Wolf Creek Hydropower Rehabilitation Analysis Report

David Bishop
Kris Atanassov

Team Cumberland, September 16, 2015

US Army Corps of Engineers
BUILDING STRONG®

Agenda

- Overview
- Water Availability
- Energy Modeling
- Preliminary Alternatives
- Equipment Uprate Potential & Scope of Work

Wolf Creek Power Plant

Location:

Russell County, KY

River Mile 460.9

Generation:

6 Units @ 45 MW

270 MW

Commissioned: 1952

AE Contract

Award: May 13, 2015

Contractor: MWH Global

Configurations – Minimum of three studied

a. Replace in-kind.

b. Uprated Turbines & Generators

c. Different sized units (Low Flow/High Flow)

Goal - Determine the Preferred Rehabilitation Option

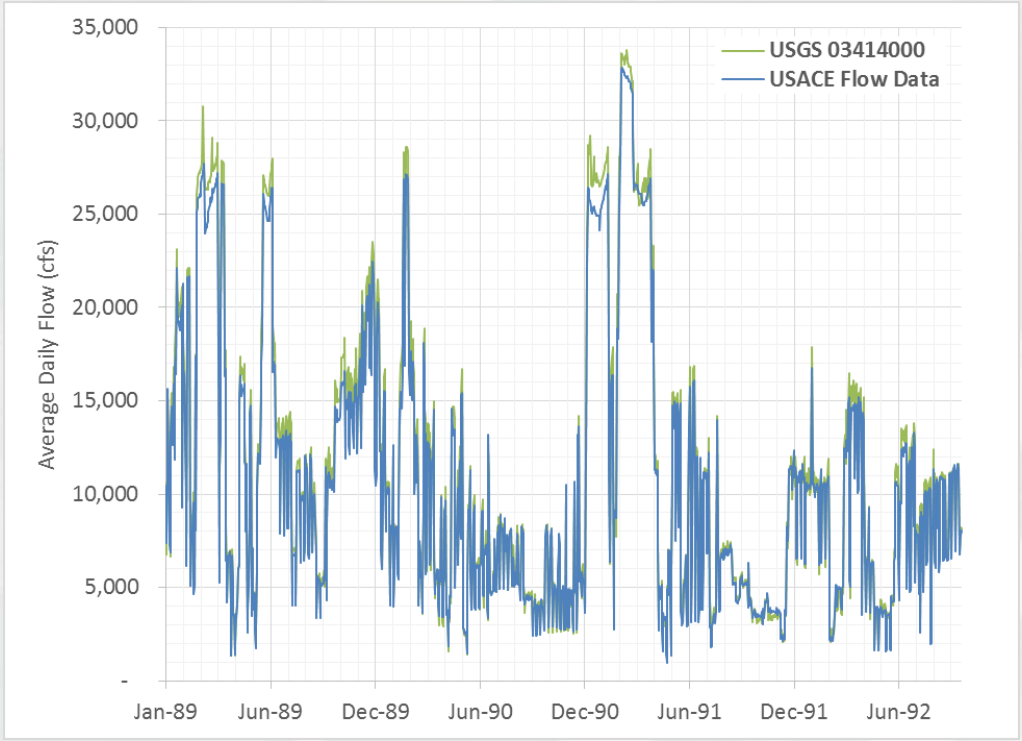
Milestones

▪ Site Visit	June 2015
▪ Provide Water Data	June 2015
▪ Methodology Report	July 2015
▪ Scoping of Alternatives	September 2015
▪ Draft Report	January 2016
▪ Comment Resolution	March 2016
▪ Final Draft Report (to Customers)	April 2016
▪ Stakeholder Workshop	May 2016

Flow Data

Available Data:

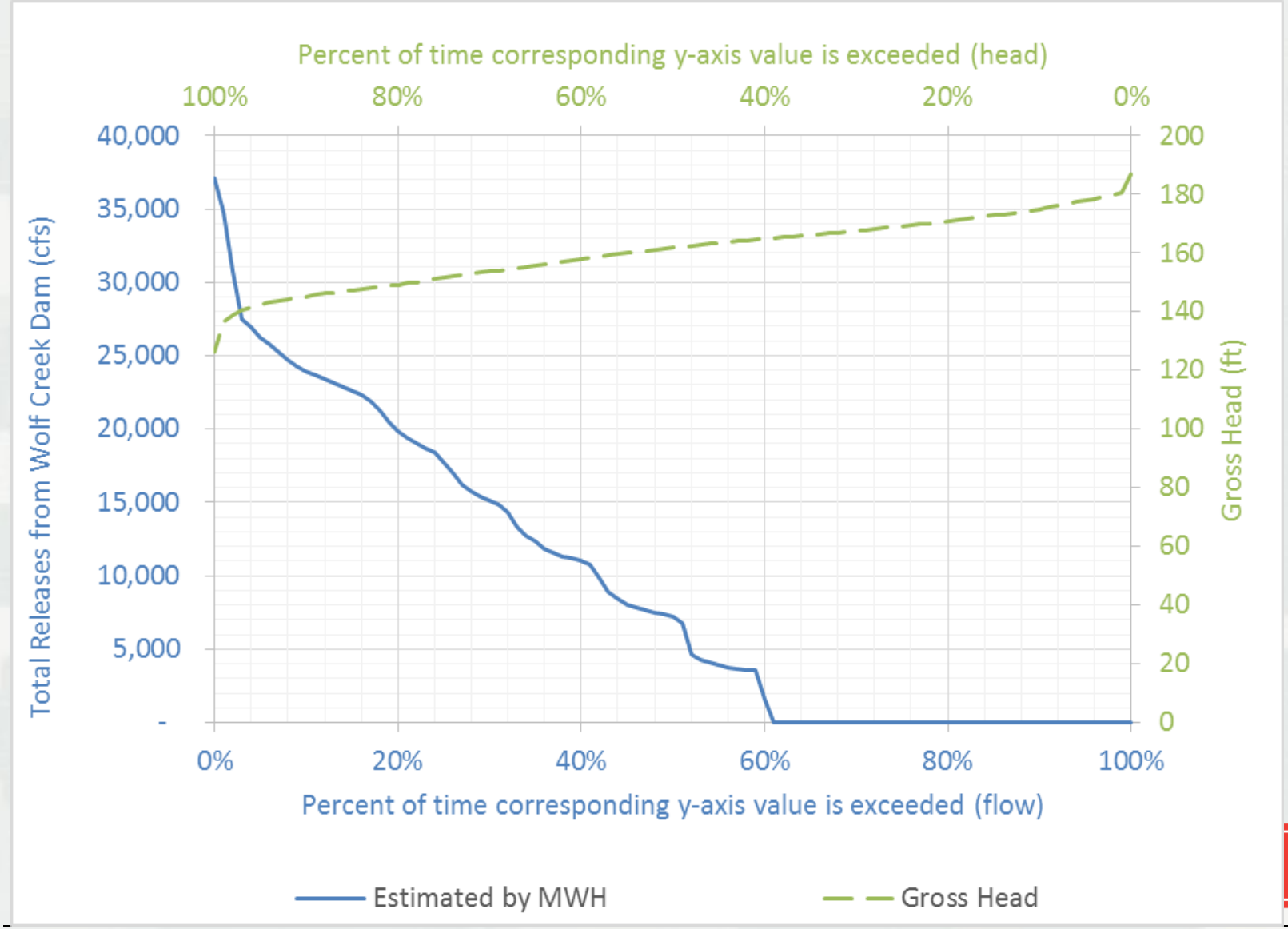
- USACE flow estimates, based on like-new equipment lookup table for powerplant releases.
- USGS daily flow record for Rowena station (partial).



Basis for Flow Dataset:

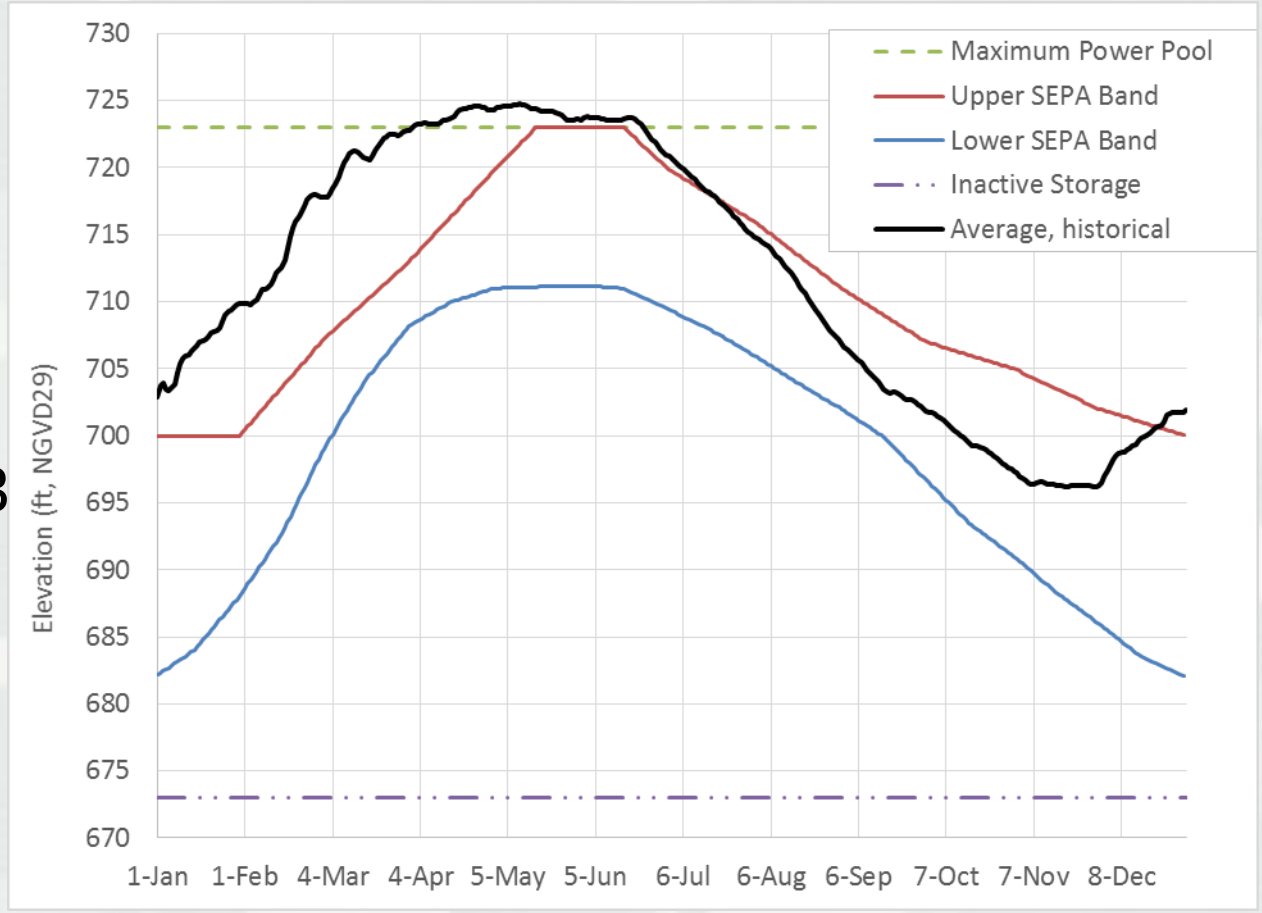
- Revised estimate of efficiency, reflecting 1987 condition, analyzing overlapping data, and applying an annual degradation of 0.03333% (beginning 1988).
- Flow estimates through the sluice gates and spillway was left as-is and assumed to be correct.

Flow and Gross Head Duration Curves



SEPA Band

- Average historical reservoir level (1989 – 2006) vs. SEPA band
- 723 ft and 623 ft are the upper and lower power pool elevations, respectively



Energy Model

- Hourly (peaking)
- Data:
  - Adjusted **outflow**, 1989 – 2006
    - Outflow rather than inflow to reduce the number of variables / potential sources of error (multipurpose reservoir; SEPA band not strictly followed)
  - Hourly **water levels** from USACE
  - **Equipment efficiency** estimates and **operating limits**
- Validation:
  - By hour: overestimates by 0.6%, avg. (median, 0.1%).
  - By month (assuming constant MW w/in ea. hr): 0.0%, avg.
- Analyses:
  - Each rehab scenario
  - Sensitivity cases … changes to:
    - Min. release requirements
    - Max. allowable releases under normal op. conditions
    - M&I withdrawals

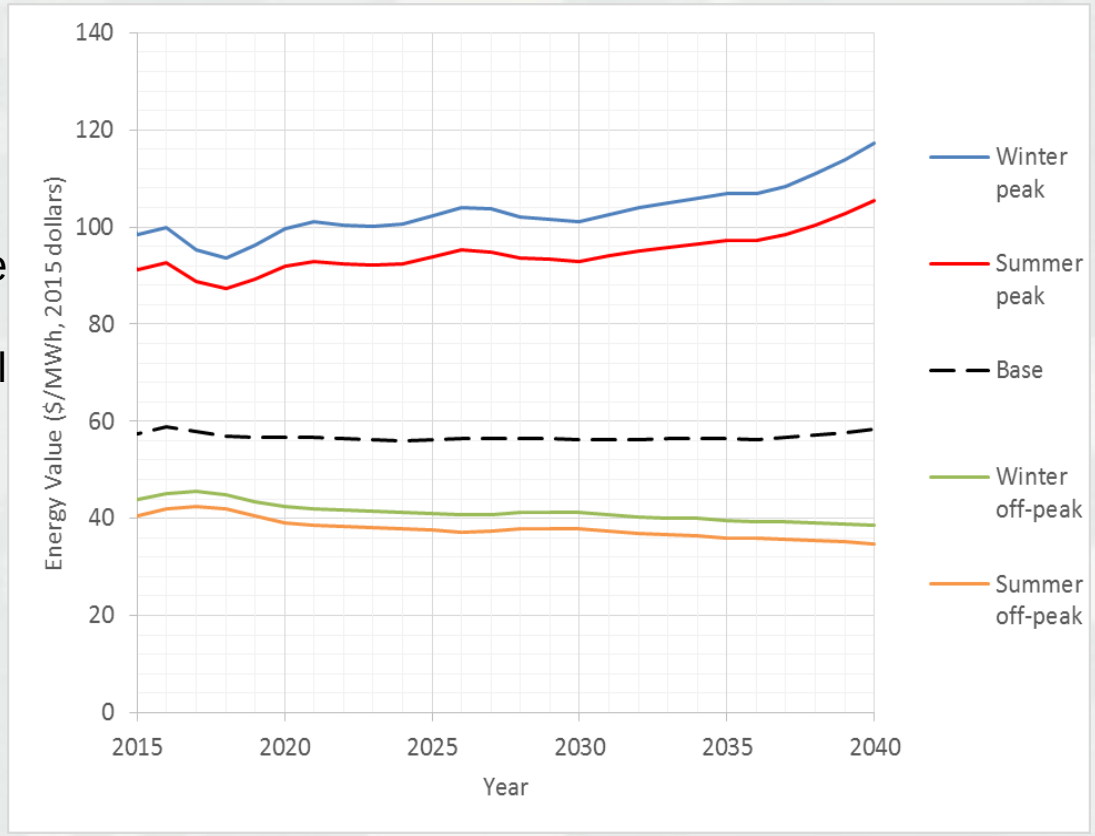
Energy Value Projections

Sources:

- 2015 Energy Information Administration's (EIA) Annual Energy Outlook (AEO)
- Projections for generation price through 2040 for SERC Reliability Corporation / Central (SRCE) region

Assumptions:

- Value ~ 80% of AEO's "generation price" to reflect wholesale prices
- Peak to off-peak ratio was based on the ratio of gas to coal fuel costs (2015 – 2040 projections from AEO)
- Winter (Nov. – Apr.)
  - ► Peak: weekdays, 4 AM to 10 AM, central
  - ► Off-peak: all other times
- Summer (May – Oct.)
  - ► Peak: 12 (noon) to 8 PM, central
  - ► Off-peak: all other times

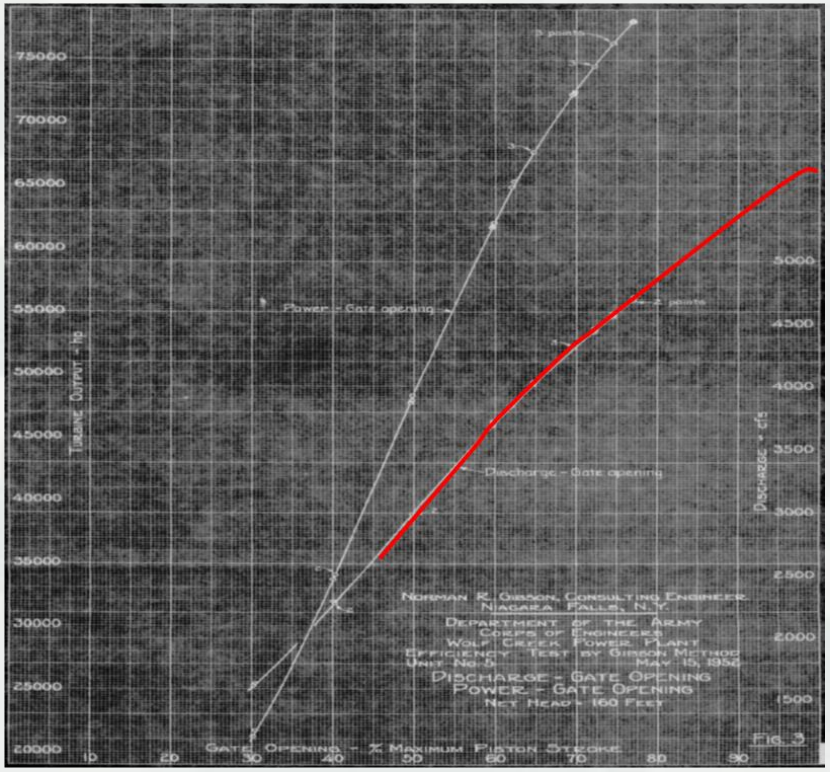


Preliminary Alternatives

- Base/Alternative 1:
  - ►6 units, 57.5 MVA (51.75 MW @ 0.9 pf)
- Alternative 2:
  - ► 5 units, 75 MVA (67.5 MW @ 0.9 pf) and
  - ►1 unit, 26.7 MVA (24.4 MW @ 0.9 pf)
- Alternative 3:
  - ► 6 units, 75 MVA (67.5 MW @ 0.9 pf)

75 MVA Uprate Selection Criteria

1) Flow Limitations (max 5,600 cfs at 95% wicket gate opening at nominal net head)



2) Net Head by Exceedance

Exceedance		Net Head, ft
2%	Max infrequent	179.7
10%	Max normal	174.6
50%	Nominal (Rated)	160.3
70%	Other	152.7
85%	Min normal	146.1
95%	Min infrequent	141.0

3) Flow by Exceedance

Exceedance	Flow, cfs
2%	30,751
10%	23,966
50%	7,239
61%	2200
>62%	20

4) Equipment Limits

Turbine Uprate Potential

Component	Max Uprate Potential @ 160 ft Hnet	Component	Max Uprate Potential @ 160 ft Hnet
Runner	60.4 MW	Bottom Ring	Over 68.8 MW [1]
Spiral case	Over 68.8 MW [1]	Servomotor	Over 68.8 MW [1]
Stay Ring	68.8 MW [1]	Turbine Shaft	68.8 MW
Facing Plates	Over 68.8 MV	Shaft Coupling	
Wicket Gates	60.4 MW	Shaft Seal	Over 68.8 MW [1]
Operating ring	Over 68.8 MW [1]	Wearing Rings	Over 68.8 MW [1]
Discharge Ring	Over 68.8 MW [1]	Turbine Guide bearing	Over 68.8 MW [1]
Draft Tube	Over 68.8 MW [1]	Generator Combined Bearing	Over 68.8 MW [1]
Head Cover	Over 68.8 MW [1]	Generator Upper Guide Bearing	Over 68.8 MW [1]

1) Subject to validation by the Contractor's hydraulic design
2) The uprate potential is power transfer at shaft

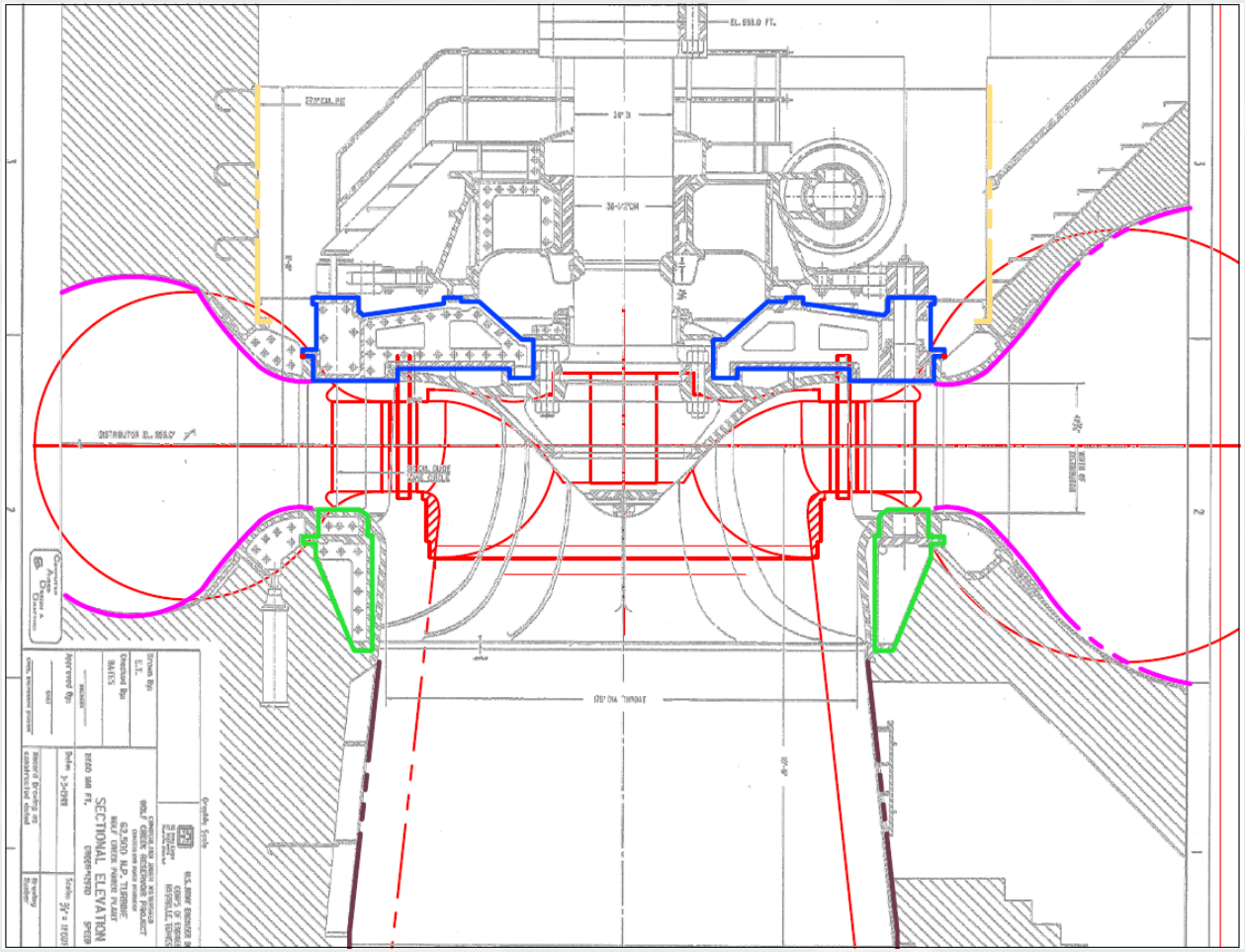
Turbine Scope of Work

Component	Alternative 1 6 x 57.5 MW	Alternative 2 5 x 68.8 MW	Alternative 2 1 x 24.4 MW	Alternative 3 6 x 68.8 MW
Runner	Replace	Replace	Replace	Replace
Spiral case	Reuse	Reuse	Replace	Reuse
Stay Ring	Reuse	Reuse	Replace	Reuse
Facing Plates	Reuse	Reuse	Replace	Reuse
Wicket Gates	Replace	Replace	Replace	Replace
Operating ring	Reuse	Reuse	Reuse	Reuse
Discharge Ring	Reuse	Reuse	Replace	Reuse
Draft Tube Cone	Reuse	Reuse	Replace	Reuse
Draft Tube Elbow	Reuse	Reuse	Reuse	Reuse
Head Cover	Reuse	Reuse	Replace	Reuse

Turbine/Governor Scope of Work

Component	Alternative 1 6 x 57.5 MW	Alternative 2 5 x 68.8 MW	Alternative 1 x 24.4 MW	Alternative 3 6 x 68.8 MW
Bottom Ring	Reuse	Reuse	Replace	Reuse
Servomotor	Reuse	Reuse	Reuse	Reuse
Turbine Shaft	Reuse	Reuse	Reuse	Reuse
Shaft Coupling	Reuse	Reuse	Reuse	Reuse
Shaft Seal	Reuse	Reuse	Reuse	Reuse
Wearing Rings	Replace with runner	Replace with runner	Replace with runner	Replace with runner
Turbine Guide bearing	Reuse	Reuse	Reuse	Reuse
Generator Combined Bearing	Reuse	Reuse	Reuse	Reuse
Generator Upper Guide Bearing	Reuse	Reuse	Reuse	Reuse
Governor	Replace	Replace	Replace	Replace

Turbine Alternative 2 Scope of Work – Low Flow Unit 24.4MW



--New Turbine

Generator Uprate Potential

Component	Max Uprate Potential	Component	Max Uprate Potential
Housing and Foundation	Over 75 MVA	Shaft	68.8 MVA
Stator Winding	57.5 MVA	Shaft Coupling	74.7 MVA
Stator Core	67MVA	Brakes and Jacks	Over 75 MVA
Stator Frame	Over 75MVA	High Pressure Oil Lift System	Not available
Field Winding	57.5 MVA	Cooling System	75 MVA
Damper Winding	70.5 MVA	Brush Rigging and Collector Ring	61 MVA
Pole Leads	Over 81 MVA	Upper Bracket	Over 75 MVA
Collector Rings	61 MVA	Lower Bracket	Over 75 MVA
Spider	87 MVA	Fire Protection System	Over 75MVA
Spider / shaft	74.5 MVA	PMG & Standstill	Over 75 MVA

Generator Scope of Work

Component	Alternative 1 57.5 MVA	Alternative 2 5 x 75 MVA	Alternative 2 1 x 26.7 MVA	Alternative 3 6 x 75 MVA
Housing and Foundation	Reuse	Reuse	Reuse	Reuse
Stator Winding	Replace	Replace	Replace	Replace
Stator Core	Reuse	Replace	Reuse	Replace
Stator Frame	Reuse	Replace	Reuse	Replace
Field Winding	Reinuslate	Reinsulate	Reinsulate	Reinsulate
Damper Winding	Reuse	Reuse 1)	Reuse	Reuse 1)
Pole Leads	Reuse	Reuse	Reuse	Reuse
Collector Rings	Reuse	Replace	Reuse	Replace
Spider	Reuse	Reuse	Reuse	Reuse
Spider / shaft	Reuse	Reuse	Reuse	Reuse
Shaft	Reuse	Reuse	Reuse	Reuse

1) Negative sequence relay needs to be reset

Generator Scope of Work

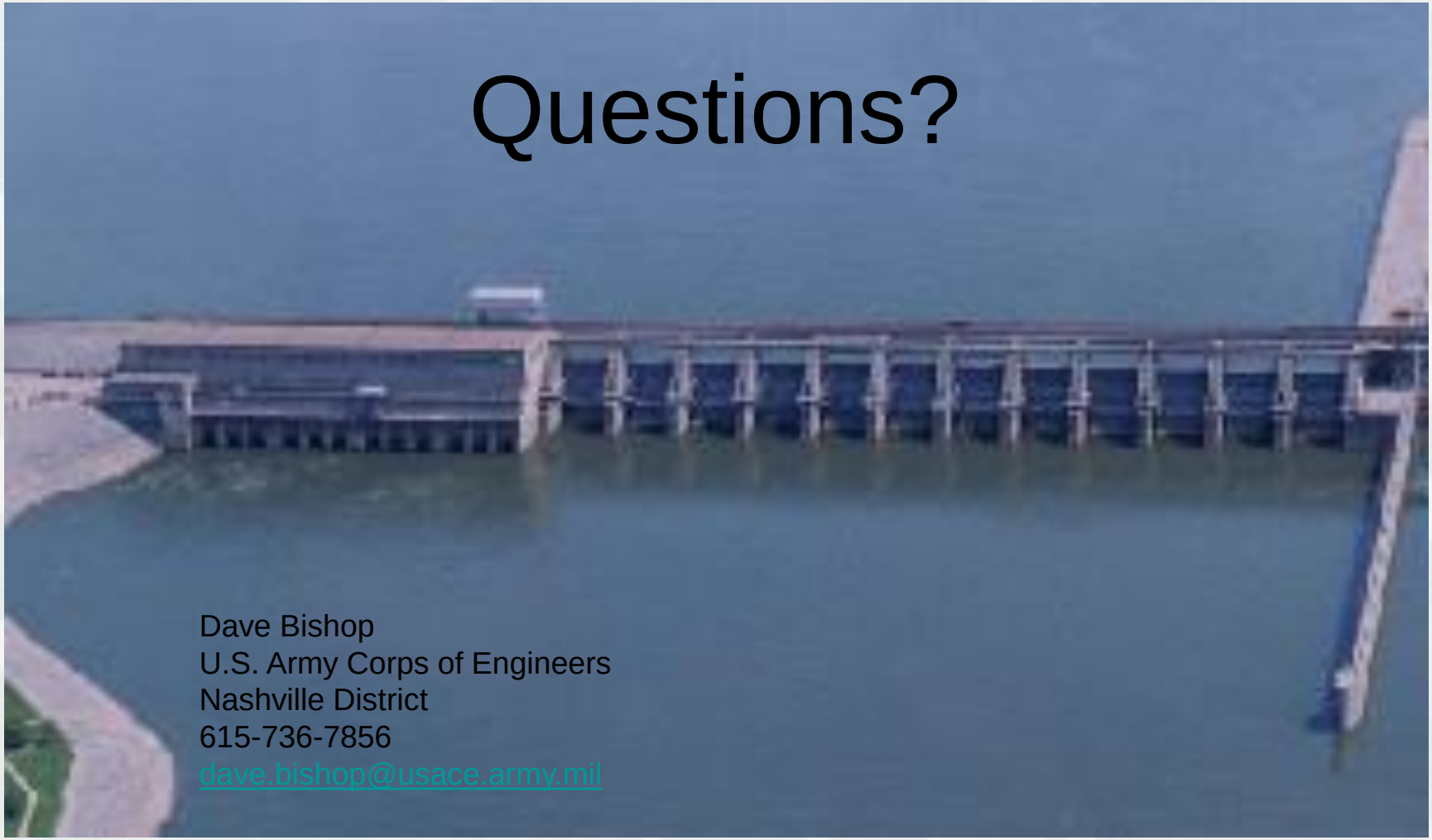
Component	Alternative 1 57.5 MVA	Alternative 2 5 x 75 MVA	Alternative 2 1 x 26.7 MVA	Alternative 3 6 x 75 MVA
Shaft	Reuse	Reuse	Reuse	Reuse
Shaft Coupling	Reuse	Reuse	Reuse	Reuse
Brakes and Jacks	Reuse	Reuse	Reuse	Reuse
High Pressure Oil Lift System	Not available	Not available	Not available	Not available
Cooling System	Reuse	Reuse	Reuse	Reuse
Brush Rigging and Collector Ring	Reuse	Replace	Reuse	Replace
Upper Bracket	Reuse	Reuse	Reuse	Reuse
Lower Bracket	Reuse	Reuse	Reuse	Reuse
Fire Protection System	Reuse	Reuse	Reuse	Reuse
Exciter	Replace	Replace	Replace	Replace

Powertrain Limits and Scope of Work

Component	Current Limit	Alt. 1 57.5 MVA	Alt. 2 5 x 75 MVA	Alt. 2 1 x 26.7 MVA	Alt. 3 6 x 75 MVA
Generator Bus	59.7 MVA	Reuse	Replace	Reuse	Replace
Generator Circuit Breaker	103.8MVA, 50kA interrupting	Reuse	Reuse[1]	Reuse	Reuse[1]
Power Cables	67.5 MVA @ 40°C	Reuse[2]	Replace	Reuse[2]	Replace
Generator Step-up Transformer	112.5 MVA (56.25 MVA)	Reuse	Replace	Replace	Replace
Switchyard Unit Breaker	Replace[3]	Replace[3]	Replace	Replace	Replace

1) Replacement may be required based on short-circuit study
2) Cable replacement may be required due to condition
3) 1200 OCB is undersized and reached the end of its useful life

Questions?



Dave Bishop
U.S. Army Corps of Engineers
Nashville District
615-736-7856
dave.bishop@usace.army.mil

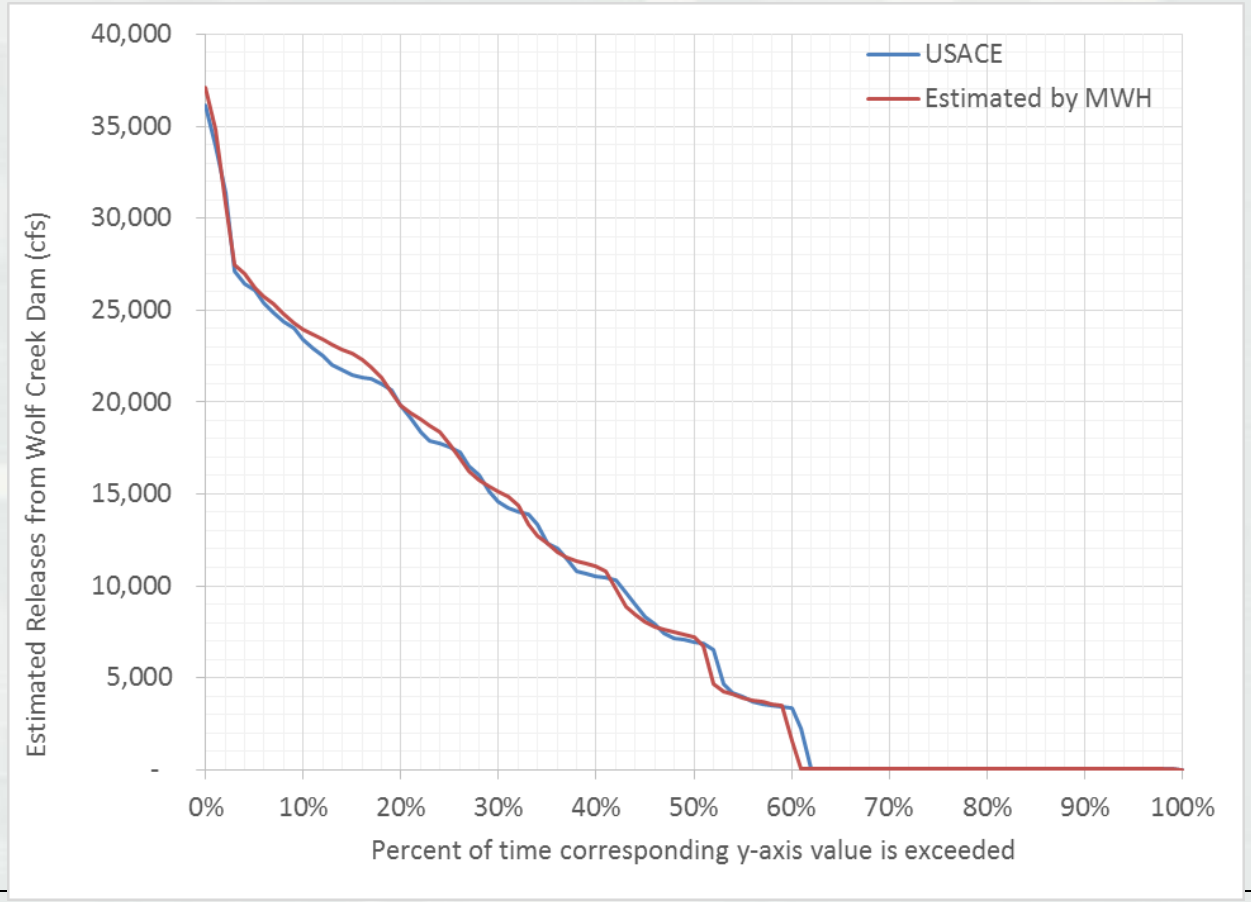
USACE Water Data

Data	Units	Type	Timestep	Start Date	End Date
Energy (Observed)	MWh	per-average	hourly	1-Jan-89	28-May-15
Energy-Net (Obs.)	MWh	per-average	hourly	30-Nov-94	28-May-15
Flow-Gate (Obs.)	cfs	per-average	hourly	1-Jan-89	28-May-15
Flow-ResOut (Obs.)	cfs	per-average	hourly	1-Jan-89	28-May-15
Flow-Turbine (Obs.)	cfs	per-average	hourly	1-Jan-89	28-May-15
Headwater Level (Obs.)	ft	instantaneous value	hourly	1-Jan-89	28-May-15
Tailwater Level (Obs.)	ft	instantaneous value	hourly	1-Jan-89	28-May-15
Energy (Obs.)	MWh	per-cumulative	daily	1-Jan-98	14-May-12
Flow-Gate (Obs.)	cfs	per-average	daily	8-Aug-50	15-Jan-15
Flow-ResOut (Obs.)	cfs	per-average	daily	8-Aug-50	15-Jan-15
Flow-Turbine (Obs.)	cfs	per-average	daily	8-Aug-50	15-Jan-15
Inflow (Obs.)	cfs	per-average	daily	1-Sep-50	7-Jan-14
Headwater Level (Obs.)	ft	instantaneous value	daily	7-Aug-50	31-Dec-14
Tailwater Level (Obs.)	ft	per-average	daily	2-Jan-89	31-Dec-05

- Hourly model (peaking operation)
- Yellow rows = data used in the model
- 2007 through 2013 were excluded due to water level restrictions

Flow Data

- On average, adjusted hourly flow estimates as 2% higher than original data from USACE



Energy Value Projections

Year	Generation $/MWh	Peak : off-peak	Summer peak $/MWh	Summer off-peak $/MWh	Winter peak $/MWh	Winter off-peak $/MWh
2015	57.48	2.25	91.30	40.57	98.54	43.79
2016	58.83	2.21	92.67	41.92	99.85	45.16
2017	57.99	2.09	88.92	42.52	95.27	45.56
2018	57.06	2.08	87.36	41.91	93.57	44.89
2019	56.70	2.21	89.28	40.41	96.19	43.54
2020	56.71	2.35	91.99	39.07	99.75	42.37
2021	56.67	2.41	92.95	38.54	101.03	41.89
2022	56.38	2.41	92.47	38.34	100.51	41.68
2023	56.11	2.42	92.14	38.10	100.19	41.42
2024	56.03	2.45	92.50	37.79	100.70	41.14
2025	56.30	2.50	93.85	37.52	102.39	40.93
2026	56.53	2.56	95.21	37.18	104.12	40.66
2027	56.51	2.54	94.88	37.32	103.68	40.79
2028	56.50	2.47	93.64	37.93	102.02	41.32
2029	56.38	2.46	93.31	37.91	101.63	41.29
2030	56.21	2.46	92.95	37.84	101.21	41.21
2031	56.31	2.51	94.06	37.43	102.66	40.85
2032	56.25	2.57	94.98	36.89	103.92	40.36
2033	56.37	2.62	95.84	36.63	105.04	40.15
2034	56.46	2.65	96.58	36.40	105.99	39.95
2035	56.44	2.70	97.22	36.05	106.88	39.62
2036	56.27	2.71	97.16	35.83	106.86	39.41
2037	56.63	2.75	98.40	35.75	108.39	39.38
2038	57.08	2.83	100.38	35.43	110.89	39.14
2039	57.67	2.93	102.79	35.12	113.93	38.92
2040	58.28	3.04	105.44	34.70	117.30	38.60

Turbine Performance Estimates