practical operating range, but necessary to determine efficiency curve shape). As expected, flow simulations at operating range below 350cfs – 400 cfs down to 150 cfs were completed with difficulties due to high computational instabilities, which are typical for highly vortexing flows within the draft tube.

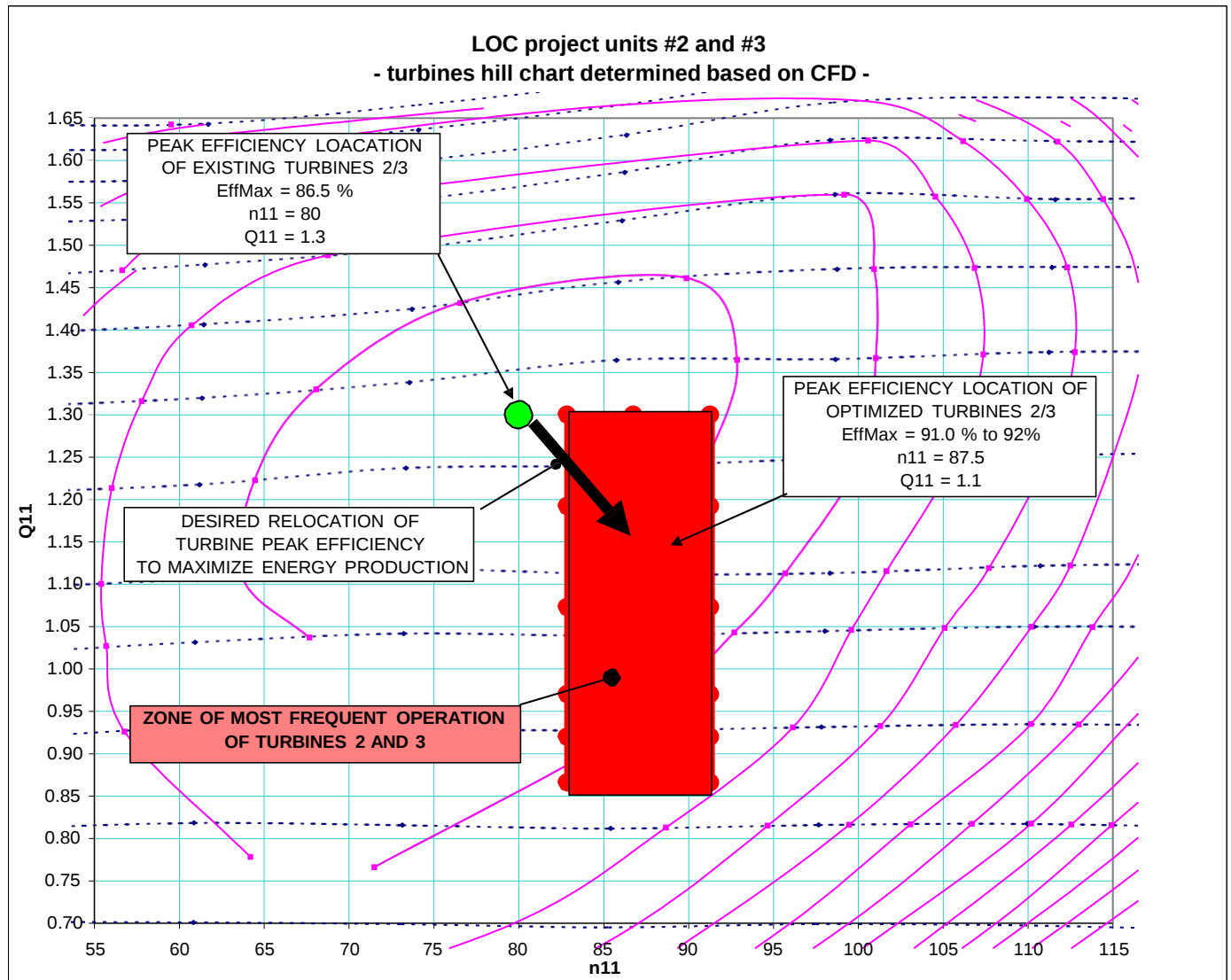


Fig. 3 Hill chart of units #2 and #3 determined based on CFD analyses.

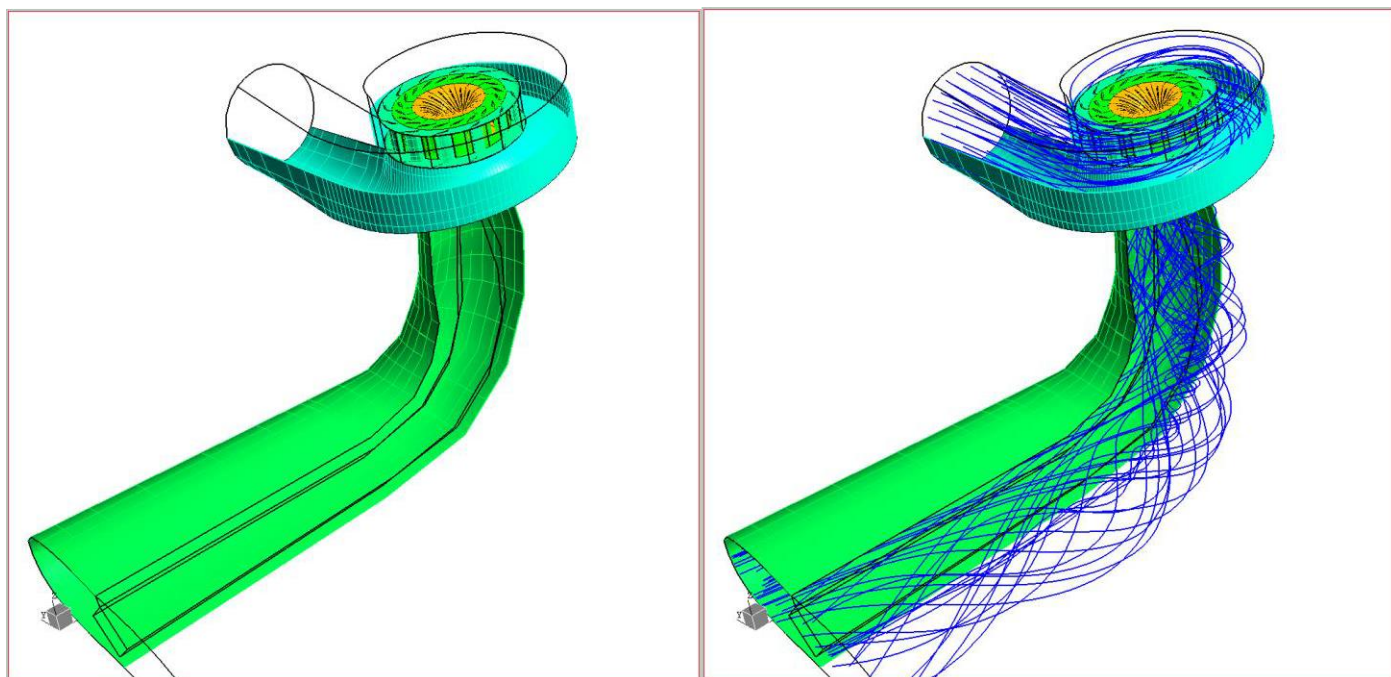


Fig. 4 Flow analysis visualization; streak lines released from turbine intake at max. efficiency point (BEP).

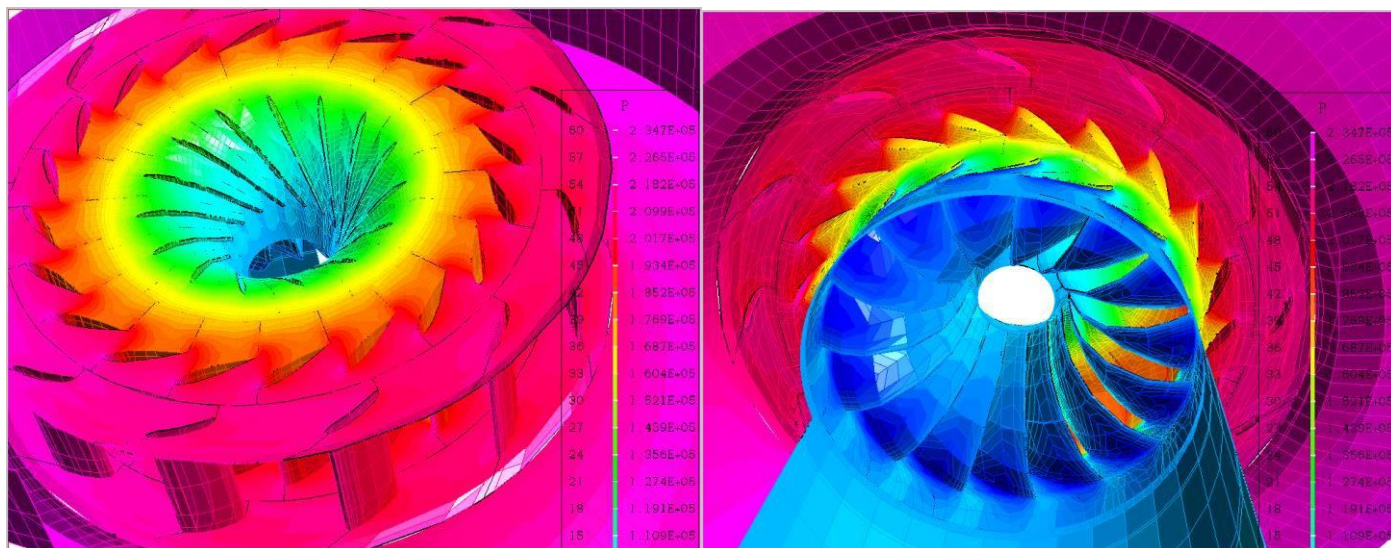


Fig. 5 Static pressure distribution on the walls of the runner-distributor assembly (BEP)

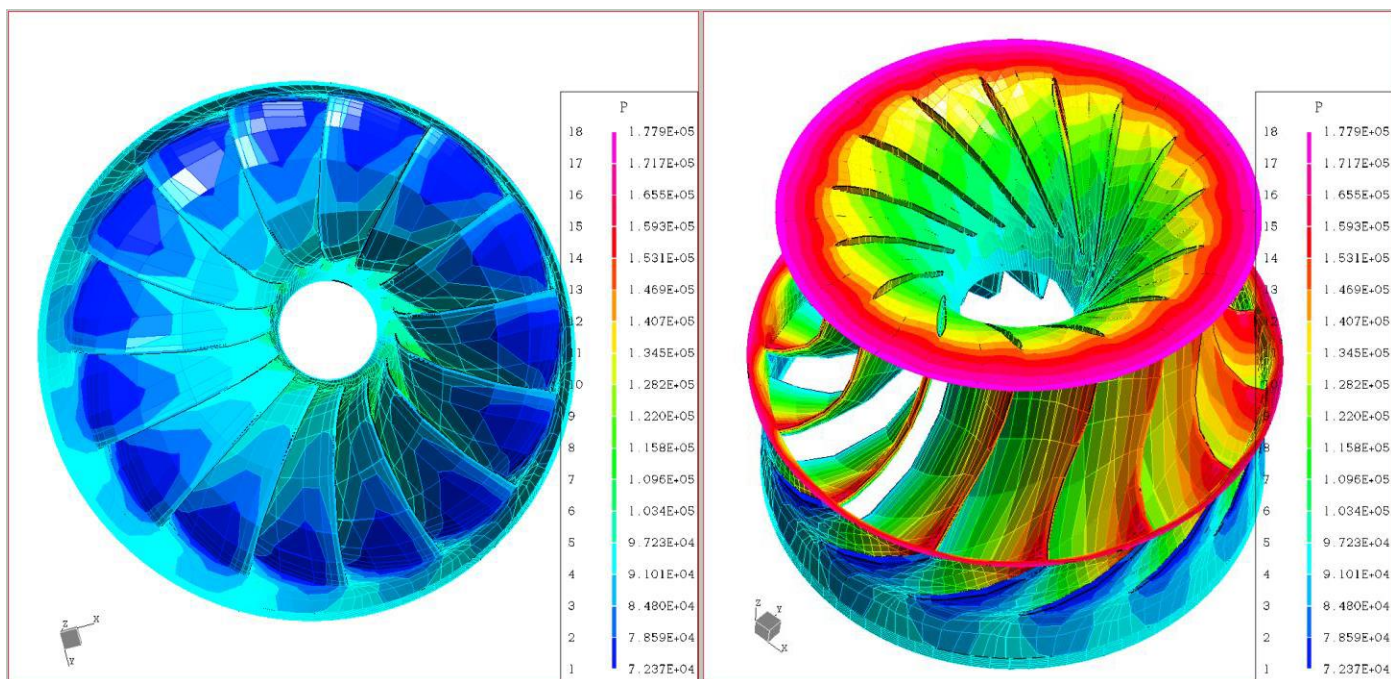


Fig. 6 Static pressure distribution on the walls of the runner (BEP).

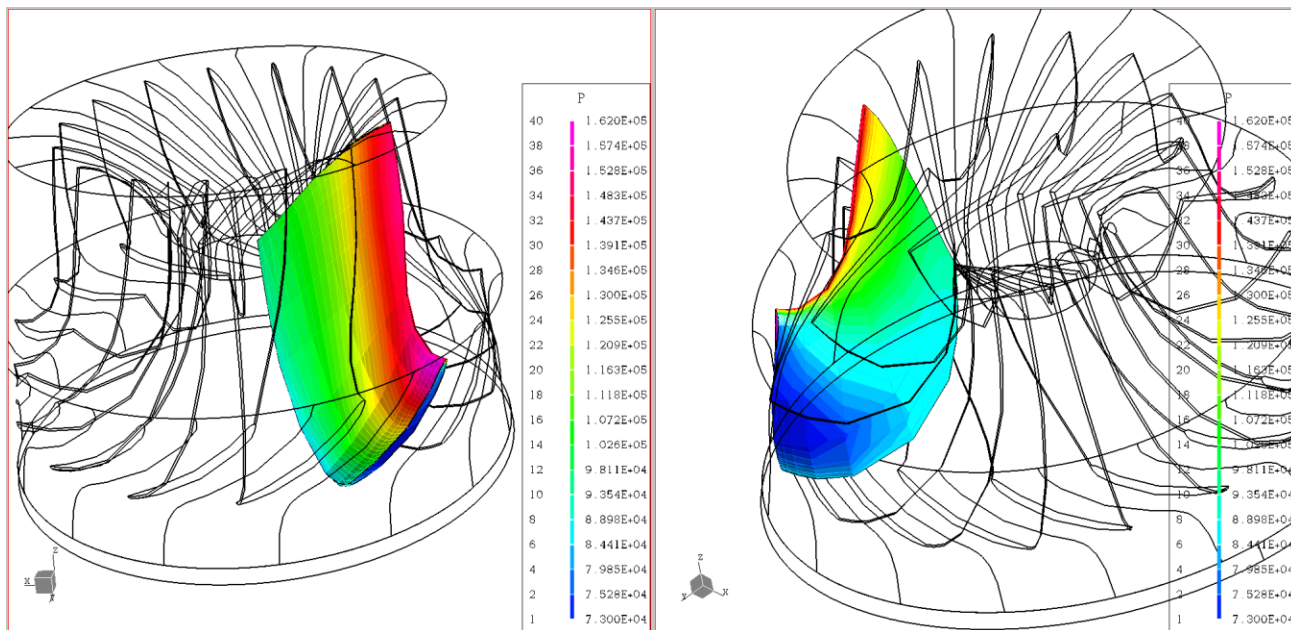


Fig. 7 Static pressure distribution on the single runner blade (BEP)

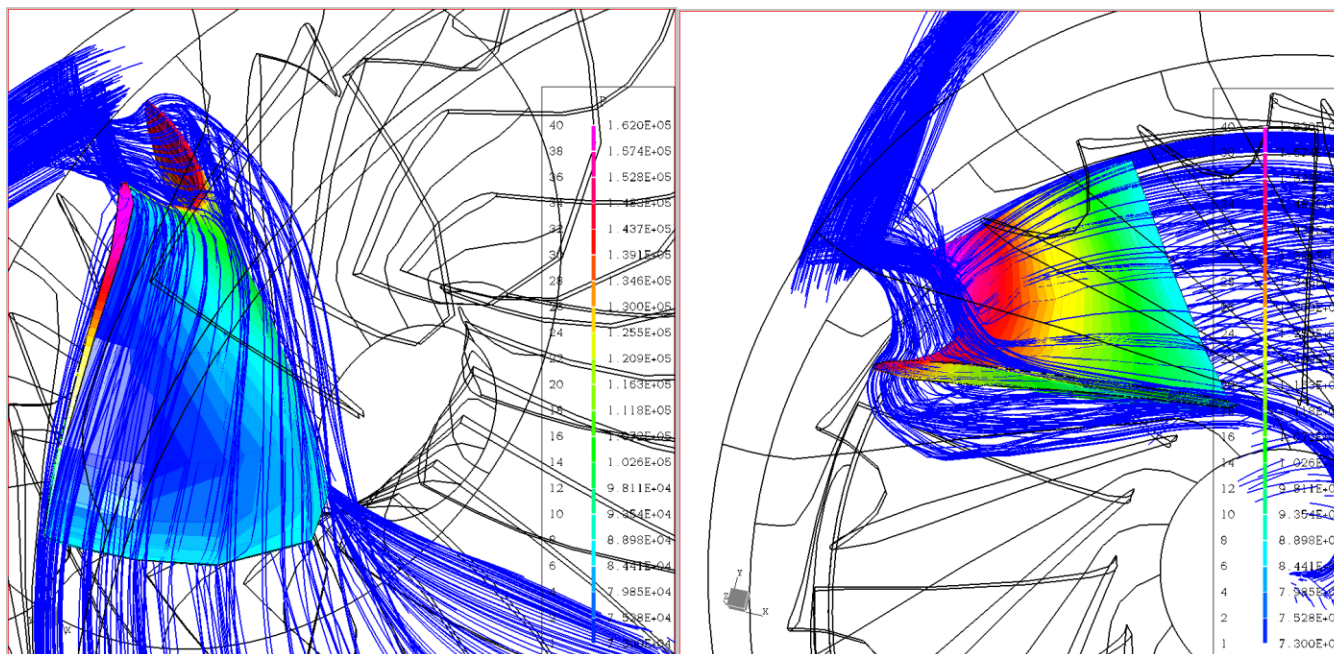


Fig. 8 Flow visualization around the single runner blade (BEP). Large attack angle responsible for reduction of hydraulic efficiency of the turbine.

Annual Energy Production

The model for annual energy production calculations incorporated:

- flow duration curve
- fluctuations of the head pond and tailrace elevations at variable flows
- predicted performance characteristics of all units (#2, #3 – based on CFD flow analysis, #1 – based on statistical data for similar units)
- calculated head losses caused by the penstock and its inlet
- principle of most efficient dispatching of units

Turbine characteristics units 1 and 2, 3

Performances of units #2 and #3 (1800 kW each) are predicted based on multiple flow simulations of the entire turbine assembly. Performances of unit #1 (250 kW) were predicted based on statistical data

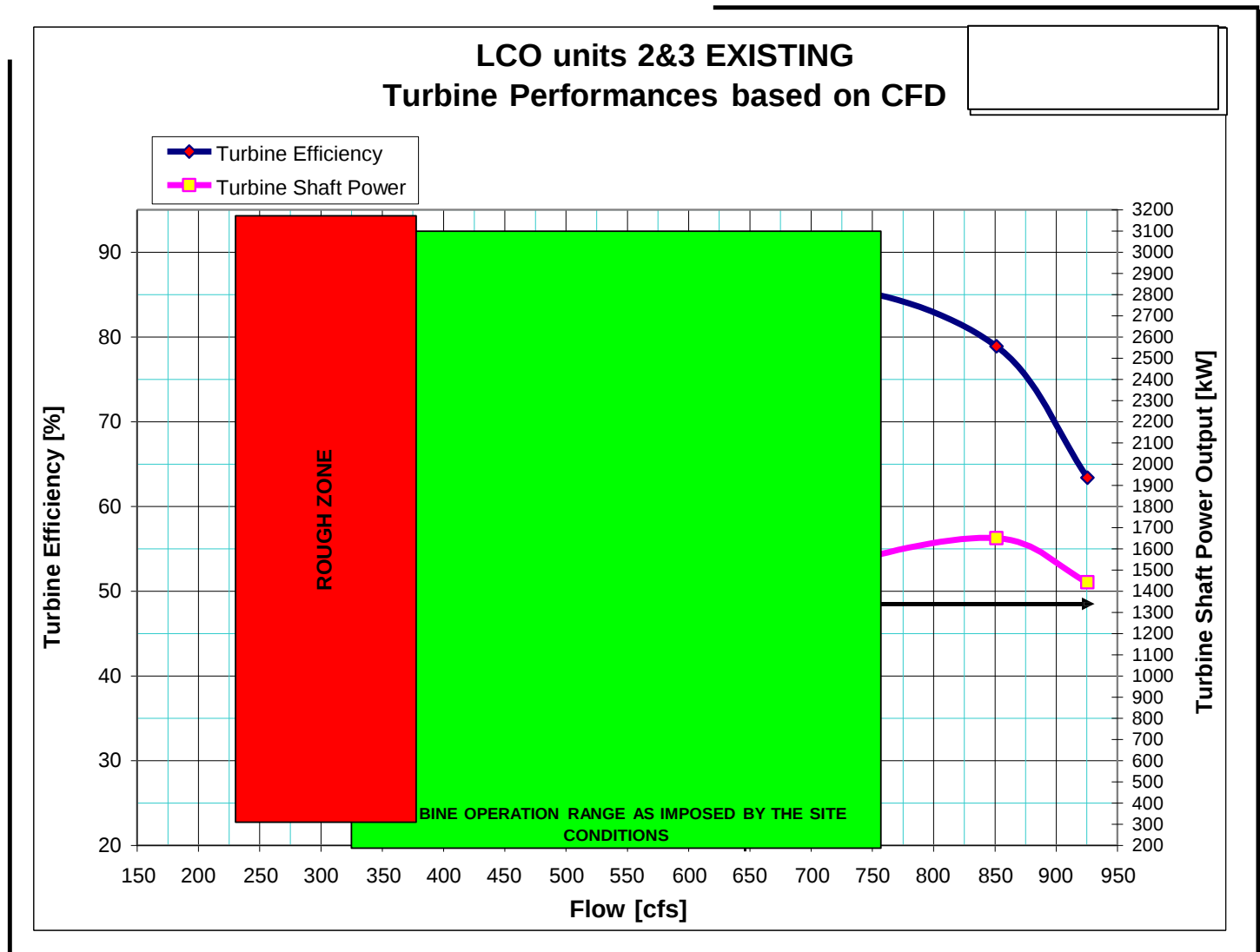


Fig.9 Performances of units #2 and #3 as determined through the CFD analyses.

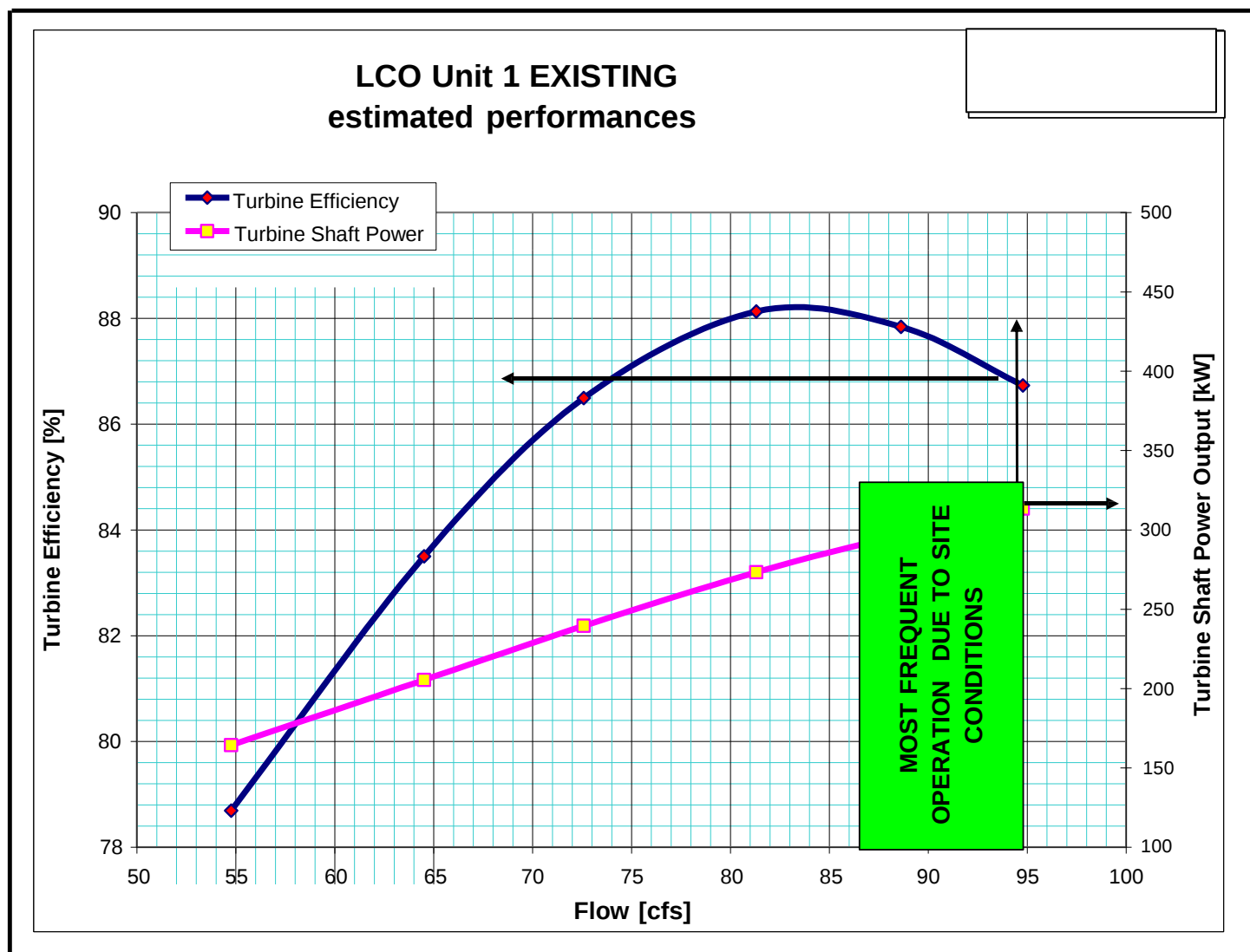


Fig. 10 Performances of unit #1 as determined through statistical data and experience.

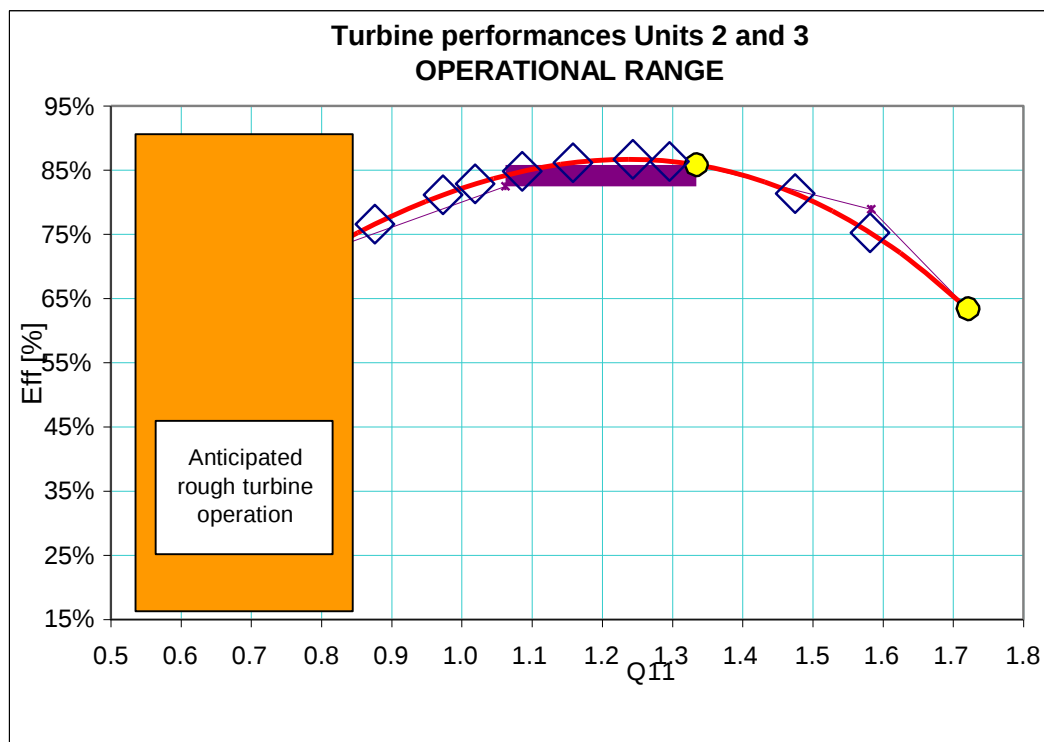


Fig.11 Practical operating range of turbines #2 and #3 determined through the analysis of the hydraulic conditions at the site ($Q_{11} = Q/\sqrt{H}/D^2$)

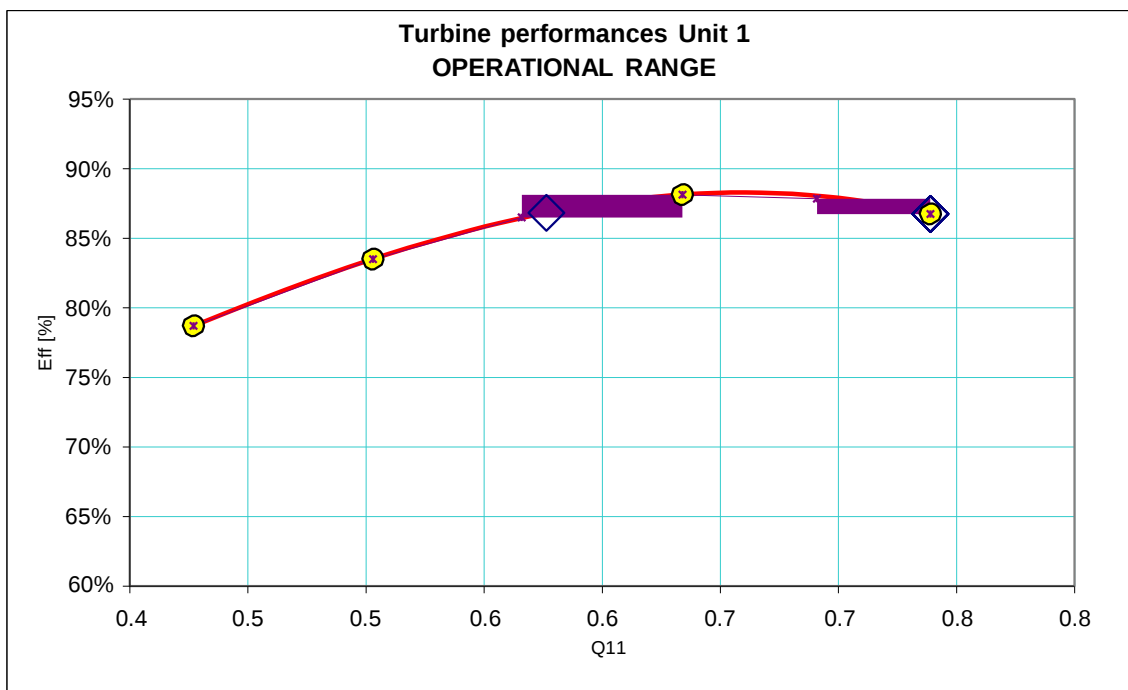


Fig.12 Practical operating range of turbine #1 determined through the analysis of the hydraulic conditions at the site

Flow duration curve and Annual Energy Production (AEP)

Flow duration curve and the dynamics of the head pond and the tailrace, which establish an input into the annual energy production calculations were supplied by the owner of the LCO project.

The curve representing Head was determined based on based on given Head pond and Tailrace levels changes based on the flow (Fig. 14)

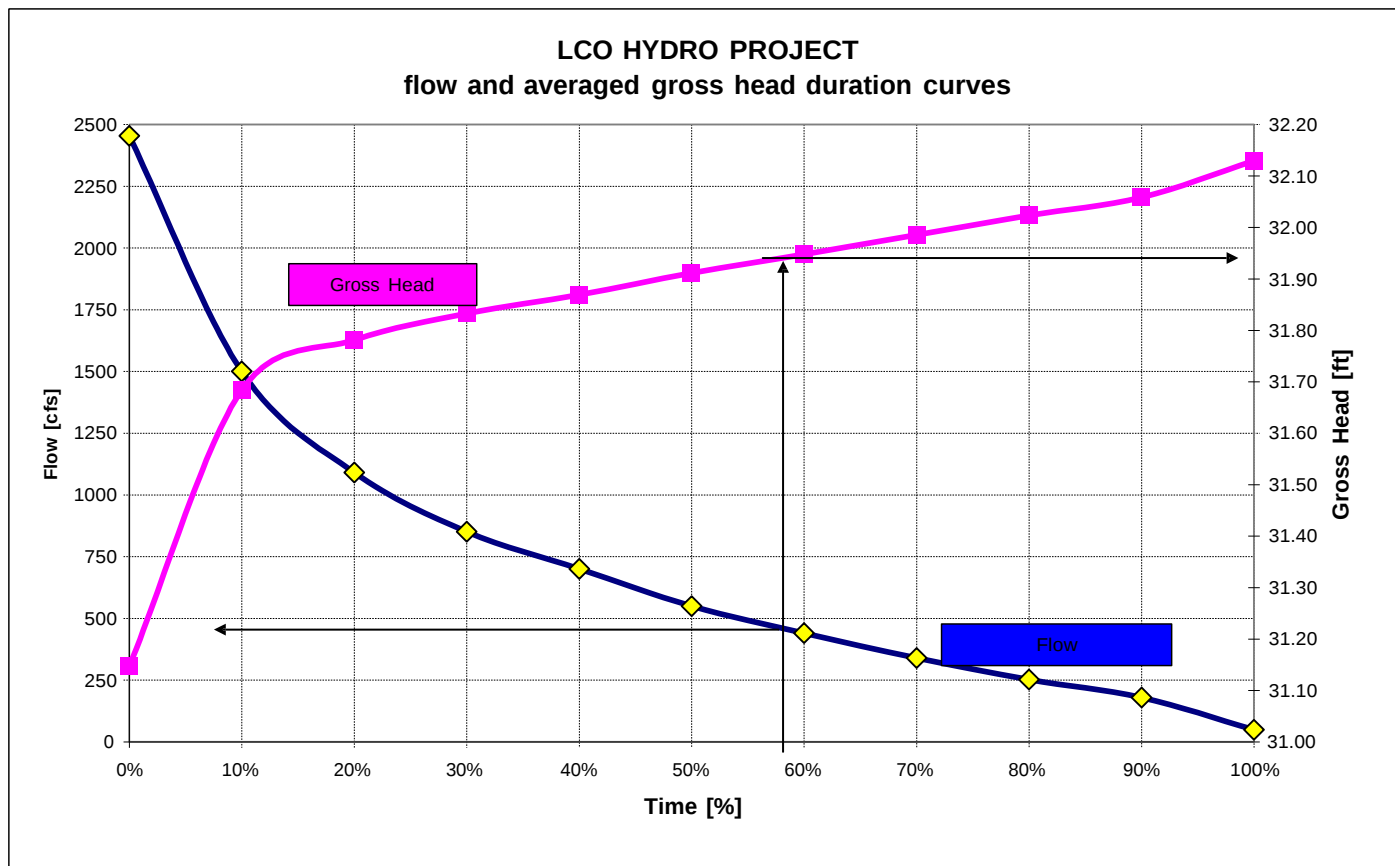


Fig.13 Flow and gross head duration curves

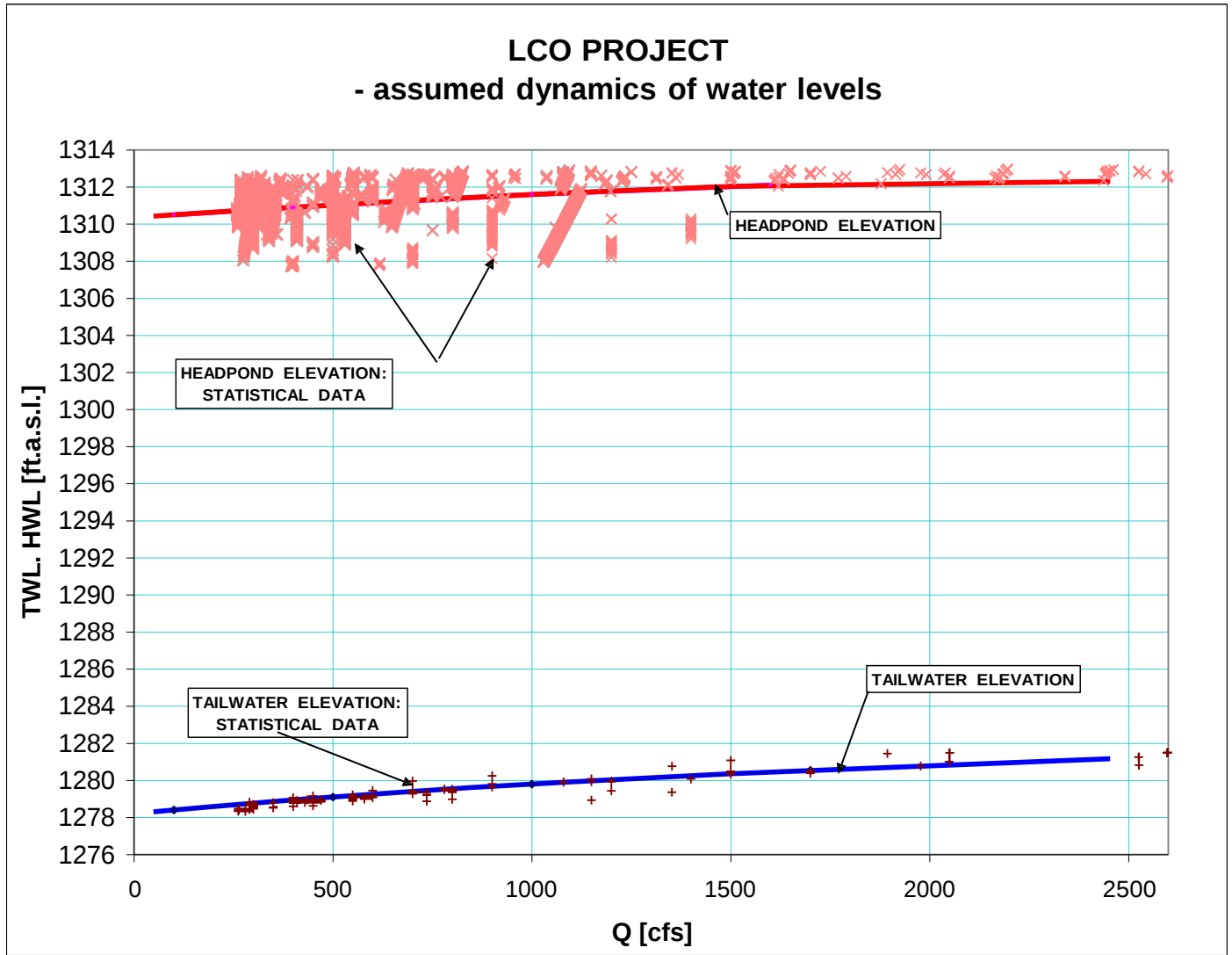


Fig.14 Fluctuations of the head pond and the tailrace assumed in the analysis.

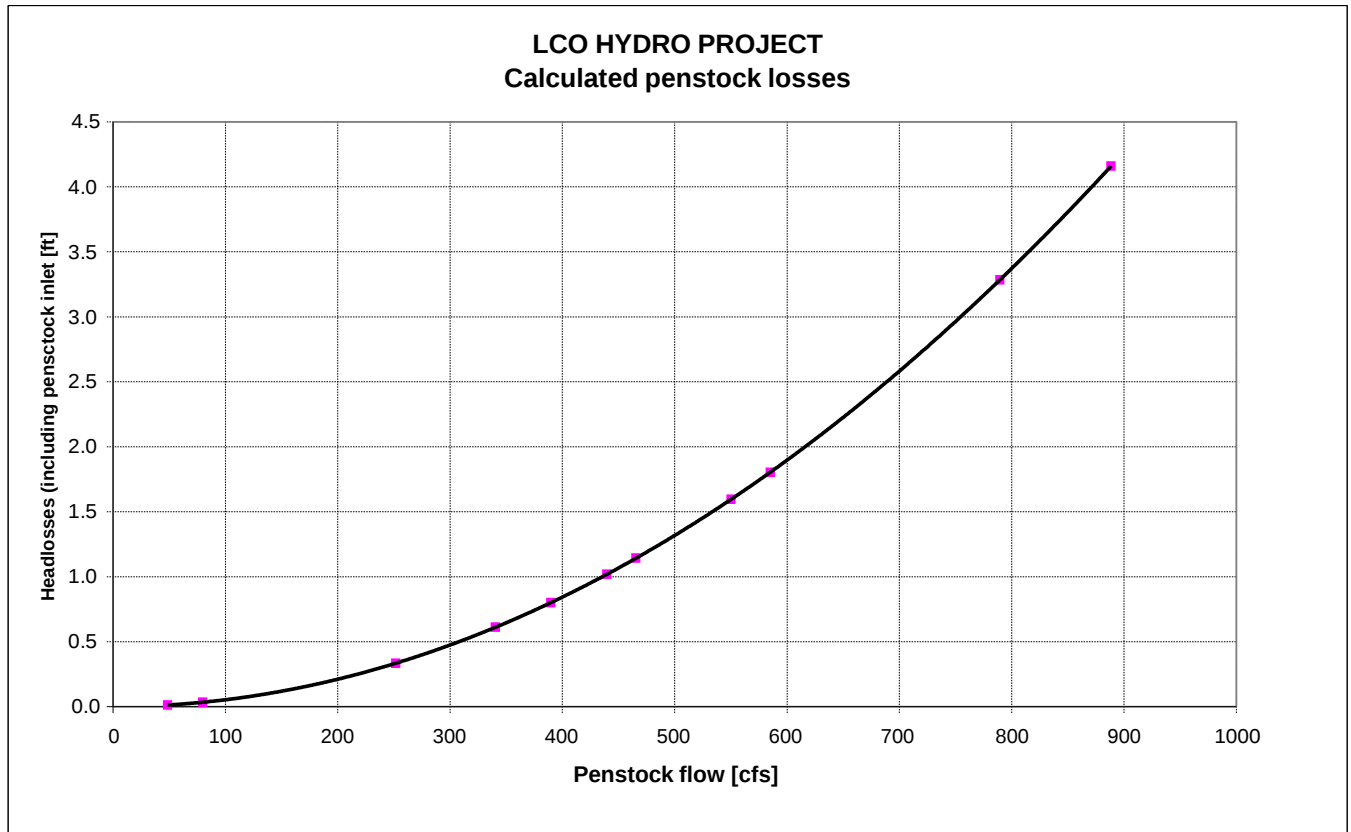


Fig.15 Calculated penstock losses.

Penstock losses were calculated based on losses coefficient published in hydraulic textbooks for the following components:

- a) sudden contraction (penstock inlet)
- b) cross-sectional change (square-to-round transition)
- c) sharp bent
- d) penstock surface roughness (steel, average rusted surface)

The resulting loss coefficient was at the end tuned-up based on information on achievable maximum generator outputs.

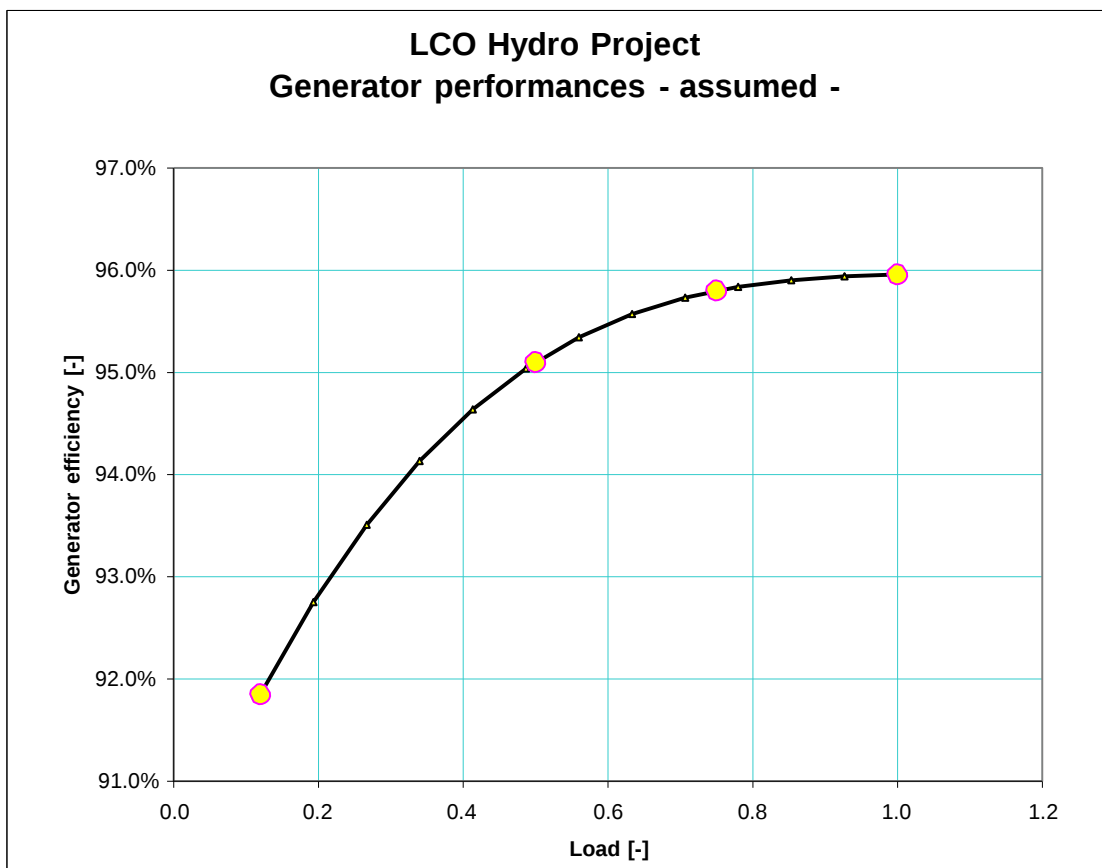


Fig.15a Calculated generator efficiency. Typical efficiency curve for the synchronous generator, which was assumed to determine efficiencies of each generator depending on portion of rated load they are exposed to.

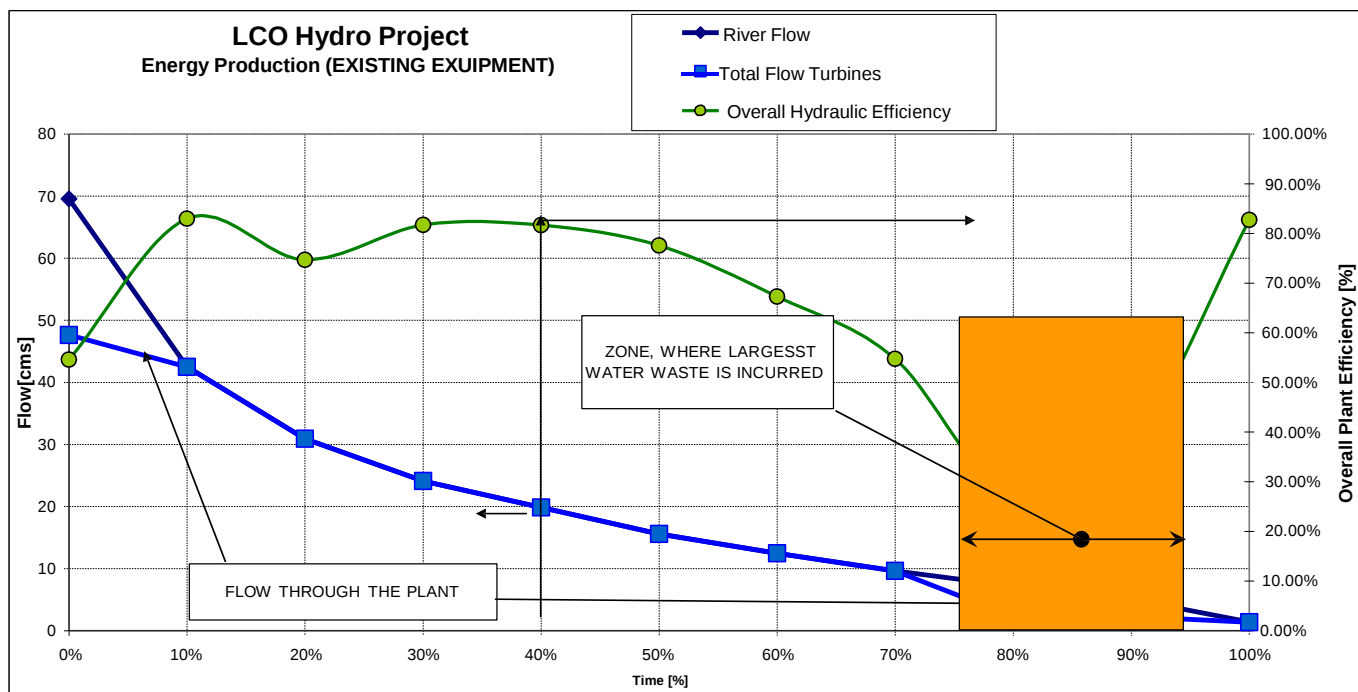


Fig.16 Calculation results presenting a history of plant operation: efficiency of turbines and flow consumed by turbines.

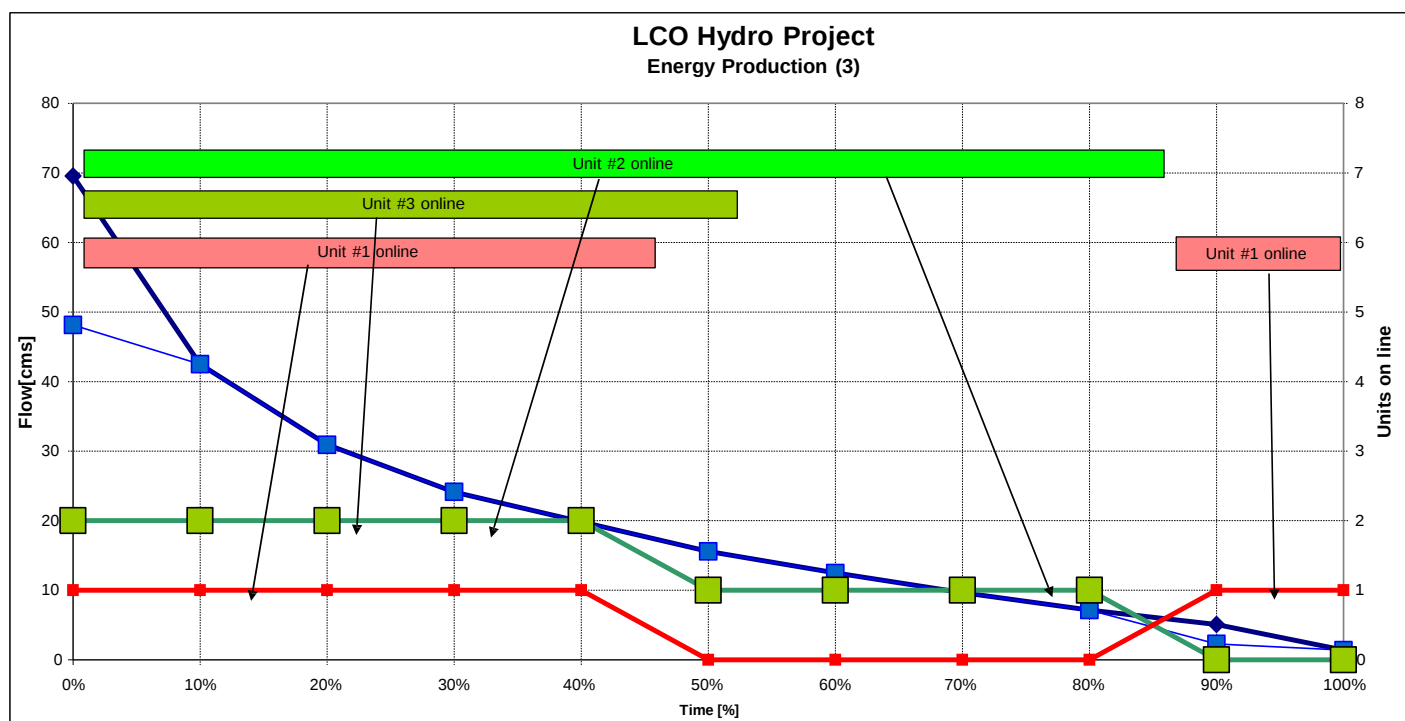


Fig.17 Operational time of all units.

									SUMMARY	
Time	River Flow	TWL	HWL	Gross Head	Hlos	Hnet	Spilling	Total Flow Turbines	Energy Production	Overall Hydraulic Efficiency
	[cfs]	[ft.a.s.l.]	[ft.a.s.l.]	[ft]	[ft]	[ft]	[cfs]	[cfs]	[kWh]	[%]
0%	2454	1281.2	1312.3	31.1	4.08	27.07	773	1681		54.6%
10%	1500	1280.4	1312.0	31.7	3.29	28.40	0	1500	2,657,356	83.0%
20%	1091	1279.9	1311.7	31.8	1.80	29.98	0	1091	2,217,852	74.7%
30%	851	1279.6	1311.4	31.8	3.82	28.02	0	851	1,629,181	81.7%
40%	700	1279.4	1311.3	31.9	2.58	29.29	0	700	1,344,386	81.7%
50%	550	1279.2	1311.1	31.9	1.60	30.32	0	550	1,101,352	77.6%
60%	440	1279.0	1311.0	31.9	1.02	30.93	0	440	819,575	67.2%
70%	340	1278.8	1310.8	32.0	0.61	31.38	0	340	556,332	54.7%
80%	252	1278.7	1310.7	32.0	0.03	31.99	172	80	295,439	26.3%
90%	179	1278.5	1310.6	32.1	0.03	32.02	99	80	157,843	37.2%
100%	49	1278.3	1310.4	32.1	0.01	32.12	0	49	127,427	82.7%

TOTAL CALCULATED ANNUAL ENERGY PRODUCTION = 10,906,743

TABLE 1: Annual energy production – calculations results – existing units.

	Production contribution	Energy produced [kWh]
Unit 1	9.2%	999,091
Unit 2	66.0%	7,193,396
Unit 3	24.9%	2,714,257
Total =	100.0%	10,906,743

TABLE 2: Contribution of each unit to the overall energy production

Proposed upgrade

The proposed upgrade is based on a set goal of achieving maximal increase in the AEP, while incurring the smallest capital investment and the lowest possible technical risk. Simulations of AEP based on existing turbines characteristics (Units 2&3 – based on CFD analysis of the existing unit, Unit 1 – formed on experience-based anticipation) shows that units 2 and 3 work on the so-called “part-load” portions of their characteristics. Maximum power of the generator is reached even before the turbine gets to its peak efficiency, which means that both units (2&3) have oversized capacities. Taking into account the fact that appropriate capacity of this plant should be approximately 40 to 42 cms (1400 cfs – 1500 cfs), size of generators 2&3 is appropriate. The reduction of turbines capacities (2&3), while increasing their hydraulic efficiency is achievable by replacing turbine runner with a modern lower capacity, design, , which will shift turbine characteristic so the machine will be capable of operating between 250cfs and 650 cfs, having best performances at approximately 450 to 550 cfs depending on the Net Head.

As the small units contributes to the AEP during the very high flow times (some 10 – 15% of the time) and at the minimal flows (below 250cfs, which happens some 25% of the time), it would be desired to increase unit 1 capacity above the existing 90 cfs. Having limited dimensional data about this unit, it was safely assumed that a higher capacity newly designed runner should bring capacity of this turbine to 100 cfs.

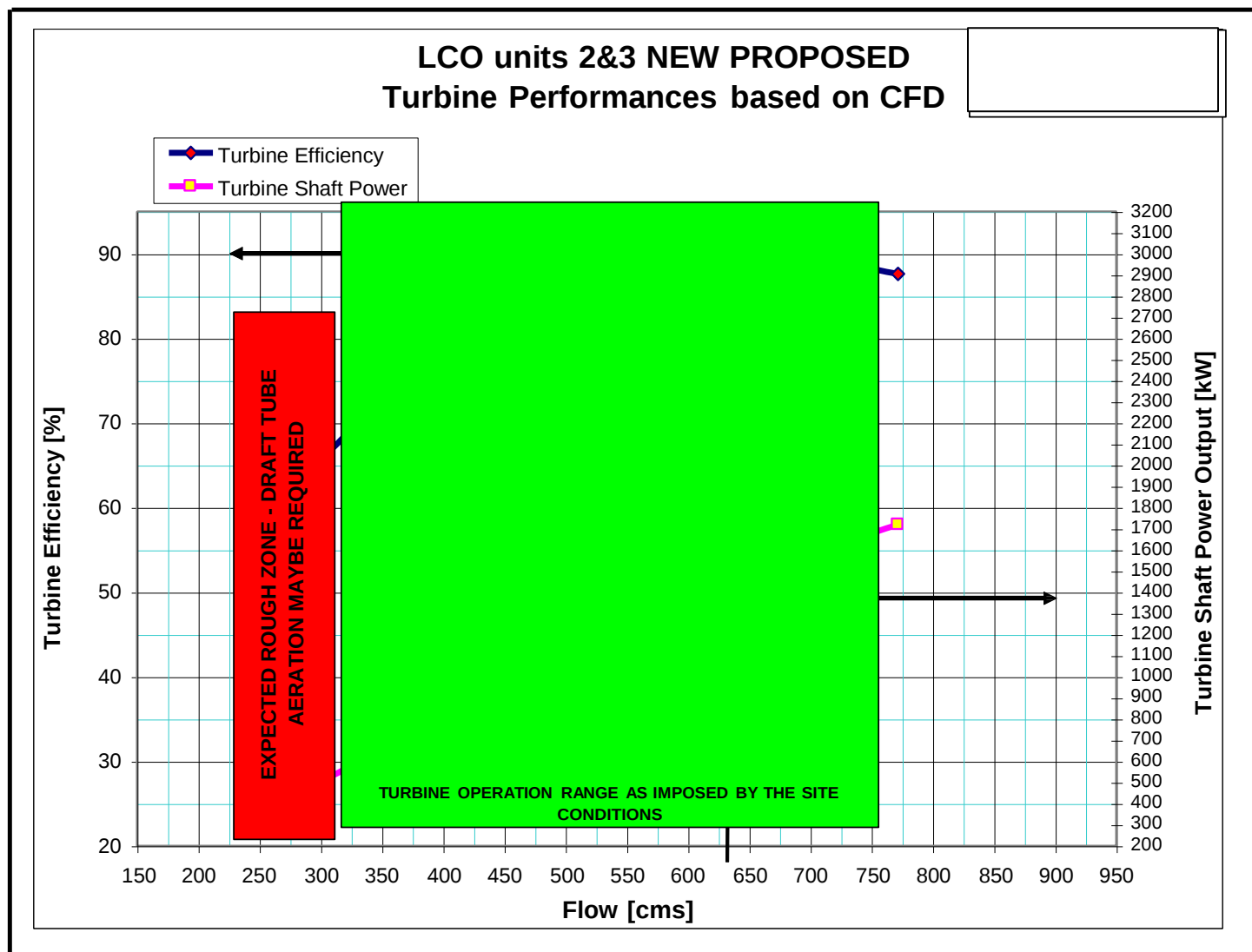


Fig.18 Expected performances of upgraded units 2 and 3: new runners only.

Peak efficiency shifted to approx. 620 cfs, while the existing unit has peak efficiency at approx. 720 cfs, which is very close to the limits of practical range of operation.

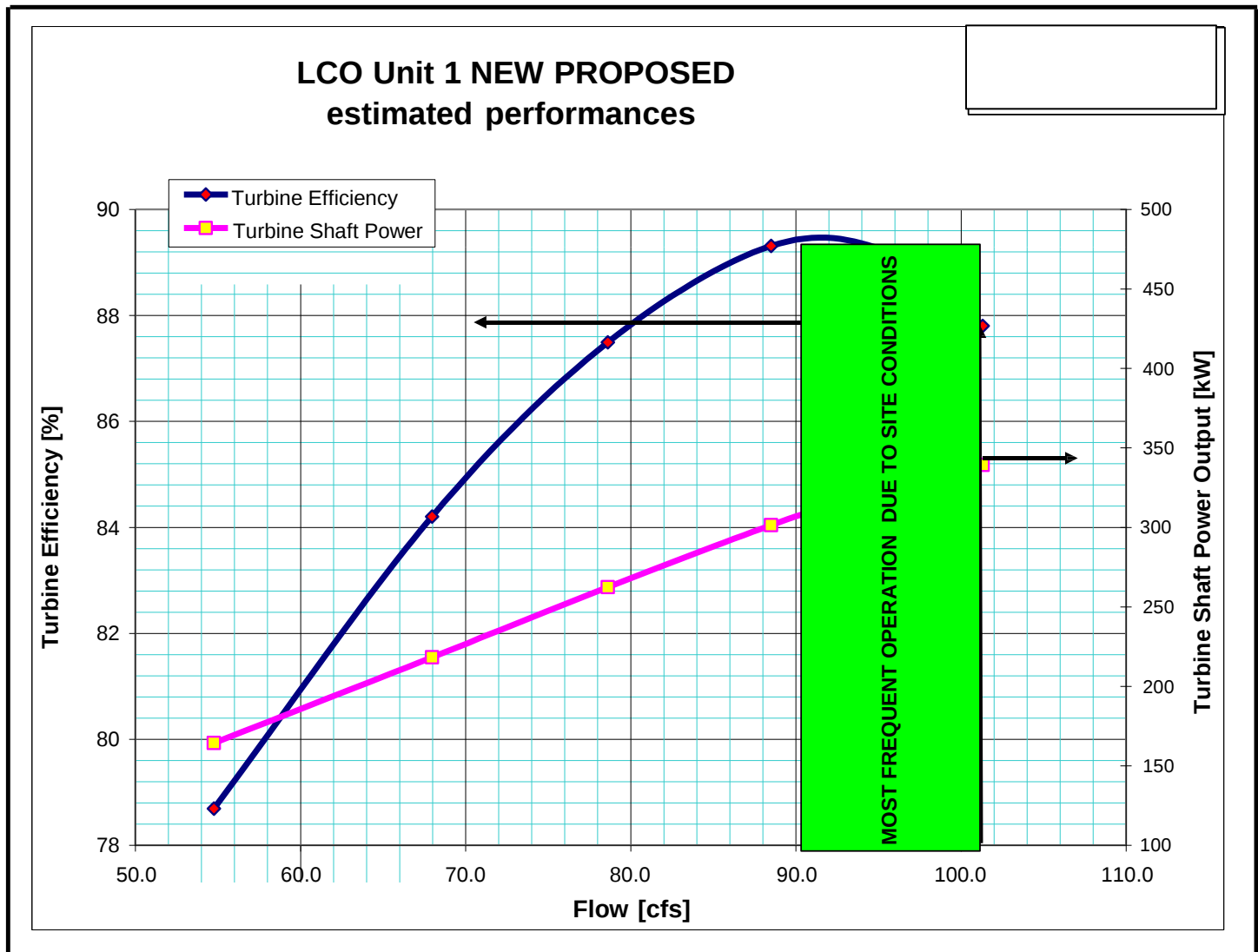


Fig.19 Expected performances of upgraded unit 1: a new runner only.

It is proposed to increase output of the small turbine by approx. 10% (15% is possible to achieve, but this may require generator upgrade) by supplying a new runner. This will add extra energy production at high flows as well as will facilitate better transition to the lowest operating flow of the large unit.

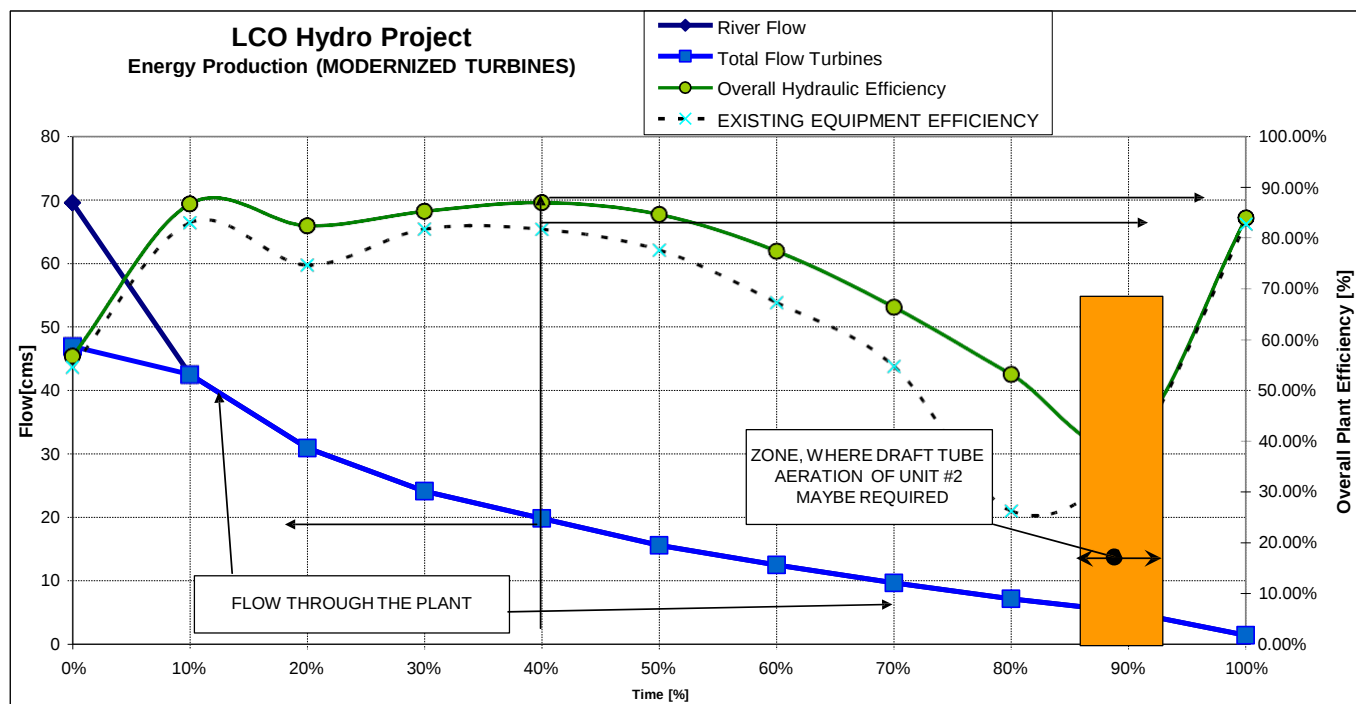


Fig.20 Calculation results presenting a history of plant operation after application of proposed turbine upgrades: efficiency of turbines and flow consumed by turbines.

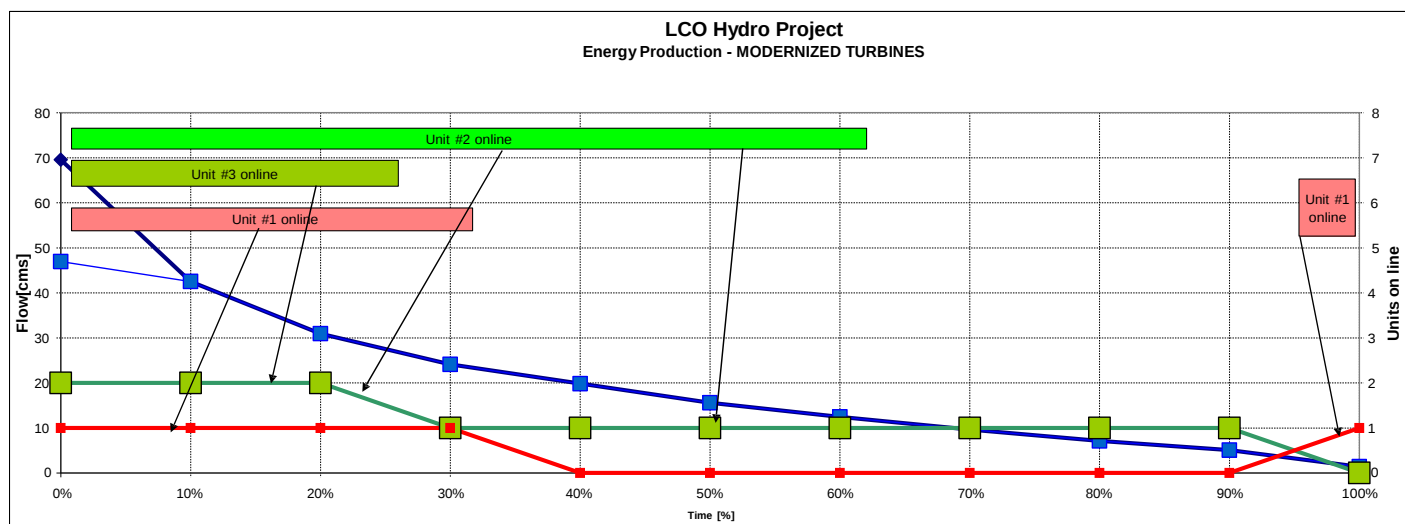


Fig.21 Operational time of all upgraded units.

LCO PROJECT - ANNUAL ENERGY PRODUCTION - UPGRADED UNITS									SUMMARY	
Time	River Flow	TWL	HWL	Gross Head	Hlos	Hnet	Spilling	Total Flow Turbines	Energy Production	Overall Hydraulic Efficiency
	[cfs]	[ft.a.s.l.]	[ft.a.s.l.]	[ft]	[ft]	[ft]	[cfs]	[cfs]	[kWh]	[%]
0%	2454	1281.2	1312.3	31.1	3.99	27.16	798	1656		56.8%
10%	1500	1280.4	1312.0	31.7	3.31	28.38	0	1500	2,772,757	86.7%
20%	1091	1279.9	1311.7	31.8	1.82	29.96	0	1091	2,367,831	82.4%
30%	851	1279.6	1311.4	31.8	3.82	28.02	0	851	1,752,838	85.2%
40%	700	1279.4	1311.3	31.9	2.58	29.29	0	700	1,415,154	86.9%
50%	550	1279.2	1311.1	31.9	1.59	30.32	0	550	1,184,826	84.6%
60%	440	1279.0	1311.0	31.9	1.02	30.93	0	440	914,292	77.4%
70%	340	1278.8	1310.8	32.0	0.61	31.38	0	340	653,511	66.4%
80%	252	1278.7	1310.7	32.0	0.33	31.69	0	252	420,351	53.2%
90%	179	1278.5	1310.6	32.1	0.17	31.89	0	179	242,593	40.1%
100%	49	1278.3	1310.4	32.1	0.01	32.12	0	49	134,014	83.9%

TOTAL CALCULATED ANNUAL ENERGY PRODUCTION = 11,858,166

TABLE 3: Annual energy production – calculations results – upgraded units.

Calculated increase of the annual energy production effecting from proposed modernization of all three turbines is **8.7% (951,423 kWh)**

	Production contribution	Energy produced [kWh]	Time online
Unit 1	4.9%	580,156	
Unit 2	70.8%	8,399,175	
Unit 3	24.3%	2,878,836	
Total =	100.0%	11,858,166	

TABLE 4: Contribution of each unit to the overall energy production – upgraded units.

Proposed partial upgrade: Unit #2 only

Scenario of a partial plant upgrade was analyzed after consultations with Kiser Hydro LLP. Energy production calculations and the turbine dispatching schedule was conducted for three various units:

Unit #1 – as is

Unit #2 – upgraded (new runner and possibly draft tube aeration system to facilitate turbine operation at lowest loads)

Unit #3 – as is.

Calculated incremental revenue is **7.3% (797,513 kWh)** higher than for the plant equipped with all existing units.

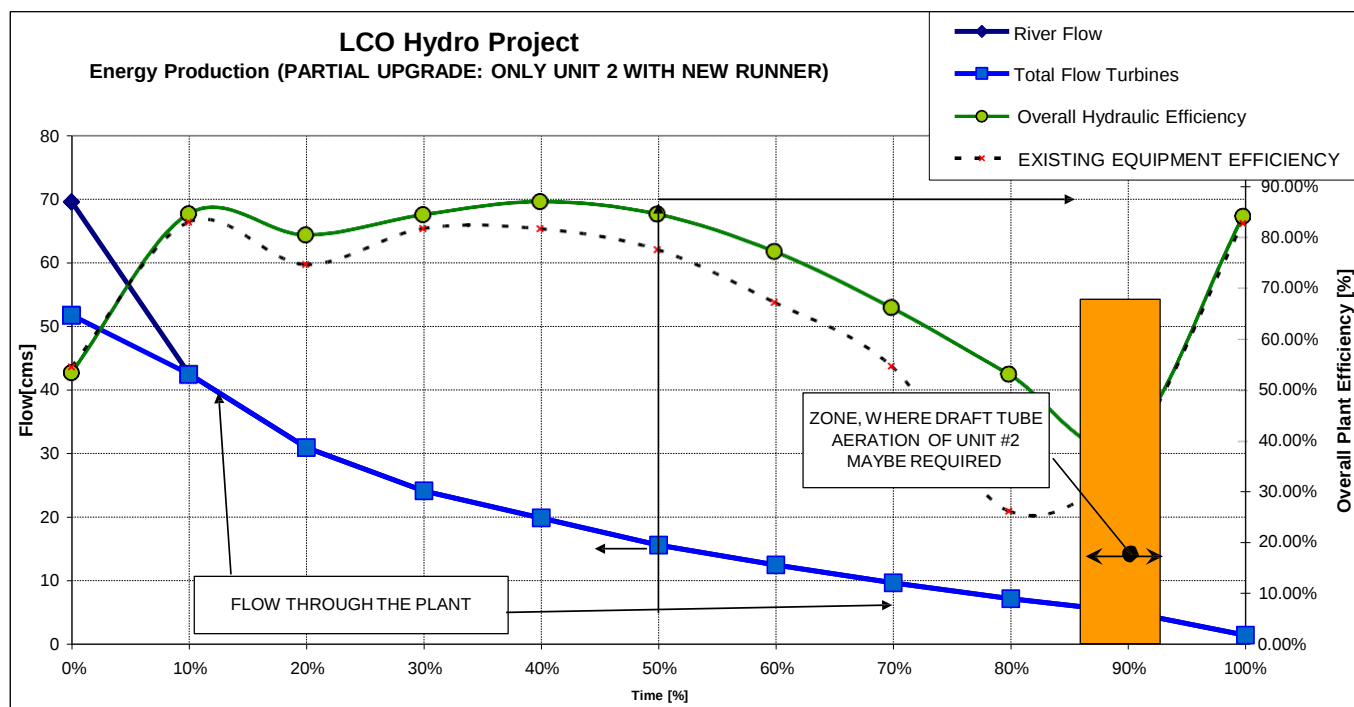


Fig.22 Calculation results presenting a history of plant operation after application of proposed partial upgrade (unit #2 only): efficiency of turbines and flow consumed by turbines.

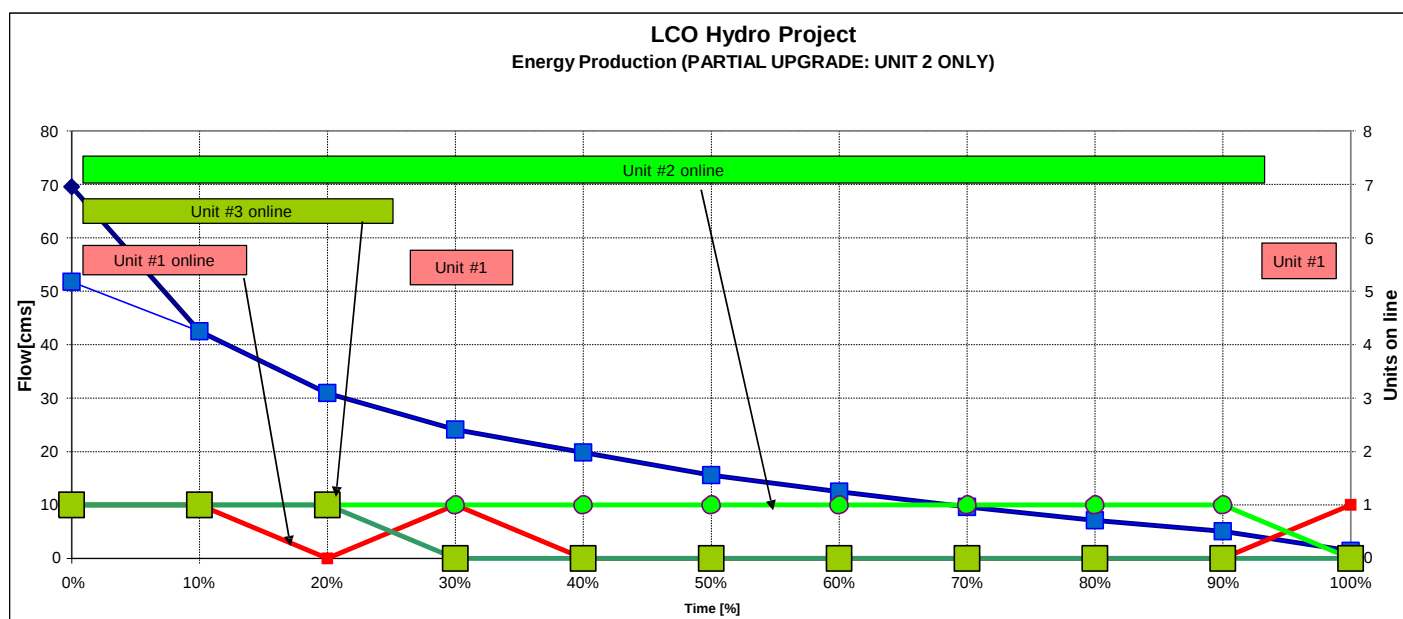


Fig.21 Operational time of all units (#1 and #3 as is, #2 upgraded).

LCO PROJECT - ANNUAL ENERGY PRODUCTION - PARTIAL UPGRADE: UNIT #2 ONLY									SUMMARY	
Time	River Flow	TWL	HWL	Gross Head	Hlos	Hnet	Spilling	Total Flow Turbines	Energy Production	Overall Hydraulic Efficiency
	[cfs]	[ft.a.s.l.]	[ft.a.s.l.]	[ft]	[ft]	[ft]	[cfs]	[cfs]	[kWh]	[%]
0%	2454	1281.2	1312.3	31.1	4.84	26.31	628	1826		53.4%
10%	1500	1280.4	1312.0	31.7	2.91	28.77	0	1500	2,634,856	84.6%
20%	1091	1279.9	1311.7	31.8	1.34	30.44	0	1091	2,346,375	80.4%
30%	851	1279.6	1311.4	31.8	3.26	28.57	0	851	1,753,466	84.4%
40%	700	1279.4	1311.3	31.9	2.58	29.29	0	700	1,423,650	87.0%
50%	550	1279.2	1311.1	31.9	1.59	30.32	0	550	1,185,007	84.6%
60%	440	1279.0	1311.0	31.9	1.02	30.93	0	440	913,268	77.2%
70%	340	1278.8	1310.8	32.0	0.61	31.38	0	340	652,140	66.2%
80%	252	1278.7	1310.7	32.0	0.33	31.69	0	252	419,690	53.1%
90%	179	1278.5	1310.6	32.1	0.17	31.89	0	179	242,099	39.9%
100%	49	1278.3	1310.4	32.1	0.01	32.12	0	49	133,704	84.1%

TOTAL CALCULATED ANNUAL ENERGY PRODUCTION = 11,704,257

TABLE 5: Annual energy production – calculations results – partial upgrade: Unit #2 only.

Calculated increase of the annual energy production effecting from this type of upgrade (unit #2 only) is **7.3% (797,513 kWh).**

	Production contribution	Energy produced [kWh]
Unit 1	3.2%	369,410
Unit 2	73.6%	8,616,462
Unit 3	23.2%	2,718,384
Total =	100.0%	11,704,257

TABLE 6: Contribution of each unit to the overall energy production – partial upgrade: Unit #2 only.



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UPGRADE ESTIMATES

SUMMARY OF UPGRADE PROPOSAL #1

After analysis of the existing units and available flows it is being proposed to upgrade all three of the existing units to operate more efficiently as well as over a wider range of flows. Unit #1 would be upgraded to operate with higher flows. Because of the higher flows and larger overall capacity, the correlating generator may also have to be replaced or rewound to accommodate the higher outputs. Units #2 and #3 would be upgraded to operate under a wider range of flows. The generators for both of these units are sized appropriately, since the overall output would not be increasing.

		ESTIMATE
UNIT #1	Design & Fabrication	\$175,000
	Removal & Installation	\$200,000
	Generator Upgrade	\$50,000
UNIT #2	Design & Fabrication	\$375,000
	Removal & Installation	\$250,000
UNIT #3	Design & Fabrication	\$375,000
	Removal & Installation	\$250,000
TOTAL		\$1,675,000

SUMMARY OF UPGRADE PROPOSAL #2

After analysis of the existing units and available flows a second, less aggressive upgrade is being proposed. This proposal includes an upgrade to Unit #2 to be operable under a wider range of flows, to go as low as the minimum flow of 250 cfs. A draft tube aeration system may be necessary to operate smoothly at lower flows. Because the need for an aeration system will not be known until further design is completed the estimate for the upgrade does not include costs associated with this.

	ESTIMATE
Design & Fabrication	\$450,000
Removal & Installation	\$250,000
TOTAL	\$700,000



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SUMMARY TABLE OF PROPOSED UPGRADES

The table below was developed to illustrate a direct comparison of the existing equipment in operation with the two proposed upgrade scenarios. The projected Annual Energy Production (AEP) was taken from the CFD Based Upgrade Analysis Final Report prepared by Swiderski Engineering Inc. The Estimated Cost of Upgrades are Rough Order of Magnitude (ROM) prices based on limited design. These estimates do include removal of the existing units as well as installation of the new designs.

Table 1: Relative Cost & Annual Energy Production Comparison

		CONTRIBUTION	ENERGY PRODUCED (kWh)	ANNUAL ENERGY PRODUCTION (kWh)	ESTIMATED COST OF UPGRADE	
EXISTING EQUIPMENT	Unit 1	9.2%	999,091	10,906,744	NA	
	Unit 2	66.0%	7,193,396			
	Unit 3	24.9%	2,714,257			
UNITS #1, #2 & #3 UPGRADE	Unit 1	4.9%	580,156	11,858,167	\$375,000	\$1,625,000
	Unit 2	70.8%	8,399,175		\$625,000	
	Unit 3	24.3%	2,878,836		\$625,000	
UNIT #2	Unit 1	3.2%	369,410	11,704,256	NA	\$700,000
	Unit 2	73.6%	8,616,462		\$700,000	
	Unit 3	23.2%	2,718,384		NA	



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FINAL REPORT

DATE: April 3, 2014

CUSTOMER: Lac Courte Oreilles Band of Lake Superior Chippewa
13394 West Trepania Road
Hayward, WI 54843

PROJECT: Turbine Analysis

JOB NUMBER: 13-33

SUMMARY OF PROJECT

Kiser Hydro has been contracted to evaluate the existing turbines at the Winter Dam Hydro facility. Existing geometry will be used in conjunction with historical flows and power production to evaluate the efficiency of the plant and its power producing capabilities. Through use of Computational Fluid Dynamics (CFD) Analysis, Kiser Hydro will be better able to determine possible turbine improvements that would benefit overall plant efficiency and annual power production.

FIELD SERVICES

Kiser Hydro performed two site visits to verify infrastructure of the units involved in the analysis. Overall measurements and orientation were confirmed with the prints that were made available to Kiser Engineering.

GKS Services was brought on site to perform a 3D laser scan of the turbine blades. By scanning the existing blades a Computer Aided Design (CAD) model was created and used in the CFD analysis. Due to the constricting geometry of Unit #1, it was not feasible to scan the existing blades. For the analysis, the scan and 3D model of the blades from Unit #2 were used to represent both Units #2 and #3, and were then scaled down and used for Unit #1.

ENGINEERING SERVICES

Kiser Hydro contracted Swiderski Engineering, Inc to perform the CFD analysis of the existing turbines. The analysis was performed using verified prints of the existing equipment and historical data of available flows. After completing analysis of the existing equipment, Swiderski Engineering analyzed two possible upgrade scenarios and summarized the findings.



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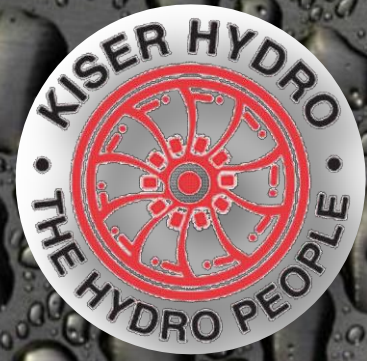
Upgrade Scenario #1 included upgrades of all three units, which resulted in an increase of annual energy production of 8.7%. Upgrade Scenario #2 consisted of a partial upgrade, in upgrading only one of the large units, Unit #2 or Unit #3. The expected increase in annual energy production is 7.3%. These upgrades would allow for the large units (Units #2 and/or #3) to be operated over a wider range of flows. This results in greater efficiencies and less “lost” water.

RECOMMENDATIONS

Given the cost comparisons of the two proposed upgrade scenarios combined with their respective expected increases in annual energy production, Kiser Hydro recommends performing a partial upgrade in upgrading Unit #2 or Unit #3. This upgrade is the most fiscally reasonable given the costs associated with upgrading one unit compared to the costs associated with upgrading all three units.

LAC COURTE OREILLES

TURBINE ANALYSIS



LCO TURBINE ANALYSIS

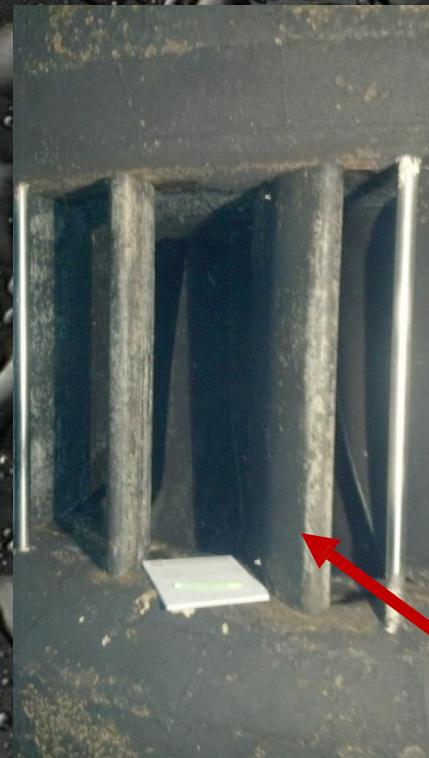
Existing Hydro System

UNIT #1

- WJ Bauer Ø40 Inch Francis Runner
- 14 Blades
- Shares Penstock with Unit #2
- Operating Flows: 86.5-95 cfs
- Duration of Annual Operation : ~46%
- Average Annual Energy Production (AEP): 1 MWh, 9.1% of Plant Total

UNIT #2 & #3

- WJ Bauer Ø93 Inch Francis Runner
- 15 Blades
- Operating Flows: 325-760 cfs
- Duration of Annual Operation Unit #2: ~86%
- Duration of Annual Operation Unit #3: ~52%
- Average AEP Unit #2: 7.2 MWh, 66% of Plant Total
- Average AEP Unit #3: 2.7 MWh, 24.9% of Plant Total

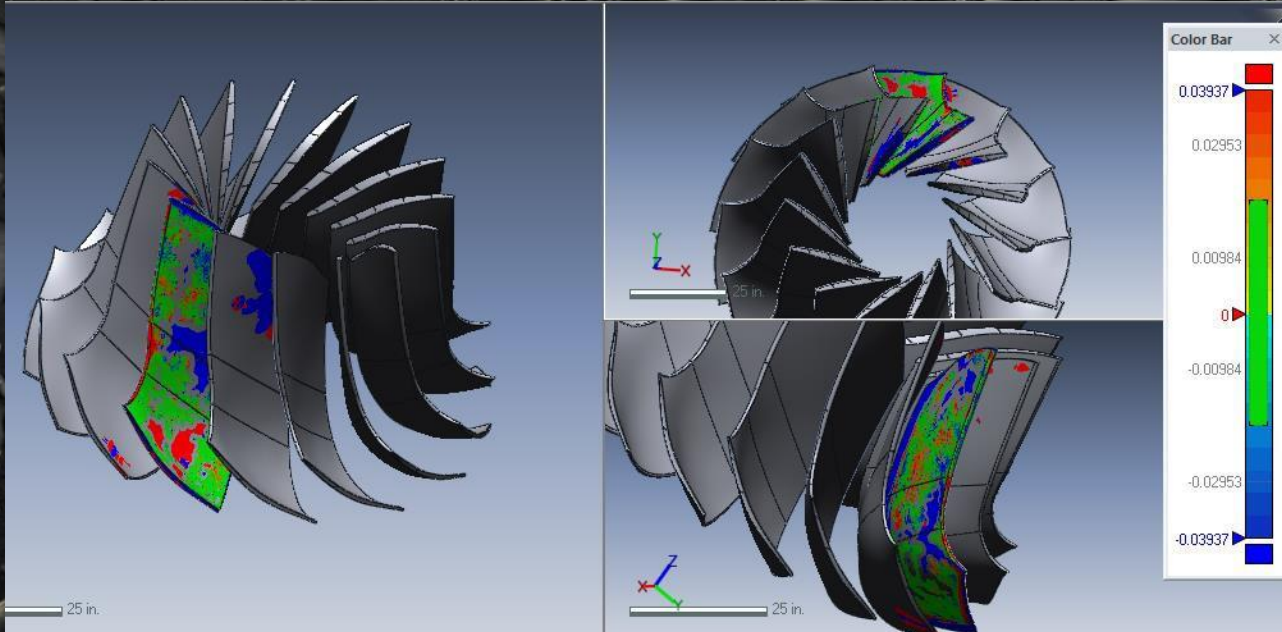


Unit #2 Runner

Unit #2 Wicket Gates

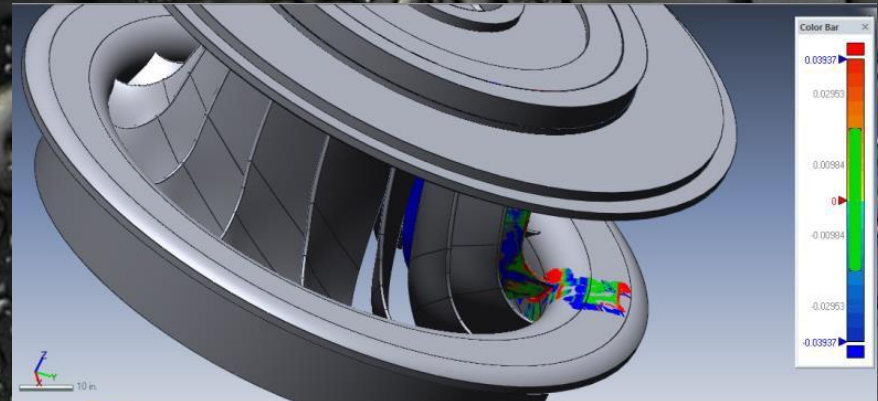
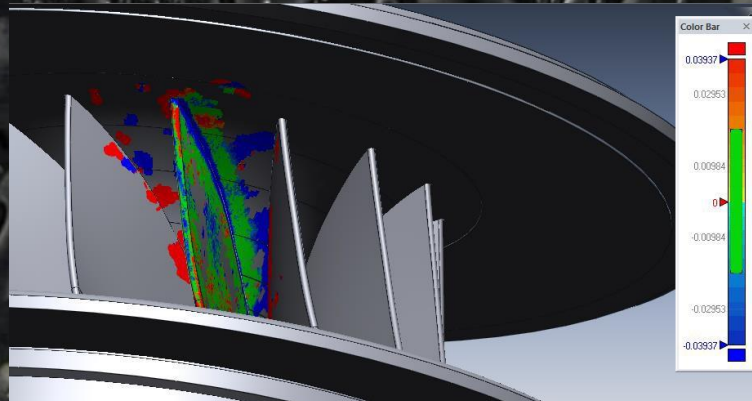
LCO TURBINE ANALYSIS

3D Laser Scan of Unit #2



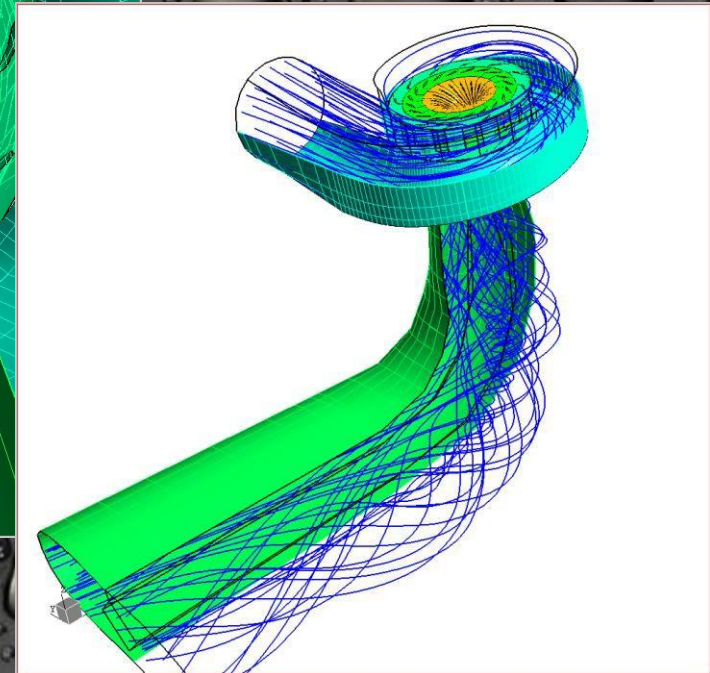
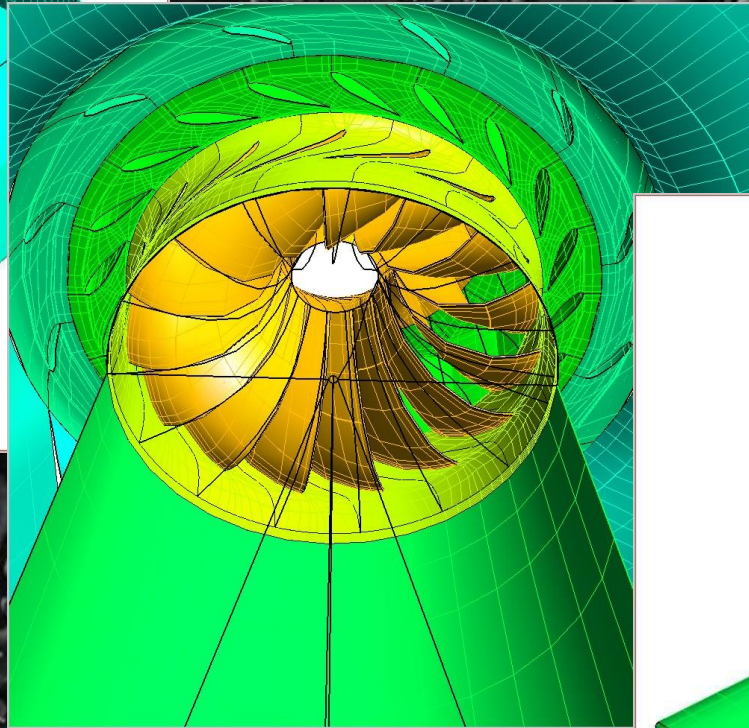
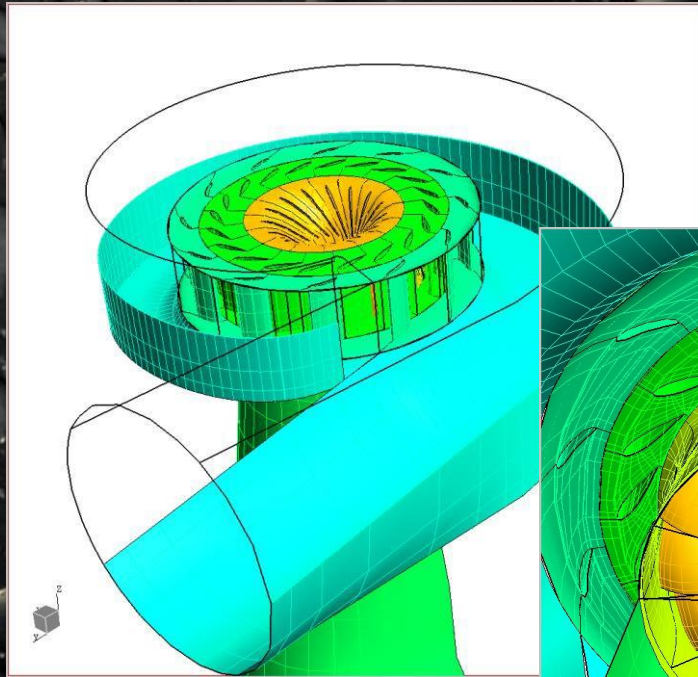
A scan of existing runner geometry was completed for use in the Computation Fluid Dynamic (CFD) analysis.

A 3D model was created with the information gathered from the scan.



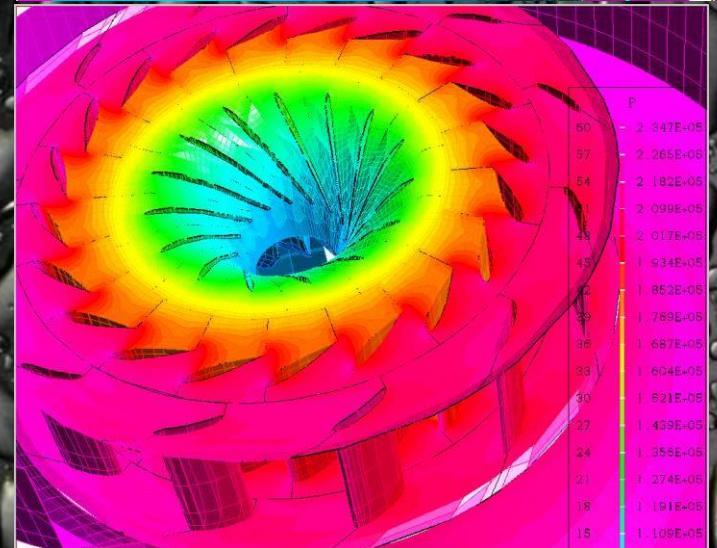
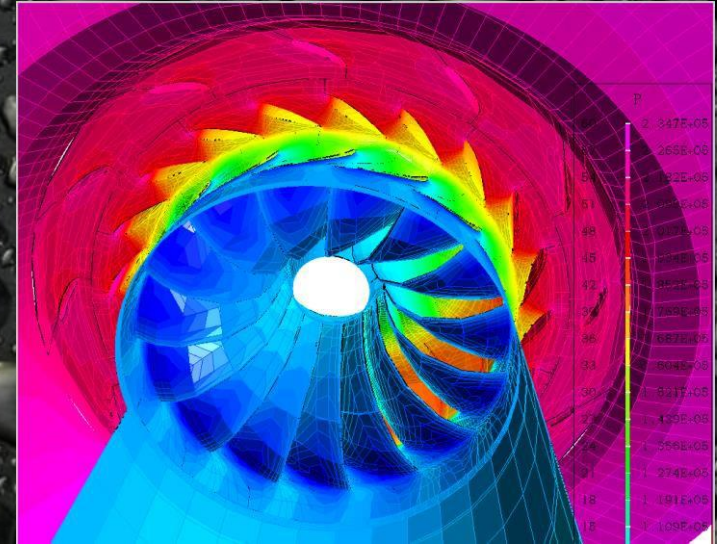
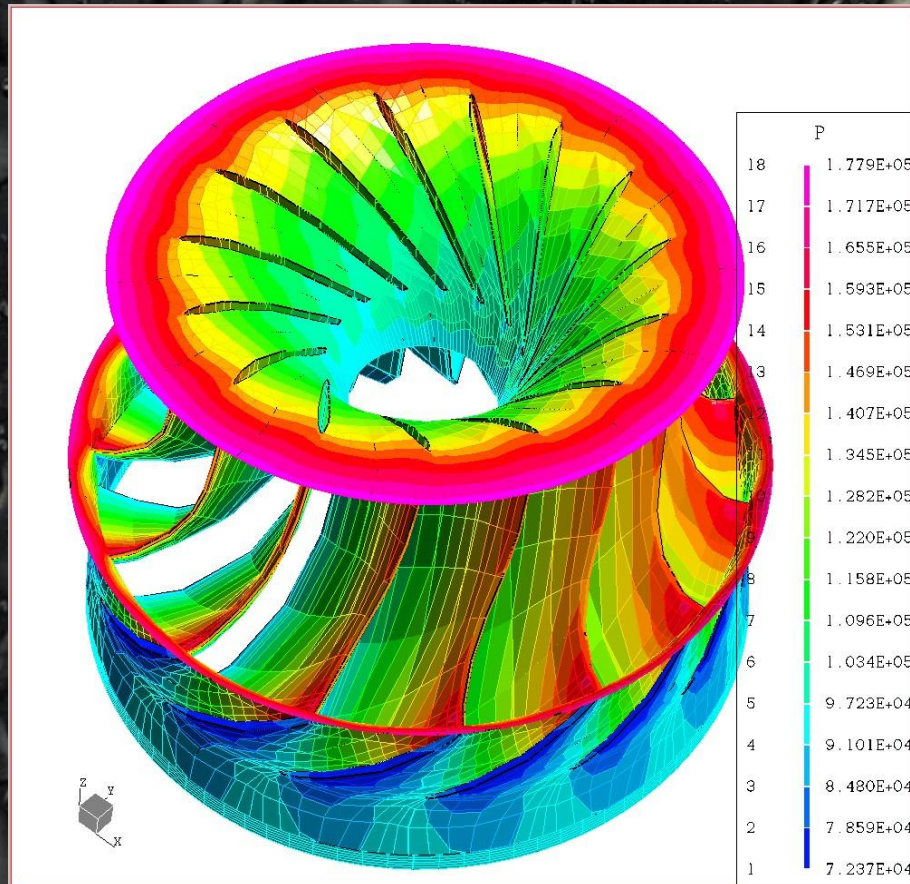
LCO TURBINE ANALYSIS

CFD Model of Existing Hydro System



LCO TURBINE ANALYSIS

Static Pressure Distribution (At Maximum Efficiency)

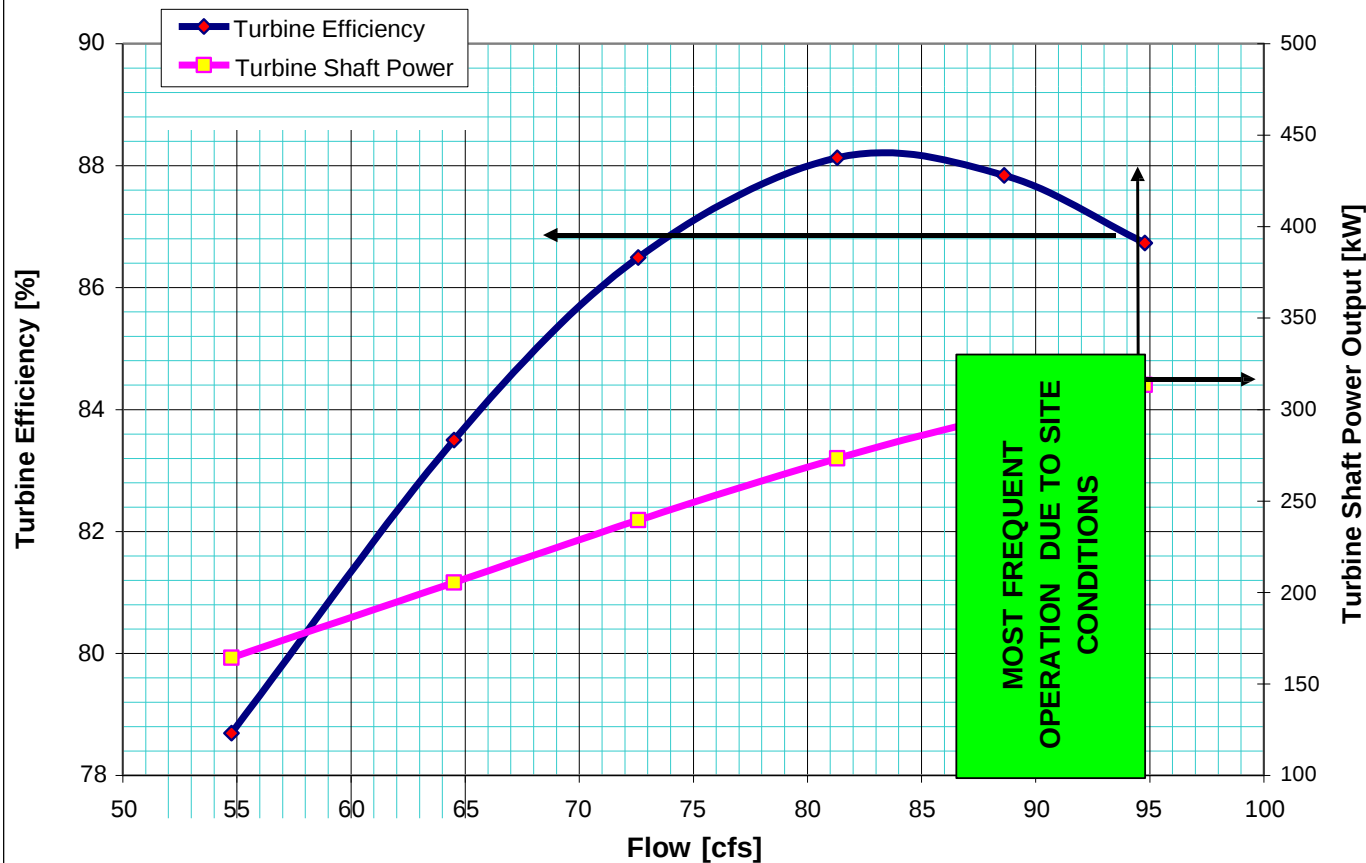


LCO TURBINE ANALYSIS

CFD Analysis of Existing Unit #1

LCO Unit 1 EXISTING
estimated performances

PRELIMINARY
PROPOSAL ONLY



MAX EFFICIENCY:
~88.3%

MAX POWER:
~312 kW

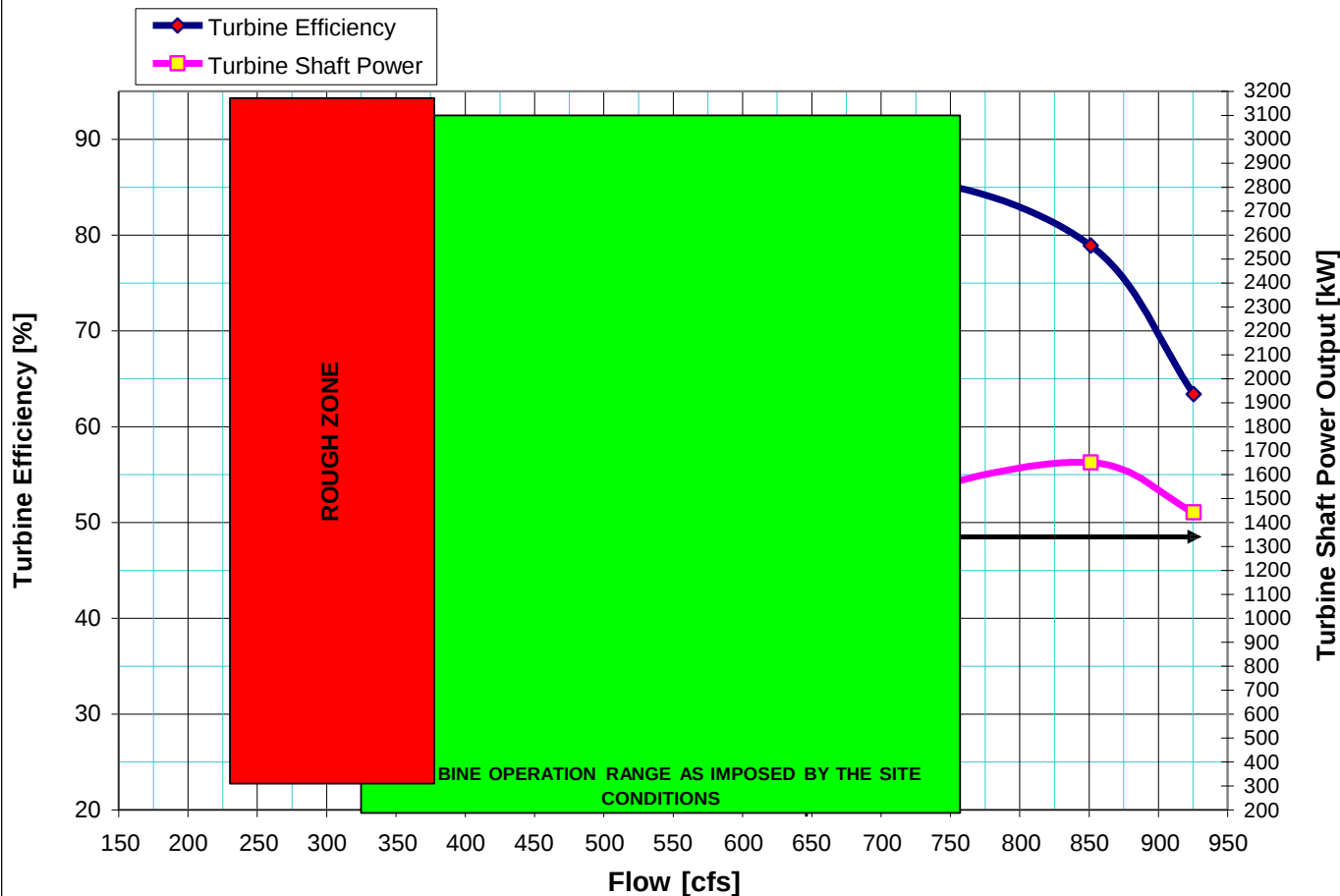
EFFICIENCY @
MAX POWER:
~86.8%

LCO TURBINE ANALYSIS

CFD Analysis of Existing Units #2 & #3

LCO units 2&3 EXISTING
Turbine Performances based on CFD

PRELIMINARY
PROPOSAL ONLY



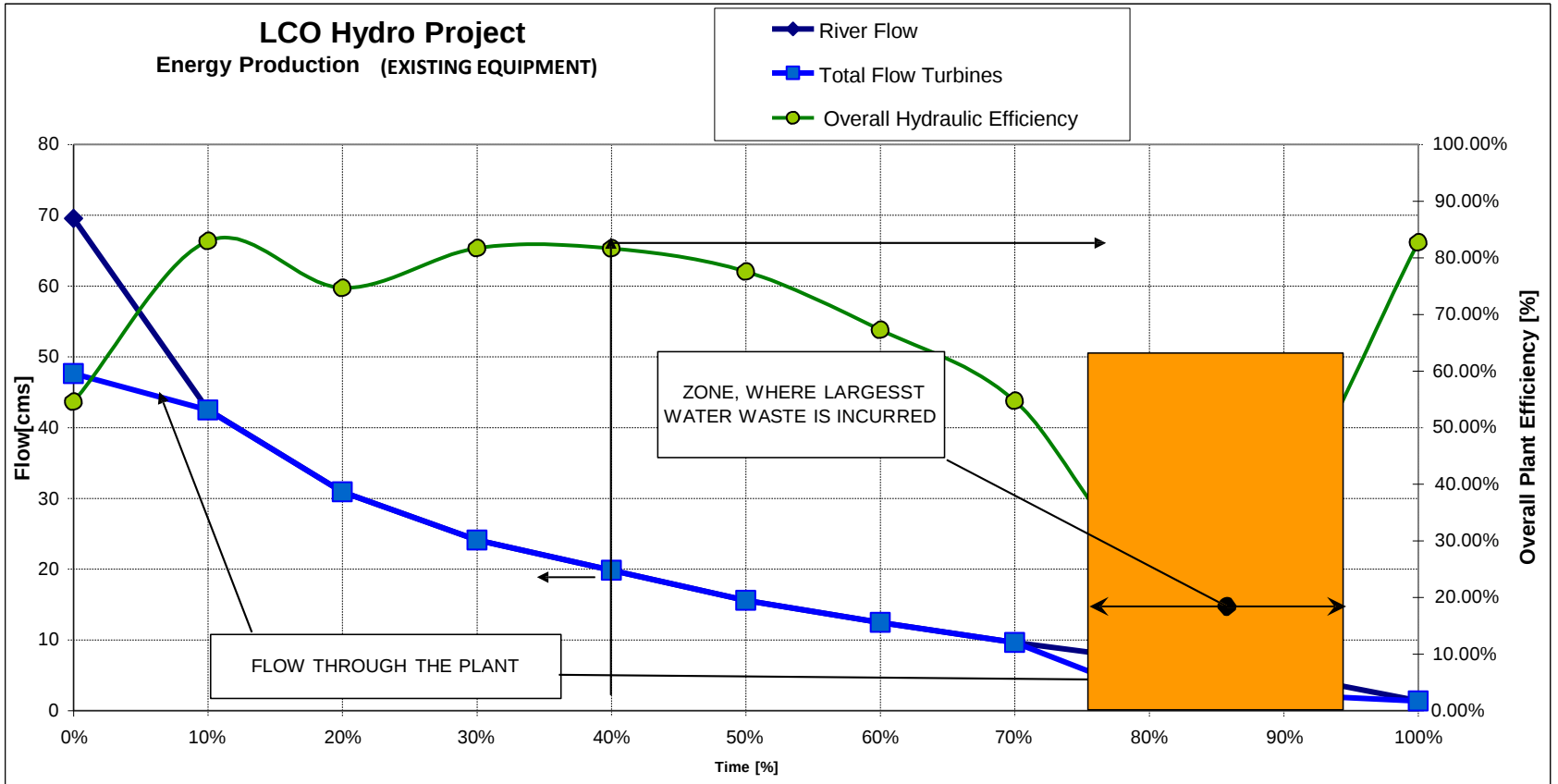
MAX EFFICIENCY:
~85%

MAX POWER:
~1650 kW

EFFICIENCY @
MAX POWER:
~79%

LCO TURBINE ANALYSIS

CFD Analysis of Existing Units



Units Are Not Properly Sized For Available Flows
Resulting in Large Amounts of Bypassing Water 75-85% of the Time

LCO TURBINE ANALYSIS

CFD Analysis of Existing Units

	Production contribution	Energy produced [kWh]
Unit 1	9.2%	999,091
Unit 2	66.0%	7,193,396
Unit 3	24.9%	2,714,257
Total =	100.0%	10,906,743

SUMMARY OF ANALYSIS FOR EXISTING UNITS

1. Turbine #1 is Undersized
2. Turbines #2 & #3 are Oversized by 30-40%
3. Combination of Undersized/Oversized Allows for Unnecessary Spilling of Water
4. Overall Hydraulic Efficiency is Low at 84% (Expected Efficiency Should Be 87-92%)
5. All Generators are Sized Properly

LCO TURBINE ANALYSIS

Proposal #1: Upgrade All Three Units

PROPOSAL #1

UPGRADE UNITS #1, #2, & #3

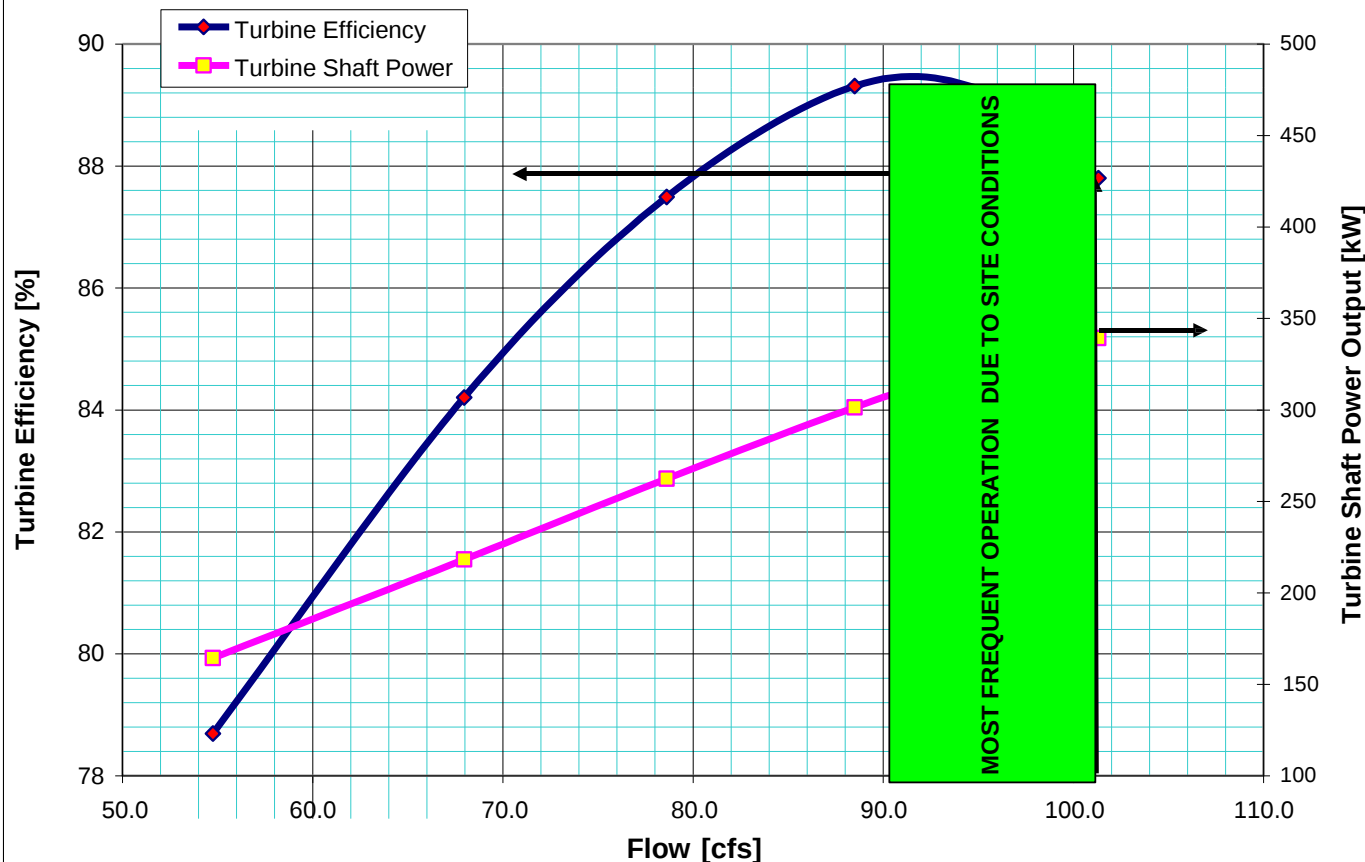
1. Design & fabricate new turbines for all three existing units
2. Unit #1 would be designed to operate up to 100-150 cfs. This would increase the unit's capacity which will also result in adjusting the capacity allowed by the existing generator.
3. Units #2 & #3 would be designed to operate at 250 -650 cfs.
4. Expected increase in Annual Energy Production of Approximately 8.7%

LCO TURBINE ANALYSIS

Proposal #1: Upgrade All Three Units

LCO Unit 1 NEW PROPOSED
estimated performances

PRELIMINARY
PROPOSAL ONLY



MAX EFFICIENCY:
~89.5%

MAX POWER:
~337 kW

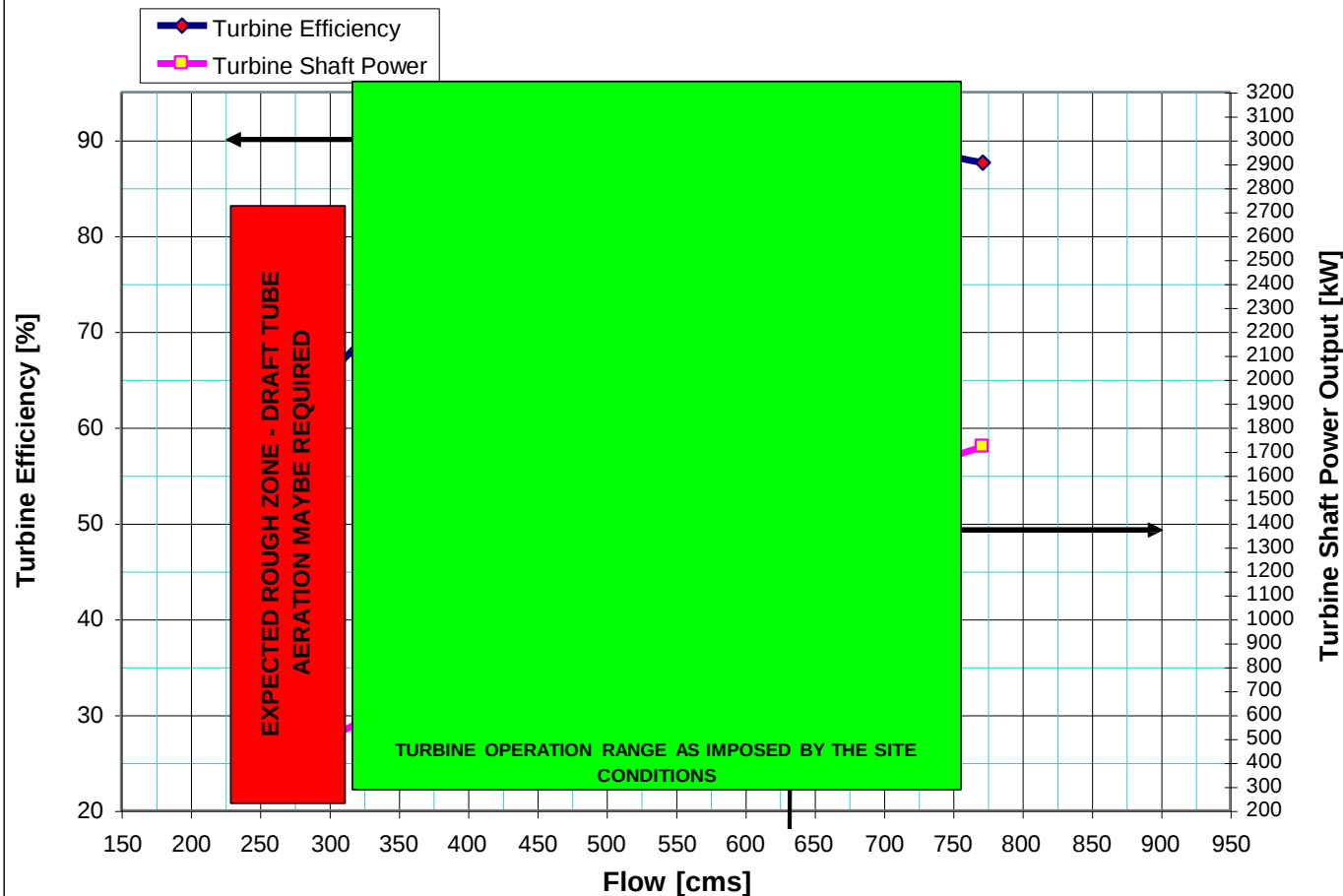
EFFICIENCY @
MAX POWER:
~87.8%

LCO TURBINE ANALYSIS

Proposal #1: Upgrade All Three Units

LCO units 2&3 NEW PROPOSED
Turbine Performances based on CFD

PRELIMINARY
PROPOSAL ONLY



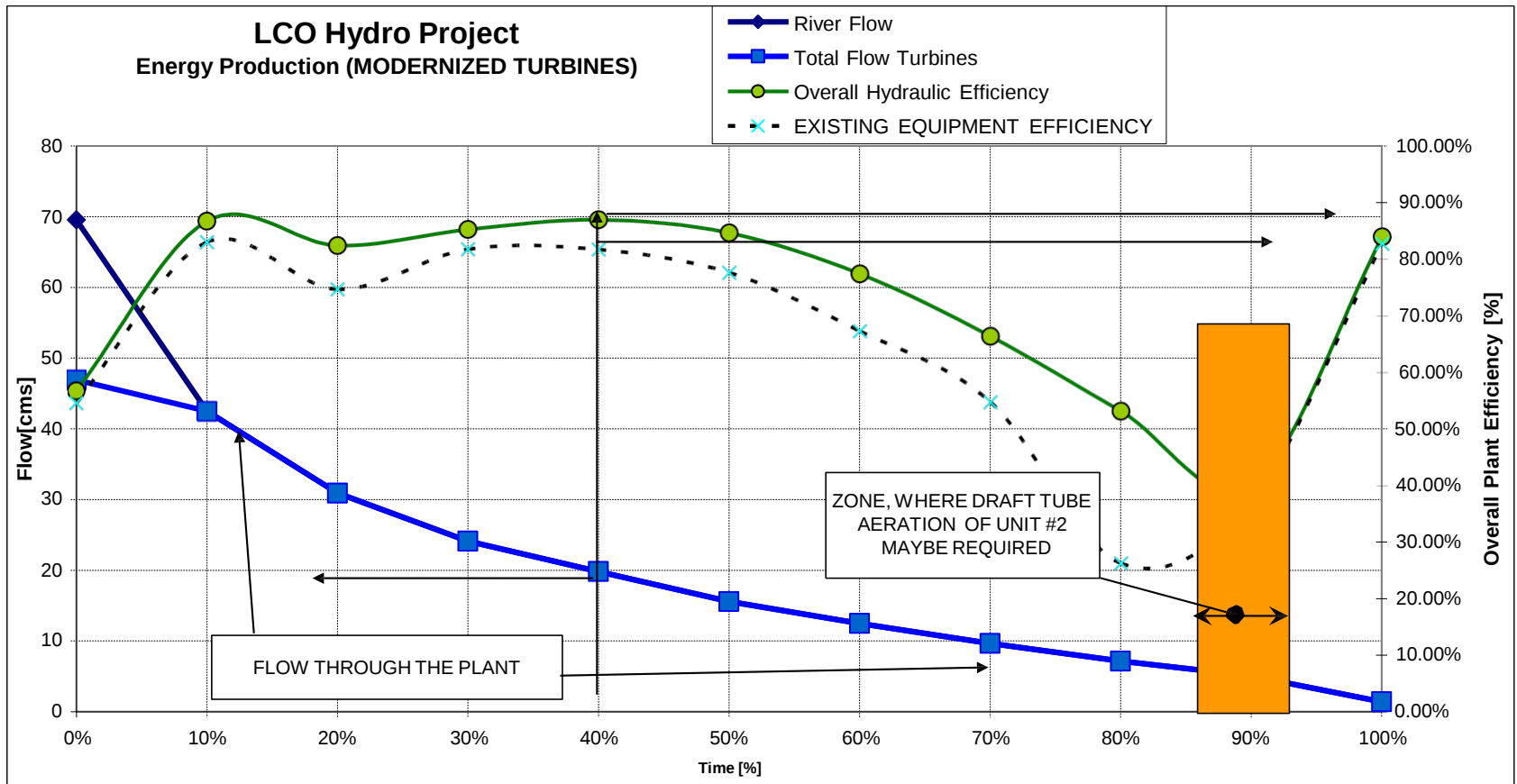
MAX EFFICIENCY:
~91%

MAX POWER:
~1750 kW

EFFICIENCY @
MAX POWER:
~88%

LCO TURBINE ANALYSIS

Proposal #1: Upgrade All Three Units



Properly Sized Units Result in Higher Hydraulic Efficiency
Amount of Spilled Water is Significantly Decreased

LCO TURBINE ANALYSIS

Proposal #1: Upgrade All Three Units

	Production contribution	Energy produced [kWh]	Time online
Unit 1	4.9%	580,156	
Unit 2	70.8%	8,399,175	
Unit 3	24.3%	2,878,836	
Total =	100.0%	11,858,166	

SUMMARY OF PROPOSAL #1 BENEFITS:

1. Increase in Annual Energy Production by Approximately 8.7% (951,423 kWh)
2. Unit #1 Will Have Increased Operating Range (Up to 100-150 cfs)
3. Units #2 & #3 Will Have Extended Operating Range (Down to 250 cfs)
4. Larger Operating Range Allows for High Overall Hydraulic Efficiencies

LCO TURBINE ANALYSIS

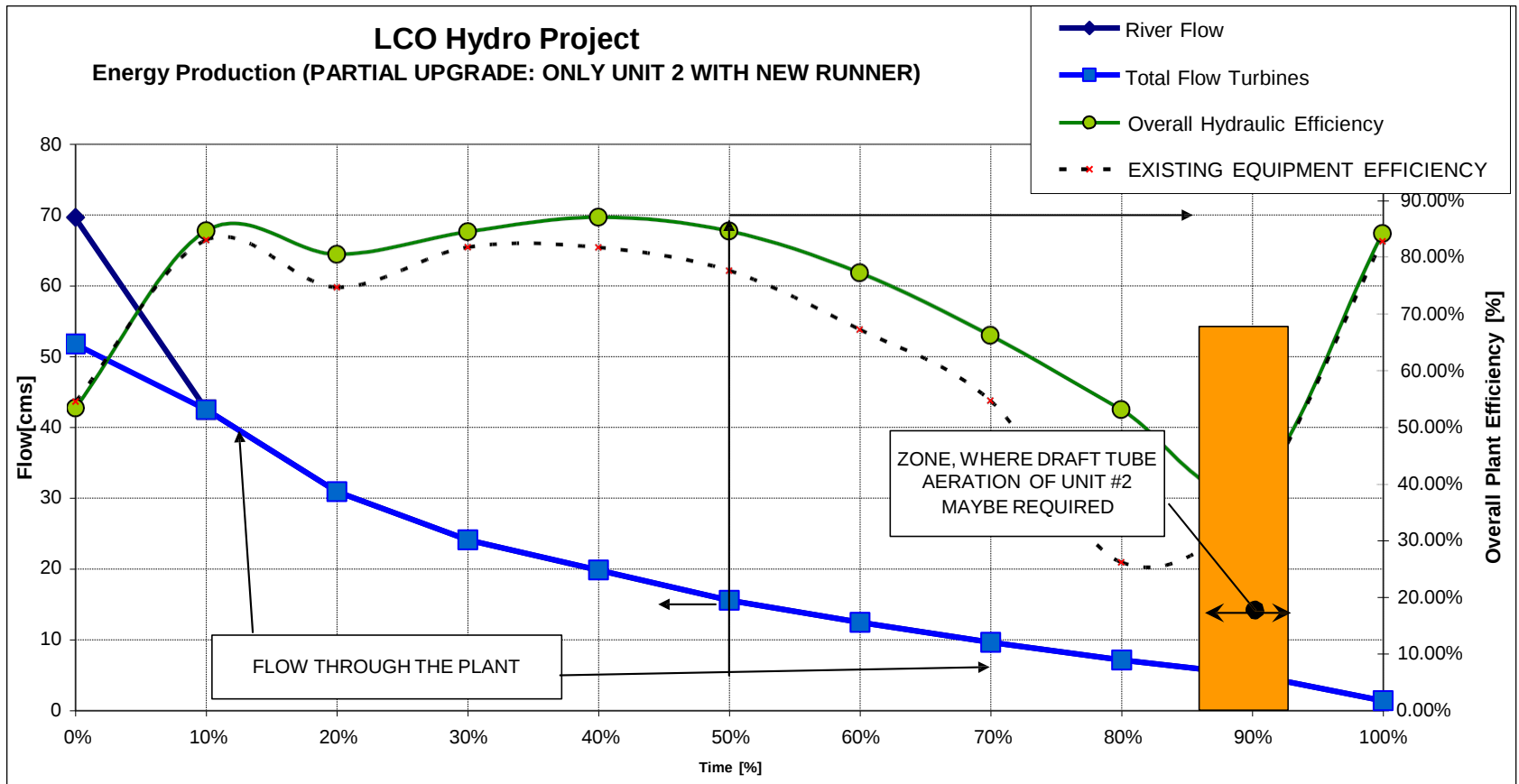
Proposal #2: Upgrade Unit #2 Only

PROPOSAL #2 UPGRADE UNITS #2 OR #3 ONLY

1. Design & fabricate a new turbines for either Unit #2 or #3
3. Runner would be designed to operate at 250 -650 cfs.
4. Optimal operating flows would range from 450-550 cfs.
4. Expected increase in Annual Energy Production of Approximately 7.3%
5. Draft tube may require aeration system to allow stable operation at low flows

LCO TURBINE ANALYSIS

Proposal #2: Upgrade Unit #2 Only



One Properly Sized Unit Results in Higher Hydraulic Efficiency
Amount of Spilled Water is Significantly Decreased

LCO TURBINE ANALYSIS

Proposal #2: Upgrade Unit #2 Only

	Production contribution	Energy produced [kWh]
Unit 1	3.2%	369,410
Unit 2	73.6%	8,616,462
Unit 3	23.2%	2,718,384
Total =	100.0%	11,704,257

SUMMARY OF PROPOSAL #2 BENEFITS:

1. Increase in Annual Energy Production by Approximately 7.3% (797,513 kWh)
2. Units #2 & #3 Will Have Extended Operating Range (Down to 250 cfs)
3. Larger Operating Range for One Large Unit Results in Higher Overall Hydraulic Efficiencies

LCO TURBINE ANALYSIS

Recommendation & Estimate of Upgrade

KISER HYDRO RECOMMENDATION

1. Proposal #2 Upgrade Runner of Unit #2
2. Economically Feasible to Upgrade One Unit While Increasing AEP of 7.3%
3. Upgrade to Include:
 - Removal of Existing Runner
 - Design & Fabrication of New Runner
 - Installation of New Runner into Existing Gate Casing

ESTIMATE OF UPGRADE COSTS

Design & Fabrication	\$450,000
Removal & Installation	\$250,000
	\$700,000

Lessons Learned

The Lac Courte Oreilles Tribe has learned a few very important lessons from owning and operating the hydro-dam and the information provided in this technical study.

1. We need to maintain our infrastructure to reduce repair cost and maintain daily electrical production quotas.
2. Our employees need to continue to receive training in order to identify issues, problems and know their personal limitations.
3. Third party inspections by engineering companies should be conducted on a frequent Scheduled basis.
4. Contracting a management company provides extended networking capabilities, technical support, training and optimum operational conditions.

Conclusion

While the tribe has owned and operated the Hydro-dam for over 20 years we are still learning the processes with this highly technical, mechanical and environmentally sensitive infrastructure. The Lac Courte Oreilles Tribal Governing Board has signed a multi-year agreement with Renewable World Energies to begin as a contract management company. Renewable world energies will provide ongoing training, inspection and oversight to ensure the productivity and profitability of the tribal investment. They will continually monitor for chances to start negotiations between transmission companies and negotiate power purchase agreements as often as the situation presents itself.

The tribe has started to see improved energy production since the contract started which reduces the loan principal and increases tribal revenue. Continued upgrades and improved maintenance will continue to benefit the Hydro dam. With returns increasing, the option to move on the various recommendations from Kiser Hydro, LLC seem worth the tribes' financial investment. A great investment into our infrastructure and our future alternative electrical production.