BC hydro

Integrated Resource Plan

Appendix 3A-31

2013 Resource Options Report Update

Mica Pumped Storage Report

HATCH™

BC Hydro

Pumped Storage at Mica Generating Station

Preliminary Cost Estimate

H336793, Rev. 0
December 2010

HATCH™

BC Hydro
Pumped Storage at Mica Generating Station

Preliminary Cost Estimate

Prepared by: Peter Rodrigue, P.Eng. — 1 December 2010 (Date)

Prepared by: Randolph Koob, P.Eng. — 1 December 2010 (Date)

Reviewed by: David Daw, P.Eng — 1 December 2010 (Date)

Distribution List

Sanjaya De Zoysa, BC Hydro
Nadja Holowaty, BC Hydro.

Disclaimer

This report has been prepared by Hatch Ltd. ("Hatch") for the sole and exclusive use of BC Hydro (the "Client") for the purpose of assisting the management of the Client in making decisions with respect to the potential development of pumped storage capability at Mica Generating Station; and shall not be (a) used for any other purpose, or (b) provided to, relied upon or used by any third party.

This report contains opinions, conclusions and recommendations made by Hatch, using its professional judgment and reasonable care. The estimate has been prepared by Hatch, using its professional judgment and exercising due care consistent with the agreed level of accuracy. Use of or reliance upon this report and estimate by Client is subject to the following conditions:

(a) the report and estimate being read in the context of and subject to the terms of the Purchase Order between Hatch and the Client dated September 22, 2010 (the "Agreement"), including any methodologies, procedures, techniques, assumptions and other relevant terms or conditions that were specified or agreed therein;

(b) the report, including the estimate contained herein, being read as a whole, with sections or parts hereof read or relied upon in context;

(c) the conditions of the site may change over time due to natural forces or human intervention, and Hatch takes no responsibility for the impact that such changes may have on the accuracy or validity or the observations, conclusions and recommendations set out in this report;

(d) the estimate is based on several factors over which Hatch has no control including without limitation, site conditions, cost and availability of inputs etc, and Hatch takes no responsibility for the impact that changes to these factors may have on the accuracy or validity of this estimate; and

(e) the report and estimate are based on information made available to Hatch by the Client or by certain third parties; and unless stated otherwise in the Agreement, Hatch has not verified the accuracy, completeness or validity of such information, makes no representation regarding its accuracy and hereby disclaims any liability in connection therewith.

Table of Contents

Appendices

List of Tables

List of Figures

Executive Summary

A preliminary study and cost estimate for addition of pumped storage at Mica Dam has been undertaken by Hatch for BC Hydro. This follows an earlier study conducted in 2008 by Hatch for BC Hydro that reviewed pumped storage potential at Mica.

Initial thinking was that the pumped storage facility would operate on a seasonal basis to store energy in the Mica reservoir in May and June when generation from Mica Generating Station and the downstream Revelstoke Generating Stations is not required. However, system modelling would be required to confirm the optimum operating pattern, and it is possible that daily or weekly pumped storage cycles would be beneficial.

The pumped storage equipment could be either pump units or reversible pump-turbines. The reversible pump-turbine units would provide additional peak generating capacity at the Mica facility.

Installing the new pumping units and pump-turbine units in an extension to the existing underground powerhouse and also on the left side of the dam in the spillway area has been considered. Because of technical difficulties relating to major construction adjacent to operating units, the left bank is the preferred location for the pumped storage facility.

The cost of a two-unit 500 MW pumped storage facility at the left bank was studied. The total capital cost is estimated as approximately $1230 per installed kW for a pumping station or approximately $1270 for a reversible pump turbine installation (single speed turbines). The construction period would be about 5.25 years. Annual operating and maintenance costs are estimated at approximately $9 per kW plus a variable cost of $0.90 per MWh generation.

1. Introduction

Mica Generating Station, located approximately 150 km north of Revelstoke, BC has a powerhouse at the earth fill dam's right abutment with four generating units, each with a nominal capacity of 435 MW at 170.7 m net head. Initial generation from the project was in 1976. The original powerhouse construction included two empty bays for future installation of Units 5 and 6, as well as the intakes, penstocks, horizontal draft tube sections, draft tube gates and connection to the tailrace tunnel for these additional units. Work is now underway on procurement of the two additional generating units for Bays 5 and 6, and construction activities are in the planning stage.

On the left side of the Mica dam (looking downstream), there is a gated spillway and the two original low level diversion rock tunnels used during construction. Tunnel #2, the left most tunnel, was plugged following construction whereas the upstream end of Tunnel #1 was diverted to a gated inlet structure and now operates as the site's primary outlet works.

As part of their assessment of resource options for the province, BC Hydro is reviewing the option of adding pumped storage to the Mica project. This follows an earlier study conducted in 2008 by Hatch for BC Hydro that reviewed pumped storage potential at Mica. The installation of reversible pump-turbines rather than conventional Francis turbines in one or both of Units 5 and 6 was briefly considered in the earlier study, but this option was later abandoned. However, there are other options for adding pumped storage at the plant. This current study has been produced by Hatch for BC Hydro to further assess the pumped storage options for Mica and estimate development costs. The specific objectives of the study were:

- To provide a summary of technical and construction issues and challenges associated with the installation of a pump unit or a reversible pump-turbine unit in the underground powerhouse in a new bay No. 7 excavated past the end of existing Bay 6;
- To review the conceptual design previously developed by Hatch in 2008 for installation of a pumping station on the left side of the dam near the spillway, and prepare a feasibility level cost estimate for the scheme; and
- To prepare a feasibility level cost estimate for the scheme described above, with a reversible pump-turbine (s), rather than a pump(s).

The application of pumped storage at Mica Dam is described in Section 2, and the hydraulic conditions are summarized in Section 3. Issues related to adding pumped storage on the right bank adjacent to Unit 6 in the existing powerhouse are discussed in Section 4. The left bank (spillway side) construction is explored in Section 5. The capital cost and schedule for construction of a pumping facility or a reversible pump-turbine facility on the left bank are presented in Sections 6 and 7 respectively. Operating and maintenance costs are described in Section 8; and performance parameters are given in Sections 9. Section 10 contains the conclusions of the study. Photographs showing portions of the dam, spillway and Outlet Works intake area are provided at the end of this report.

2. Pumped Storage Concept

The reservoir (Kinbasket Lake) impounded by Mica Dam has a live storage volume of 15 x 10^9 m^3 water between El 754.4 and El 701.1 m. The reservoir is drawn down annually. Each of the four units at Mica has a maximum discharge of approximately 283 m^3/s and the new Units 5 and 6 will have marginally higher discharge. The flow from Mica goes into Revelstoke Lake where it passes through the Revelstoke Generating Station.

The Mica reservoir is drawn down over the winter and early spring and is allowed to refill in late spring and early summer. In late spring, water is abundant throughout the province and power rates are quite low. For this reason, the Mica generating units are not operated in May and June, and there is typically no discharge from Mica into Revelstoke Lake during this time due to the ample storage in Mica reservoir. However, there is still flow into Revelstoke Lake from the watershed that covers the 150 km distance between Mica and Revelstoke, and because the lake has minimal storage, this water is used to generate relatively low value power at the Revelstoke plant.

If the May and June inflow into Revelstoke Lake were to be pumped into the Mica reservoir rather than being passed through the Revelstoke units, the water could be used by both the Mica and Revelstoke power plants later (in summer) when power values are much higher. Preliminary investigations by BC Hydro have indicated that pumped storage at Mica could be economically attractive.

The pumped storage operation discussed above would be on a seasonal basis rather than the more common (in North America) daily or weekly storage. There are plants with seasonal pumped storage in Europe. Nevertheless, pumped storage at Mica need not be limited to seasonal operation. System modelling would be required to determine optimum operation, which may show benefit for some daily or weekly cycling. Pumped storage could also be useful to effectively store power produced by existing and proposed run-of-river hydro plants and wind farms in the province as these facilities do not have storage and generate whenever resources are available.

As there is already significant generating capacity at Mica, the addition of pumped storage only requires the addition of pumping units. However, the installation of reversible pump-turbines would also provide added peak generating capacity during periods of high energy demand. Being a reversible unit, the turbine efficiency would be slightly lower than for conventional units. Nevertheless, the reversible unit would provide a capacity benefit.

3. Hydraulic Conditions for Mica Pumped Storage

The hydraulic conditions for the present Mica facility are as follows:

Reservoir level

- Maximum (flood) El. 757.4 m
- Maximum (normal) El. 754.4 m
- Average El. 745.2 m
- Minimum El. 707.1 m

Tailwater level

- Maximum El. 576.1 m
- Normal El. 570.6 m
- Minimum El. 567.5 m

Gross head

- Maximum 183.8 m
- Normal 174.6 m
- Minimum 136.5 m

Turbine net head

- Maximum 182.9 m
- Rated 170.7 m

Flow per generating unit

- Units 1 to 4 283 m^3/s
- Units 5 & 6 300 m^3/s (approximate).

During the May-June period when there would be significant pumping operations, the typical hydraulic conditions have been approximated as follows (note that these are mean values from BC Hydro's level monitoring data for the period 2003-2008):

Reservoir level

- Maximum El. 750.1 m
- Average El. 732.5 m
- Minimum El. 715.7 m

Tailwater level

- Maximum El. 574.1 m
- Normal El. 572.7 m
- Minimum El. 571.9 m

Gross head

- Maximum 177.0 m
- Normal 160.0 m
- Minimum 142.9 m

4. Pumped Storage - Extend Existing Powerhouse

4.1 General

While installation of a reversible-pump turbine in Bay 5 or Bay 6 at Mica is no longer an option due to current generation expansion plans, it would still be possible to install a pumping unit, or a reversible pump-turbine unit, in an extension to the Mica powerhouse in a new Bay 7.

The maximum capacity of the unit may be dictated by shipping considerations for the pump or pump-turbine impeller/runner. A single piece impeller/runner is a definite preference. While a two piece runner is possible, costs are higher and the hydraulic design is less efficient. Site welding on a runner is possible but would result in added complexity with construction and would also increase costs, particularly for a single unit installation. Two pumping units, or two pump-turbine units could be installed if higher capacities are required.

An impeller/runner of 6.6 m (the size of the Revelstoke Unit 6 runner) or possibly more could be shipped. Using the 6.6 m runner size as a limit to pump or pump-turbine size, the preliminary unit parameters for a single unit would be as follows:

	Pump	Pump-Turbine
Runner diameter	6660 mm	6660 mm
Speed	171.4 rpm	171.4 rpm
Runner/impeller centerline	El 541 m	El 541 m
Pump mode – Head – Discharge – Power	 165 m 166 m^3/s 295 MW	 165 m 166 m^3/s 295 MW
Turbine mode – Head – Discharge – Power		 170 m 205 m^3/s 308 MW.

On a preliminary basis, the pumping unit would have the same (pump) parameters as the reversible pump-turbine, since a pump-turbine is basically designed as "a pump that also operates as a turbine". Unlike a pump, a reversible pump-turbine has wicket gates, but when operating in the pump-mode, the gates are not used to control discharge. The gate position does vary somewhat with head, allowing slightly better efficiency at high and low heads. Otherwise, there is minimal difference in performance between a pump and a pump-turbine operating in the pump mode.

4.2 Pumping Unit Installation

Adding pumped storage to the Mica facility by installation of a pumping unit in a new excavation adjacent to Unit 6 has a number of attractive features including:

- By extending the present crane runway, the existing powerhouse cranes can be used for construction, installation, and ongoing maintenance activities;
- Electrical interconnection would be relatively straightforward when compared to the left-bank options. The pumping units will not operate when the Unit 6 generating unit is on line; therefore the pumping unit can utilize the Unit 6 main generator step-up transformer. The 500 kV bus and switchgear would remain unchanged;
- Electrical services can be shared with existing powerhouse electrical services;
- Pump starting using either Unit 5 or Unit 6 in a "back-to-back" starting configuration, with interconnection at generator voltage levels, should be possible;
- Mechanical services can be shared with existing powerhouse mechanical services;
- The pump discharge conduit could be connected via a Y-branch to the Unit 6 penstock; therefore only a short length of high pressure conduit would be required; and
- The pump intake may utilize the No. 2 tailrace tunnel as the intake conduit, although the existing tailrace channel may have to be excavated deeper to allow pumping operation at the lower tailwater levels.

Nevertheless, the scheme has a number of disadvantages such as:

- A significant amount of new excavation in close proximity to existing operating units would be required. Excavation quantity could be about 50,000 m^3. Removal of this amount or rock by mechanical means is likely impractical, and careful, controlled blasting would be necessary for much of the rock. Removal of the rock by transport over the operating units would be an issue, and while not impractical, has a number of obvious concerns. Overall, excavation costs would be very high. This is the major drawback with this scheme;
- New excavation in the draft tube hoist chamber and manifold area would also be required for the pump suction side bulkhead gates. The existing draft tube stoplog storage area would have to be relocated;
- Concrete and new equipment for the pumping unit would have to be transported over the existing operating units. This is possible using techniques planned for the Unit 5 and 6 installation, nevertheless this does represent a project risk; and
- To avoid excessive velocity (and head loss) in the suction conduit (No 2 tailrace tunnel) pumping operations would have to be curtailed if the tailwater level drops to approximately El 571. The base of the tailrace tunnel could be excavated to allow pumping operation with lower tailwater levels but, in addition to the added cost, there would be the outage of Units 4, 5 and 6 that must be considered. A new tailrace could be constructed, again at added cost. A benefit of the new tailrace is that it could be used for rock removal during the powerhouse excavation, and possibly for the movement of construction materials and equipment into the excavation thereby limiting the movement of equipment over the existing generators to mechanical and electrical components.

4.3 Reversible Pump-Turbine Installation

Installation of a reversible pump-turbine unit rather than a pump adjacent to Unit 6 would increase the peak generating capacity of the Mica facility. However, there are added difficulties with the concept when compared to the pumping unit option. These issues are related primarily to the fact that the added unit must be able to operate in the generating mode in parallel with the other six units at the plant, including:

- If the pump-turbine is interconnected to the Unit 6 penstock, the penstock velocities will become very high (14 m^3/s in the concrete section and 18 m^3/s in the steel section - perhaps beyond precedent for a power conduit), increasing the head losses and creating waterhammer issues. The waterhammer could perhaps be mitigated with longer turbine wicket gate times, but overspeed on load rejection will increase;
- A new penstock and intake could theoretically be installed next to the Unit 6 penstock with an intake constructed behind a rock plug type cofferdam. However, the topography of the site would make the new intake very costly, if not impractical, and require underwater excavation near the existing intakes;
- As the pump-turbine unit will have to operate in generating mode in parallel with Unit 6, it can not share the Unit 6 transformer. A new transformer would be required and the transformer gallery lengthened to accommodate the new equipment. It is presumed that the 500 kV SF_6 bus would have ample capacity for the added current levels with one more unit. Nevertheless, additional high voltage breakers would be required in the transformer gallery; and
- The existing tailrace tunnels are designed as free flow tunnels. With the added discharge of the additional unit, plus a small increase in maximum discharge for Units 5 and 6, which have a higher rating than the original Units 1 to 4, the tailrace tunnel hydraulic design would have to be studied, and may be marginal in size. The tunnel could be enlarged, or a second tunnel added as discussed in Section 4.2 above.

5. Pumped Storage on the Left Bank (Spillway Area)

5.1 Unit Size

Addition of a pumping unit or a reversible pump-turbine unit on the left side of the dam (looking downstream) allows considerable flexibility on number and size of units. Shipping limitations may influence the maximum possible unit size, but added capacity can be provided by multiple units. The most economic pumping capacity will depend on available water during the May to June time frame, and would be an economic trade-off of capital cost versus amount of energy stored.

For this preliminary study, a two unit facility with a nominal capacity of 500 MW has been selected, as agreed with BC Hydro. A single unit development would be limited to approximately 300 MW as discussed for the right side scheme in Section 4. Two units provides added capacity and the flexibility/reliability of a two unit installation. Clearly, further study would be required on number and size of units if the pumped storage scheme is potentially attractive.

The preliminary parameters for each of the two units are as follows:

	Pump	Pump-Turbine
Runner diameter	6105 mm	6105 mm
Speed	189.4 rpm	189.4 rpm
Runner/impeller centerline	El. 539.5 m	El. 539.5 m
Pump mode		
– Head	165 m	165 m
– Discharge	154 m^3/s	154 m^3/s
– Power	274 MW	274 MW
Turbine mode		
– Head		156 m
– Discharge		185 m^3/s
– Power		250 MW

5.2 Facility Arrangement

Various configurations for the pumping station and pump-turbine powerhouse were considered including:

- A silo (shaft) type pumping station/powerhouse located in the spillway area;
- An underground powerhouse in the spillway area;
- An underground powerhouse located much further upstream along the diversion tunnel;
- A high pressure conduit that connects to the existing outlet works tunnel near the downstream end;

- A high pressure conduit that connects to the existing outlet works tunnel near the upstream end of the lower tunnel; and
- A new high pressure tunnel and intake that is separate from the existing outlet works.

The required deep submergence for the pump or pump-turbine will favour a shaft type pumping station/powerhouse or an underground pumping station/powerhouse. A shaft type pumping station was considered in the Hatch Mica 2008 study; this concept avoids the requirement for a long (700 m) access tunnel into the underground facility. However, a further assessment assuming a two-unit development indicated that the excavation volume for a shaft type powerhouse would be more than for an underground plant combined with an access tunnel. In addition, a shaft type powerhouse has added crane and elevator costs. An underground powerhouse appeared to be more attractive for this scheme, although a shaft type scheme may still be preferred for a single unit facility.

These preliminary studies have indicated that the most economical configuration for the left bank development is to use the existing Outlet Works intake structure and sloping discharge tunnel as the high pressure conduit for the pumping station or pump-turbine units. The proposed preliminary layout of this facility is shown in **Figures 5.1 and 5.2**. This concept requires the addition of a very large isolating gate structure to allow pressurizing the outlet tunnel. It would also necessitate the addition of a steel liner to a significant portion of the tunnel to allow the tunnel to be pressurized to reservoir level. Nevertheless, it is estimated that the cost of constructing a new intake and the additional power tunnel would increase the cost of the left bank option by about 20%. This is because the construction of the intake would be in the reservoir between the Outlet Works intake and the spillway, and much of the work would have to be completed during the normal low reservoir cycle in March and April each year. Furthermore, much of the excavation would be underwater work. By using the existing Outlet Works intake, most work would be underground, except the switchyard, draft tube, and river excavation, so construction can proceed year round.

The two diversion tunnels and the adjacent access tunnel would be used as much as possible to eliminate large quantities of underground excavation.

Using the 30 foot diameter sloping Outlet Works tunnel would probably require a grouted steel liner over a portion of the tunnel since the tunnel was originally designed as a free flow tunnel rather than a pressure tunnel. The existing concrete lining would then probably not withstand the pressures, or the effects of rapid dewatering (due to significant external pressures) if the upstream gates were closed in an emergency. This adds significant cost, but the scheme is still estimated to be less expensive than excavating a new tunnel and Outlet Works intake structure.

As the Outlet Works (which includes the use of downstream portion of original Diversion Tunnel No. 1) will still be required after installation of the new pumps or pump-turbines, the concept has a lined and embedded 30 foot diameter conduit that runs a minimum distance in the existing 45 foot tunnel to a bifurcation to the new underground powerhouse and to the new gates discharge structure. For low level discharge, the pumps or pump-turbines would be stopped, the tunnel dewatered by closing the existing upstream gates, the downstream gates opened, and the existing upstream control gates used to regulate free discharge as required. After the discharge cycle is completed, the upstream gates would be closed, the downstream discharge gates closed, the penstocks filled, and the pumps or turbines started again. With a steel lined tunnel, the change from Outlet Works to pumped storage operation would take a few hours, whereas without lining the tunnels, the switchover to dewater the tunnel could take about four days at a normal 2 m/hour dewatering rate for unlined tunnels.

It is estimated to be less costly to excavate a new cross tunnel from the bifurcation in Diversion Tunnel No.1 though to Diversion Tunnel No.2 and then run a free standing steel penstock in the (unused) Diversion Tunnel No.2 to where the penstock branches off to the new underground powerhouse.

If the 30 foot penstock was extended along Diversion Tunnel No.1, the penstock would have to be embedded as velocities in the tunnel would be very high during Outlet Works discharge, with potential operational difficulties if the penstock was free standing. The alternative to re-line the existing 45 foot diameter tunnel to allow use as a pressurized tunnel, would also be very costly. By placing the new discharge structure further upstream in Diversion Tunnel No.1, the large Outlet Works discharges would be diffused before entering the river downstream of Mica Dam.

The underground powerhouse chosen at this location has about 80 m of overburden since the left bank downstream of Mica Dam is very steep, thus making use of a shaft type powerhouse more expensive even though a long access tunnel is needed to get to the powerhouse. The low voltage isolated bus shaft and access tunnel would be used as exhaust vents, with supply air being drawn in through an egress stairway tunnel that is also used as a control cable gallery to the new powerhouse from the existing Mica powerhouse. The low voltage bus shaft would be used as secondary ladder egress if there was a fire in the access tunnel and/or egress stairway.

The powerhouse concept is a typical configuration, with the two runs of medium voltage (15kV) isolated phase bus routed through a vertical shaft excavated to the surface switchyard where the transformers will be located. This eliminates the use of SF_6 high voltage bus (500 kV), reduces fire potential in the underground facility, but makes the switchyard larger. This arrangement is still considered less costly due to elimination of the SF_6 buses, and not requiring underground excavation for the transformer bay.

The conceptual powerhouse has the draft tube bulkhead gates adjacent to Diversion Tunnel No.2 discharge works with access to the gate structure via the upgraded construction road on the left bank. The switchyard would also be accessed by upgrading the existing road to the higher level on the left bank.

As the discharge structures on the left bank were designed for free discharge, the outlet structure for the new powerhouse tailrace needs to be excavated about 5 m deeper, and the raised rock structure has to be excavated about 11 m deeper to get adequate depth to get the water back to the powerhouse for pumping. These depths are estimated assuming the river is maintained near the Revelstoke maximum forebay elevation, or else these areas, and a portion of the river downstream of the dam would have to be dredged. Note that if the river level drops to the minimum tailwater level at Mica, which is about 6 m below Revelstoke maximum FBE, the discharge works and river would have to excavated about 6 m deeper, requiring significant additional costs for this in-river excavation.

5.3 Electrical Interconnection

The proposed electrical connection for the above left bank 2-250 MW pump turbine is shown in **Figures 5.3** and **5.4**. The two 250 MW (277.77 MVA) generators will each be connected to a generator switchgear assembly with a run of 15kV isolated phase bus. The generator switchgear assembly will consist of a generator circuit breaker module and a switching module that will allow the phase reversal switching that is required to switch the unit between the pump and turbine modes. The switchgear assembly will also include the generator surge arrestor and capacitors as well as safety grounding switches.

Starting of the units in turbine mode will be by a static frequency converter (SFC). A single SFC will be provided for both units and be switchable between the units. The SFC will be connected to the generator switchgear with an isolated phase bus tap and associated disconnect switch on either side of the generator breaker. A station service feed will share the isolated phase bus tap with the SFC on the line side of the generator breaker on each of the generator switchgear assemblies. It is assumed that current limiting reactors will be used to reduce the rating requirements for the station service and SFC switchgear.

The generator switchgear will be connected to the 13.8-500kV generator step-up (GSU) transformers located in the surface substation via two runs of 15kV isolated phase bus installed in a vertical shaft connecting the underground powerhouse to the surface switchyard. Each GSU transformer will be connected to the 500kV overhead transmission line via a 500kV dead tank circuit breaker and associated 500kV disconnect switch. There will be a single 500kV transmission line interconnecting the new surface switchyard to the existing 500kV substation building on the right bank of the dam.

6. Capital Cost

The estimated capital cost of the pumping unit facility and reversible pump-turbine plant using the existing diversion tunnels and intakes are summarised in **Tables 6.1** and **6.2**. The base estimates are based on single speed pumping units and single speed reversible pump-turbine units, but estimated totals have also been included to allow for facilities with variable speed motors and motor-generators. The estimated total capital costs in 2010 Canadian dollars are as follows:

	Pumping Station	Reversible Pump-Turbine Powerhouse
Single speed units	$ 615,000,000	$ 637,000,000
Variable speed units	$ 637,000,000	$ 669,000,000

The basis for the cost estimates are as follows:

- Equipment pricing from other studies and projects;
- Project Contingency of 25%;
- Engineering and administration equal to 10% of the total capital cost;
- High level quantity takeoffs for excavation and construction;
- Normalized industry pricing for excavation, penstocks and concrete; and
- BC Hydro management and overhead costs are excluded.

These estimates are at an early feasibility level and should be used considering a variance of -35%/+50%.

7. Operating and Maintenance Cost

Operating and maintenance costs for pumped storage plants in the United States was reviewed. As anticipated there is a significant variation in costs. Using average values, an estimated fixed cost of $9 per MW has been used. Variable costs per MWh of generation or pumping are quite low and are assumed to be approximately $0.90 per MWh generation energy for a pumped storage plant. Variable costs are assumed to be approximately $0.60 per MWh for pumping energy for a pumping plant. The higher variable costs for the pumped storage plant are because of the reciprocal pumping time that is required.

The resulting annual operating and maintenance costs for the Mica pumped storage facility are as follows:

	Pumping Station	Reversible Pump-Turbine Powerhouse
Fixed cost	$3,500,000	$3,300,000
Variable costs	$0.90 per MWh	$0.60 per MWh

8. Schedule

The preliminary schedule for the project is shown on **Figure 8.1**. The schedule would be approximately the same for the pumping station and the reversible pump-turbine facility. Total construction time is estimated to be 5.25 years, with critical path going through:

- Permitting;
- Engineering;
- Pumping/generating unit procurement, design; and
- Equipment installation and testing.

9. Performance Parameters

Performance curves form the pumping units and reversible pump-turbine units for the left bank 2-250 MW pump turbines are included in **Figures 9.1** to **9.12**. The performance curves are based on overall efficiency including head losses, pump and turbine efficiency, and motor and generator efficiency.

Waterway head losses (HL) are estimated to be as follows:

$$HL = k1 \times (Q_T)^2 + k2 \times (Q_U)^2$$

Where:

Q_T = total discharge from both operating units

Qu = discharge from one operating unit

k1 = constant

= 8.5×10^{-5} (pumping)

= 5.3×10^{-5} (generating)

k2 = constant

= 4.0×10^{-5} (pumping)

= 3.3×10^{-5} (generating)

Pump and turbine efficiency, flow and power values are estimated to be as follows:

a) Single Speed Units

Pumping

Total dynamic head (m)	145	165	180
Discharge (m^3/s)	181	152	127
Efficiency (%)	92.8	94.0	92.4
Power (MW)	277	261	242

Generating at Optimum Efficiency

Net head (m)	140	155	175
- Discharge (m^3/s)	158	163	173
- Efficiency (%)	92.8	93.5	94.0
- Power (MW)	201	232	279

a) Variable Speed Units

Pumping

Total dynamic head (m)	145	165	180
Discharge (m^3/s)	150	152	162
Efficiency (%)	93.9	94.0	94
Power (MW)	227	261	304

Generating with optimum efficiency

Net head	140	155	175
- Discharge (m^3/s)	163	162	162
- Efficiency (%)	93.6	94.0	94.0
- Power (MW)	209	231	261

Motor and motor-generator efficiency is estimated to be as follows:

- 250 MW 98.2%
- 200 MW 98.1%
- 150 MW 97.6%.

10. Conclusions

The provision of pumped storage at Mica Dam is technically feasible, and this can be accomplished with the addition of pumping units or reversible pump-turbines.

The pumping units or pumping/generating units could be installed on the right side of the dam (looking downstream) in an extension to the existing powerhouse or on the left side of the dam in the spillway area. An installation in an extension to the powerhouse is technically difficult primarily because of the requirement for large amounts of rock excavation adjacent to operating units. The concept is also particularly difficult for a reversible pump-turbine unit because it must operate in parallel with the adjacent Unit 6 generating unit, and therefore will require its own penstock and intake.

There are numerous options for construction of a facility on the left side of the dam in the spillway area. For a two-250 MW unit scheme, the option that appears to have promise incorporates:

- An underground pumping station or powerhouse near the spillway;
- 700 m access tunnel to the pumping station/powerhouse;
- Surface transformers and switchyard to an overhead 500 kV transmission line to the right bank; and
- A high pressure conduit that utilises the existing Outlet Works gate structure as an upper reservoir intake/outlet.

The use of the outlet facilities for the high pressure conduit has features that add to the cost. These include a substantial downstream gate structure to allow pressurizing the outlet works, steel lining of portions of the tunnel, and providing substantial lengths of steel penstock.

A complete new high pressure tunnel and upper reservoir intake/outlet would also be possible, but was judged to be more costly due to additional excavation costs and excavation in the existing reservoir adjacent to the Outlet Works intake and the chute spillway. Should the pumped storage concept be found attractive, a more detailed further evaluation of options would be warranted.

The estimated capital cost of the facility, considering single speed motors/motor-generators, is as follows:

- Pumping units - $615 million; or
- Reversible pump-turbine units - $637 million.

Variable speed equipment would increase the above total project costs by approximately 3%, but would result in improved pump and turbine efficiency.

Operating and maintenance costs are estimated as $9 per kW and variable costs are expected to be roughly $0.90 per MWh.

Tables

HATCH™

Table 6.1
Mica Dam - Pumped Storage Development (2-250 MW)
Cost Estimate for Pumping Station Installation at Left Bank
(Using Existing Diversion Tunnels and Intake)

30-Nov-10

Item	Description	Estimated Quantity	Unit	Unit Price ($/Unit)	Sub-Total	TOTAL
1	**Contractor's Construction Indirect & General Items**					
1.1	Mobilization and Demobilization	1	LS	$7,575,000	$7,575,000	
1.2	Construction Facilities, General Expenses & Site Services	48	Mo	$349,500	$16,776,000	
1.3	Site Supervision Work	48	Mo	$490,500	$23,544,000	
1.4	Site Surveys & Quality Control	48	Mo	$210,450	$10,101,600	
1.5	Transportation of Workers & Subsistence	1	LS	$12,629,100	$12,629,100	
1.6	Bonding & Insurance	1	LS	$7,587,000	$7,587,000	
1.5	Environmental Protection	1	LS	$5,000,000	$5,000,000	
	Subtotal-1-Construction Indirects					**$83,213,000**
2	**Civil Works**					
2.1	**Preliminary Works & Site Facilities**					
2.1.1	Access Roads	1,500	m	$250	$375,000	
2.1.2	Cofferdams & Construction Roads (install & Remove)	20,000	m3	$20	$400,000	
2.1.3	Equipment Building (Construction)	1,000	m2	$2,000	$2,000,000	
	Subtotal				**$2,775,000**	
2.2	**Clearing & Fill**					
2.2.1	Draft Tube Gate Portals (Slope & Base Preparation)	3,600	m3	$25	$90,000	
2.2.2	Random Granular Fill (*)	3,200	m3	$35	$112,000	
2.2.3	Fine Granular Fill (*)	2,400	m3	$40	$96,000	
	Subtotal				**$298,000**	
2.3	**500 kV Switchyard**					
2.3.1	**Civil Works**					
2.3.1.1	Switchyard (60m x 60m excavate)	21,600	m3	$44	$950,400	
2.3.1.2	Slope & Base Preparation (Switchyard)	600	m3	$40	$24,000	
2.3.1.3	Foundation Preparation	150	m3	$40	$6,000	
2.3.1.4	Compacted Back Fill: Ground Grid	1,800	m3	$45	$81,000	
2.3.1.5	Ground Grid Conductor	1,000	m	$90	$90,000	
2.3.1.6	Concrete Foundations - Switchyard Equipment	200	m3	$375	**$75,000**	
2.3.1.7	Oil Water Separator	1	LS	$20,000	**$20,000**	
2.3.1.8	Drainage Ditch	250	m	$15	$3,750	
2.3.1.9	Trench and Ducts	200	m	$200	$40,000	
2.3.1.10	Perimeter Fence	240	m	$150	$36,000	
2.3.1.11	Landscaping	1	LS	$50,000	$50,000	
2.3.2	**Electrical Equipment**					
2.3.2.1	GSU Transformer (13.8/500kV) 3-Phase (Surface Swyd)	2	ea	$4,100,000	$8,200,000	
2.3.2.2	500kV Dead Tank Circuit Breaker	2	ea	$765,000	$1,530,000	
2.3.2.3	500kV Disconnect Switch	2	ea	$175,000	$350,000	
2.3.2.4	500kV CVT	3	ea	$80,000	$240,000	
2.3.2.5	500kV Surge Arrestors	9	ea	$50,000	$450,000	
2.3.2.6	500kV Buswork and Structures	1	LS	$350,000	$350,000	

HATCH™

Table 6.1

Mica Dam - Pumped Storage Development (2-250 MW)

Cost Estimate for Pumping Station Installation at Left Bank

(Using Existing Diversion Tunnels and Intake)

30-Nov-10

Item	Description	Estimated Quantity	Unit	Unit Price ($/Unit)	Sub-Total	TOTAL
2.3.2.7	Lighting Protection	1	LS	$150,000	$150,000	
2.3.2.8	500kW Diesel Generator	1	LS	$145,000	$145,000	
2.3.2.9	Control and Protection	1	LS	$540,000	$540,000	
2.3.2.10	Control Building	1	LS	$110,000	$110,000	
	Subtotal				**$13,441,150**	
2.4	**500 kV Transmission Line (Single cct)**					
2.4.1	**Dead End Structures (Steel & Foundation)**	**1.0**	**Ea**	**$250,000**	**$250,000**	
2.4.2	**Tower Structure (Steel & Foundation)**	**1.0**	**Ea**	**$270,000**	**$270,000**	
2.4.3	**Supply & Install Insulators & Hardware**	**800.0**	**cctm**	**$200**	**$160,000**	
2.4.4	**Supply & String Conductors**	**800.0**	**cctm**	**$450**	**$360,000**	
2.4.5	**Rem Existing Dead End and Connect to Overhead Lines**	**1.0**	**LS**	**$100,000**	**$100,000**	
	Subtotal				**$1,140,000**	
2.5	**Excavation Underground (Incl. Rock Support)**					
2.5.1	Div. No.1 to 2 Cross Tunnel 28'D-shape	5,200	m3	$650	**$3,380,000**	
2.5.2	Div. No.2 to PH Tunnel 28'D-shape	7,500	m3	$650	**$4,875,000**	
2.5.3	Powerhouse Access Tunnel 20'x20'x1800'L	20,400	m3	$650	**$13,260,000**	
2.5.4	Discharge Gate House (48'W x25' L x60'H)	2,000	m3	$650	**$1,300,000**	
2.5.5	Gate Access Tunnel widen to 20'Wx15H' x750'L	2,500	m3	$650	**$1,625,000**	
2.5.6	Gate Access Tunnel 20'Wx15H' x80'L	700	m3	$650	**$455,000**	
2.5.7	Low Voltage Bus/Vent Shaft (22' dia. x 260' high)	2,800	m3	$650	**$1,820,000**	
2.5.8	Egress & Cable Tunnel 15'Wx15H' x300'L	1,900	m3	$650	**$1,235,000**	
2.5.9	Powerhouse Turbines (120'L x80'W x35'D)	9,500	m3	$500	**$4,750,000**	
2.5.10	Powerhouse (200'L x80'W x65'D)	29,400	m3	$500	**$14,700,000**	
2.5.11	Service Bay (60'L x80'W x20'D)	2,700	m3	$500	**$1,350,000**	
2.5.12	Draft Tubes (40'D-shape x 200' L)	18,100	m3	$650	**$11,765,000**	
2.5.13	Draft Tube Gate Structure (15'W x100' L x90'D)	4,000	m3	$650	**$2,600,000**	
	Subtotal				**$63,115,000**	
2.6	**Rock Support & Shotcrete**					
2.6.1	Penstock Tunnel Liners 2" Thick	200	m3	$1,200	**$240,000**	
2.6.2	Powerhouse Access Tunnel Liner 2" Thick	500	m3	$1,200	**$600,000**	
2.6.3	Powerhouse Cavern 2" Thick	400	m3	$1,200	**$480,000**	
2.6.4	Gate House Access Tunnel Liner 2" Thick	200	m3	$1,200	**$240,000**	
	Subtotal				**$1,560,000**	
2.7	**Concrete**					
2.7.1	Vertical Penstock 29' steel in 30' (820' L)	1,100	m3	$1,500	**$1,650,000**	
2.7.2	Discharge Penstock Liner 30' steel in 45' (300' L)	7,500	m3	$1,500	**$11,250,000**	
2.7.3	Penstock Liner to PH 26' steel in 28' (375' L)	900	m3	$1,500	**$1,350,000**	
2.7.4	Cross Tunnel Liner 26' steel in 28' (260' L)	600	m3	$1,500	**$900,000**	
2.7.5	Low Voltage Bus/Vent Shaft Liner (22' ID x 260' H x 1' thick)	500	m3	$1,500	**$750,000**	
2.7.6	Egress/Cable Gallery Shaft Base (12'W x 300'H x 0.5' thick)	100	m3	$1,500	**$150,000**	
2.7.7	Discharge Gate Shaft Base	1,900	m3	$1,500	**$2,850,000**	
2.7.8	Discharge Gate House	20	m3	$1,500	**$30,000**	

HATCH™

Table 6.1
Mica Dam - Pumped Storage Development (2-250 MW)
Cost Estimate for Pumping Station Installation at Left Bank
(Using Existing Diversion Tunnels and Intake)

30-Nov-10

Item	Description	Estimated Quantity	Unit	Unit Price ($/Unit)	Sub-Total	TOTAL
2.7.9	Draft Tube Gates	3,200	m3	$1,500	**$4,800,000**	
2.7.10	Powerhouse Turbines (200'L x100'W x65'D x 50%)	1,800	m3	$1,500	**$2,700,000**	
2.7.11	Powerhouse (200'L x100'W x 4' thick)	2,300	m3	$1,500	**$3,450,000**	
2.7.12	Service Bay (100'L x100'W x2''D)	600	m3	$1,500	**$900,000**	
	Subtotal				**$30,780,000**	
2.8	**Penstock Steel (supply & Installation)**					
2.8.1	30' dia. at 2" Thick	1,319,000	kg	$10	**$13,190,000**	
2.8.2	29' dia. at 1.75" Thick	565,000	kg	$10	**$5,650,000**	
2.8.3	29' dia. at 1.38" Thick	586,000	kg	$10	**$5,860,000**	
2.8.4	29' dia. at 1.0" Thick	357,000	kg	$10	**$3,570,000**	
2.8.5	26' dia. at 2.25" Thick	1,200,000	kg	$10	**$12,000,000**	
2.8.6	26' dia. at 1.75" Thick	3,200,000	kg	$10	**$32,000,000**	
	Subtotal				**$72,270,000**	
	Subtotal-2-Civil Works					**$185,379,000**
3	**Mechanical & Electrical Works**					
3.1	**Intake**					
3.1.1	Trashracks	0	Ea.	$400,000	$0	
3.1.2	Intake Gates	0	LS	$3,000,000	$0	
3.1.3	Intake Bulkhead Gates	0	LS	$1,500,000	$0	
3.1.4	Intake Bulkhead Gate Crane	0	LS	$1,000,000	$0	
	Subtotal					**$0**
3.2	**Discharge Gate House**					
3.2.1	Discharge Gates (with Hydraulic Cylinders)	3	Ea.	$1,500,000	$4,500,000	
	Subtotal					**$4,500,000**
3.3	**Draft Tube Gate Structures**					
3.3.1	Draft Tube Gate Hoist	2	Ea.	$100,000	$200,000	
3.3.2	Draft Tube Bulkhead Gates	2	Ea.	$400,000	$800,000	
3.3.3	Tailrace Trashracks	2	Ea.	$500,000	$1,000,000	
	Subtotal					**$2,000,000**
3.4	**Pumping Units**					
3.4.1	Supply Pumps and Governors	2	Ea.	$21,700,000	$43,400,000	
3.4.2	Supply Valves	2	Ea.	$3,500,000	$7,000,000	
3.4.3	Supply Motors and Exciters	2	Ea.	$18,000,000	$36,000,000	
3.4.4	Supply Starting equipment	1	LS	$10,000,000	$10,000,000	
3.4.5	Installation & Commissioning of Turbine-Generator	1	LS	$23,000,000	$23,000,000	
	Subtotal					**$119,400,000**
3.5	**BOP Electrical & Mechanical Equipment**					
3.5.1	BOP Mechanical Supply, Installation & Commissioning	1	LS	$25,000,000	$25,000,000	
	Subtotal					**$25,000,000**
3.5.2	BOP Electrical Supply, Installation & Commissioning	1	LS	$35,000,000	$35,000,000	

HATCH™

Table 6.1
Mica Dam - Pumped Storage Development (2-250 MW)
Cost Estimate for Pumping Station Installation at Left Bank
(Using Existing Diversion Tunnels and Intake)

30-Nov-10

Item	Description	Estimated Quantity	Unit	Unit Price ($/Unit)	Sub-Total	TOTAL
	Subtotal					**$35,000,000**
3.5.3	Powerhouse Bridge Cranes (with Spreader Beam)	2	Ea.	$2,000,000	$6,000,000	
3.5.4	Elevator	1	LS	$375,000	$375,000	
3.5.5	Structural Steel	1	LS	$1,700,000	$1,700,000	
	Subtotal					**$8,075,000**
Subtotal-3-Mechanical & Electrical Works						**$193,975,000**
Subtotal -1 - Construction Facilities & Indirect Costs						$83,213,000
Subtotal -2 - Civil Works						$185,379,000
Subtotal- 3 - Mechanical & Electrical Works						$193,975,000
Total Estimated Construction Cost without Contingencies						**$462,567,000**
Environmental, Engineering, Administration & Site Inspection		8%	LS			**$37,005,000**
Contingencies						
Contingency		25%		$462,567,000	$115,642,000	
Subtotal-4-Contingencies						**$115,642,000**
Total Estimated Project Cost						**$615,214,000**
				Estimated Cost $/kW		**$1,230**

Exclusions:

- Escalation beyond October 2010
- HST
- Land acquisition
- Financing / IDC
- Owner's costs

HATCH™

Table 6.2
Mica Dam - Pumped Storage Development (2-250 MW)
Cost Estimate for Reversible Pump Turbine Installation at Left Bank
(Using Existing Diversion Tunnels and Intake)

30-Nov-10

Item	Description	Estimated Quantity	Unit	Unit Price ($/Unit)	Sub-Total	TOTAL
1	**Contractor's Construction Indirect & General Items**					
1.1	Mobilization and Demobilization	1	LS	$7,575,000	$7,575,000	
1.2	Construction Facilities, General Expenses & Site Services	48	Mo	$349,500	$16,776,000	
1.3	Site Supervision Work	48	Mo	$490,500	$23,544,000	
1.4	Site Surveys & Quality Control	48	Mo	$210,450	$10,101,600	
1.5	Transportation of Workers & Subsistence	1	LS	$12,629,100	$12,629,100	
1.6	Bonding & Insurance	1	LS	$7,907,000	$7,907,000	
1.5	Environmental Protection	1	LS	$5,000,000	$5,000,000	
	Subtotal-1-Construction Indirects					**$83,533,000**
2	**Civil Works**					
2.1	**Preliminary Works & Site Facilities**					
2.1.1	Access Roads	1,500	m	$250	$375,000	
2.1.2	Cofferdams & Construction Roads (install & Remove)	20,000	m3	$20	$400,000	
2.1.3	Equipment Building (Construction)	1,000	m2	$2,000	$2,000,000	
	Subtotal				**$2,775,000**	
2.2	**Clearing & Fill**					
2.2.1	Draft Tube Gate Portals (Slope & Base Preparation)	3,600	m3	$25	$90,000	
2.2.2	Random Granular Fill	3,200	m3	$35	$112,000	
2.2.3	Fine Granular Fill	2,400	m3	$40	$96,000	
	Subtotal				**$298,000**	
2.3	**500 kV Switchyard**					
2.3.1	**Civil Works**					
2.3.1.1	Switchyard (60m x 60m excavate)	21,600	m3	$44	$950,400	
2.3.1.2	Slope & Base Preparation (Switchyard)	600	m3	$40	$24,000	
2.3.1.3	Foundation Preparation	150	m3	$40	$6,000	
2.3.1.4	Compacted Back Fill: Ground Grid	1,800	m3	$45	$81,000	
2.3.1.5	Ground Grid Conductor	1,000	m	$90	$90,000	
2.3.1.6	Concrete Foundations - Switchyard Equipment	200	m3	$375	**$75,000**	
2.3.1.7	Oil Water Separator	1	LS	$20,000	**$20,000**	
2.3.1.8	Drainage Ditch	250	m	$15	$3,750	
2.3.1.9	Trench and Ducts	200	m	$200	$40,000	
2.3.1.10	Perimeter Fence	240	m	$150	$36,000	
2.3.1.11	Landscaping	1	LS	$50,000	$50,000	
2.3.2	**Electrical Equipment**					
2.3.2.1	GSU Transformer (13.8/500kV) 3-Phase (Surface Swyd)	2	ea	$4,100,000	$8,200,000	
2.3.2.2	500kV Dead Tank Circuit Breaker	2	ea	$765,000	$1,530,000	
2.3.2.3	500kV Disconnect Switch	2	ea	$175,000	$350,000	
2.3.2.4	500kV CVT	3	ea	$80,000	$240,000	
2.3.2.5	500kV Surge Arrestors	9	ea	$50,000	$450,000	
2.3.2.6	500kV Buswork and Structures	1	LS	$350,000	$350,000	

HATCH™

Table 6.2
Mica Dam - Pumped Storage Development (2-250 MW)
Cost Estimate for Reversible Pump Turbine Installation at Left Bank
(Using Existing Diversion Tunnels and Intake)

30-Nov-10

Item	Description	Estimated Quantity	Unit	Unit Price ($/Unit)	Sub-Total	TOTAL
2.3.2.7	Lighting Protection	1	LS	$150,000	$150,000	
2.3.2.8	500kW Diesel Generator	1	LS	$145,000	$145,000	
2.3.2.9	Control and Protection	1	LS	$540,000	$540,000	
2.3.2.10	Control Building	1	LS	$110,000	$110,000	
	Subtotal				**$13,441,150**	
2.4	**500 kV Transmission Line (Single cct)**					
2.4.1	**Dead End Structures (Steel & Foundation)**	**1.0**	**Ea**	**$250,000**	**$250,000**	
2.4.2	**Tower Structure (Steel & Foundation)**	**1.0**	**Ea**	**$270,000**	**$270,000**	
2.4.3	**Supply & Install Insulators & Hardware**	**800.0**	**cctm**	**$200**	**$160,000**	
2.4.4	**Supply & String Conductors**	**800.0**	**cctm**	**$450**	**$360,000**	
2.4.5	**Rem Existing Dead End and Connect to Overhead Lines**	**1.0**	**LS**	**$100,000**	**$100,000**	
	Subtotal				**$1,140,000**	
2.5	**Excavation Underground (Incl. Rock Support)**					
2.5.1	Div. No.1 to 2 Cross Tunnel 28'D-shape	5,200	m3	$650	**$3,380,000**	
2.5.2	Div. No.2 to PH Tunnel 28'D-shape	7,500	m3	$650	**$4,875,000**	
2.5.3	Powerhouse Access Tunnel 20'x20'x1800'L	20,400	m3	$650	**$13,260,000**	
2.5.4	Discharge Gate House (48'W x25' L x60'H)	2,000	m3	$650	**$1,300,000**	
2.5.5	Gate Access Tunnel widen to 20'Wx15H' x750'L	2,500	m3	$650	**$1,625,000**	
2.5.6	Gate Access Tunnel 20'Wx15H' x80'L	700	m3	$650	**$455,000**	
2.5.7	Low Voltage Bus/Vent Shaft (22' dia. x 260' high)	2,800	m3	$650	**$1,820,000**	
2.5.8	Egress & Cable Tunnel 15'Wx15H' x300'L	1,900	m3	$650	**$1,235,000**	
2.5.9	Powerhouse Turbines (120'L x80'W x35'D)	9,500	m3	$500	**$4,750,000**	
2.5.10	Powerhouse (200'L x80'W x65'D)	29,400	m3	$500	**$14,700,000**	
2.5.11	Service Bay (60'L x80'W x20'D)	2,700	m3	$500	**$1,350,000**	
2.5.12	Draft Tubes (40'D-shape x 200' L)	18,100	m3	$650	**$11,765,000**	
2.5.13	Draft Tube Gate Structure (15'W x100' L x90'D)	4,000	m3	$650	**$2,600,000**	
	Subtotal				**$63,115,000**	
2.6	**Rock Support & Shotcrete**					
2.6.1	Penstock Tunnel Liners 2" Thick	200	m3	$1,200	**$240,000**	
2.6.2	Powerhouse Access Tunnel Liner 2" Thick	500	m3	$1,200	**$600,000**	
2.6.3	Powerhouse Cavern 2" Thick	400	m3	$1,200	**$480,000**	
2.6.4	Gate House Access Tunnel Liner 2" Thick	200	m3	$1,200	**$240,000**	
	Subtotal				**$1,560,000**	
2.7	**Concrete**					
2.7.1	Vertical Penstock 29' steel in 30' (820' L)	1,100	m3	$1,500	**$1,650,000**	
2.7.2	Discharge Penstock Liner 30' steel in 45' (300' L)	7,500	m3	$1,500	**$11,250,000**	
2.7.3	Penstock Liner to PH 26' steel in 28' (375' L)	900	m3	$1,500	**$1,350,000**	
2.7.4	Cross Tunnel Liner 26' steel in 28' (260' L)	600	m3	$1,500	**$900,000**	
2.7.5	Low Voltage Bus/Vent Shaft Liner (22' ID x 260' H x 1' thick)	500	m3	$1,500	**$750,000**	
2.7.6	Egress/Cable Gallery Shaft Base (12'W x 300'H x 0.5' thick)	100	m3	$1,500	**$150,000**	
2.7.7	Discharge Gate Shaft Base	1,900	m3	$1,500	**$2,850,000**	
2.7.8	Discharge Gate House	20	m3	$1,500	**$30,000**	

HATCH™

Table 6.2

Mica Dam - Pumped Storage Development (2-250 MW)

Cost Estimate for Reversible Pump Turbine Installation at Left Bank

(Using Existing Diversion Tunnels and Intake)

30-Nov-10

Item	Description	Estimated Quantity	Unit	Unit Price ($/Unit)	Sub-Total	TOTAL
2.7.9	Draft Tube Gates	3,200	m3	$1,500	**$4,800,000**	
2.7.10	Powerhouse Turbines (200'L x100'W x65'D x 50%)	1,800	m3	$1,500	**$2,700,000**	
2.7.11	Powerhouse (200'L x100'W x 4' thick)	2,300	m3	$1,500	**$3,450,000**	
2.7.12	Service Bay (100'L x100'W x2''D)	600	m3	$1,500	**$900,000**	
	Subtotal				**$30,780,000**	
2.8	**Penstock Steel (supply & Installation)**					
2.8.1	30' dia. at 2" Thick	1,319,000	kg	$10	**$13,190,000**	
2.8.2	29' dia. at 1.75" Thick	565,000	kg	$10	**$5,650,000**	
2.8.3	29' dia. at 1.38" Thick	586,000	kg	$10	**$5,860,000**	
2.8.4	29' dia. at 1.0" Thick	357,000	kg	$10	**$3,570,000**	
2.8.5	26' dia. at 2.25" Thick	1,200,000	kg	$10	**$12,000,000**	
2.8.6	26' dia. at 1.75" Thick	3,200,000	kg	$10	**$32,000,000**	
	Subtotal				**$72,270,000**	
	Subtotal-2-Civil Works					**$185,379,000**
3	**Mechanical & Electrical Works**					
3.1	**Intake**					
3.1.1	Trashracks	1	Ea.	$400,000	$400,000	
3.1.2	Intake Gates	0	LS	$3,000,000	$0	
3.1.3	Intake Bulkhead Gates	0	LS	$1,500,000	$0	
3.1.4	Intake Bulkhead Gate Crane	0	LS	$1,000,000	$0	
	Subtotal					**$400,000**
3.2	**Discharge Gate House**					
3.2.1	Discharge Gates (with Hydraulic Cylinders)	3	Ea.	$1,500,000	$4,500,000	
	Subtotal					**$4,500,000**
3.3	**Draft Tube Gate Structures**					
3.3.1	Draft Tube Gate Hoist	2	Ea.	$100,000	$200,000	
3.3.2	Draft Tube Bulkhead Gates	2	Ea.	$400,000	$800,000	
3.3.3	Tailrace Trashracks	2	Ea.	$500,000	$1,000,000	
	Subtotal					**$2,000,000**
3.4	**Pumping / Generating Units**					
3.4.1	Supply Pump-turbines and Governors	2	Ea.	$29,000,000	$58,000,000	
3.4.2	Supply Valves	2	Ea.	$3,500,000	$7,000,000	
3.4.3	Supply Motor-generators and Exciters	2	Ea.	$18,500,000	$37,000,000	
3.4.4	Supply Starting equipment	1	LS	$10,000,000	$10,000,000	
3.4.5	Installation & Commissioning of Turbine-Generator	1	LS	$23,000,000	$23,000,000	
	Subtotal					**$135,000,000**
3.5	**BOP Electrical & Mechanical Equipment**					
3.5.1	BOP Mechanical Supply, Installation & Commissioning	1	LS	$25,000,000	$25,000,000	
	Subtotal					**$25,000,000**
3.5.2	BOP Electrical Supply, Installation & Commissioning	1	LS	$35,000,000	$35,000,000	

HATCH™

Table 6.2
Mica Dam - Pumped Storage Development (2-250 MW)
Cost Estimate for Reversible Pump Turbine Installation at Left Bank
(Using Existing Diversion Tunnels and Intake)

30-Nov-10

Item	Description	Estimated Quantity	Unit	Unit Price ($/Unit)	Sub-Total	TOTAL
	Subtotal					**$35,000,000**
3.5.3	Powerhouse Bridge Cranes (with Spreader Beam)	2	Ea.	$2,000,000	$6,000,000	
3.5.4	Elevator	1	LS	$375,000	$375,000	
3.5.5	Structural Steel	1	LS	$1,700,000	$1,700,000	
	Subtotal					**$8,075,000**
Subtotal-3-Mechanical & Electrical Works						**$209,975,000**
Subtotal -1 - Construction Facilities & Indirect Costs						$83,533,000
Subtotal -2 - Civil Works						$185,379,000
Subtotal- 3 - Mechanical & Electrical Works						$209,975,000
Total Estimated Construction Cost without Contingencies						**$478,887,000**
Environmental, Engineering, Administration & Site Inspection		8%	LS			**$38,311,000**
Contingencies						
Project Contingency		25%		$478,887,000	$119,722,000	
	Subtotal					**$119,722,000**
Total Estimated Project Cost						**$636,920,000**
				Estimated Cost $/kW		**$1,274**

Exclusions:

- Escalation beyond October 2010
- HST
- Land acquisition
- Financing / IDC
- Owner's costs

Figures

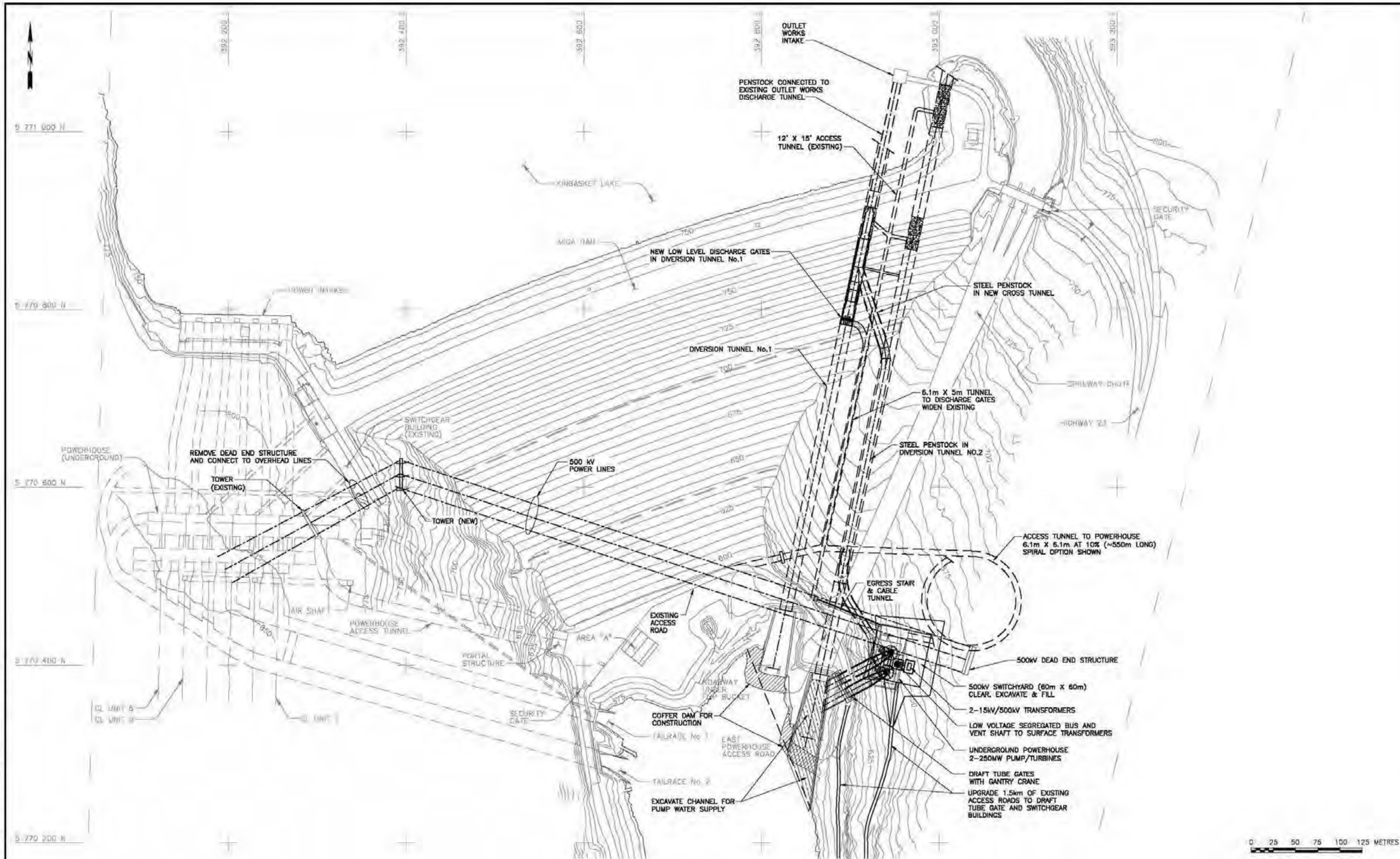


FIGURE 5.1
MICA DAM PUMP STORAGE OPTION - LEFT BANK 2-250 MW PUMP TURBINES
CONCEPTUAL LAYOUT USING DIVERSION TUNNELS - SITE PLAN

HATCH™

Plotted: Dec 01, 2010 — 1:05pm
Drawing: P:\BCHYDRO\336793\CAD\C\336793 FIGURE 5.1.dwg

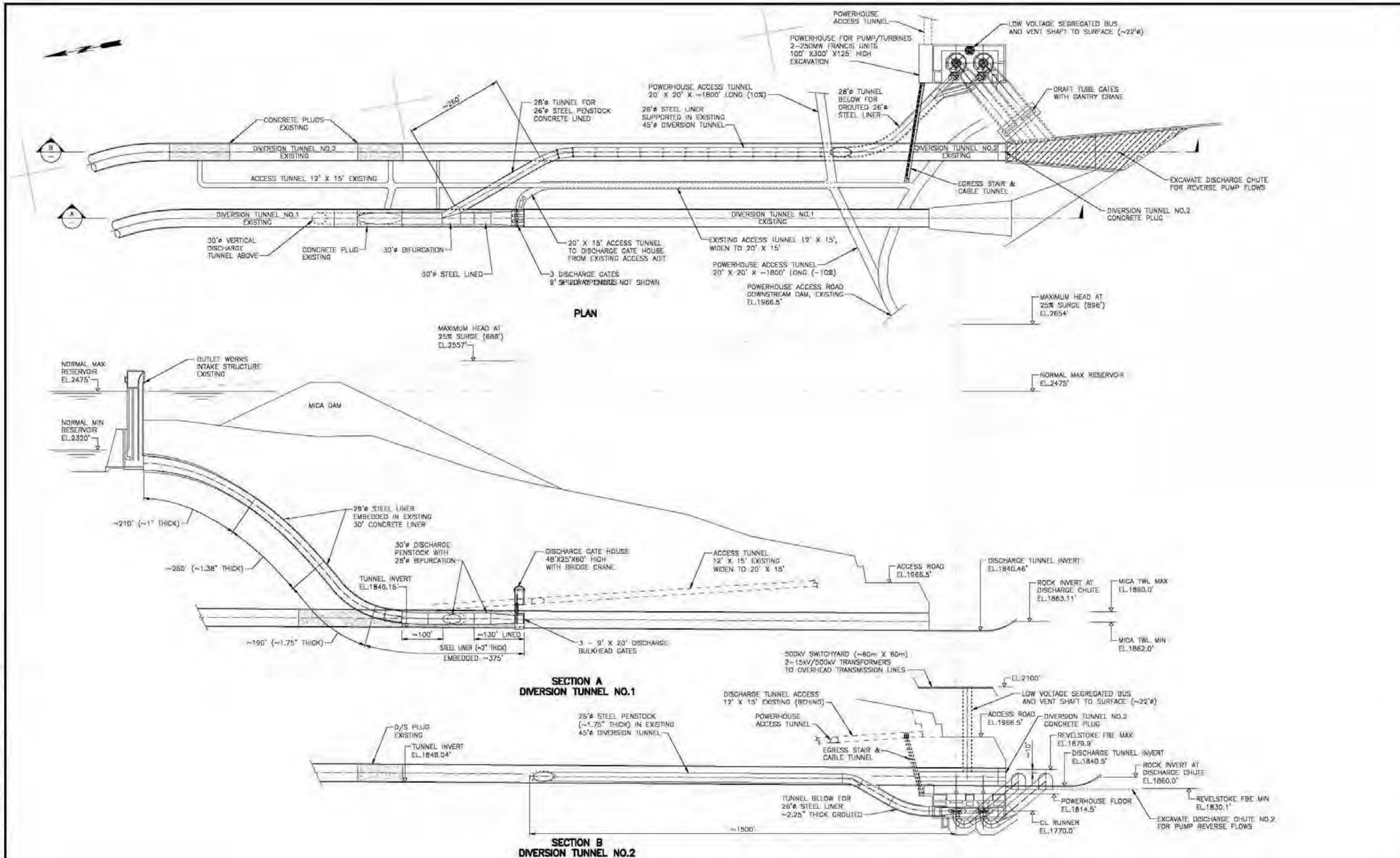


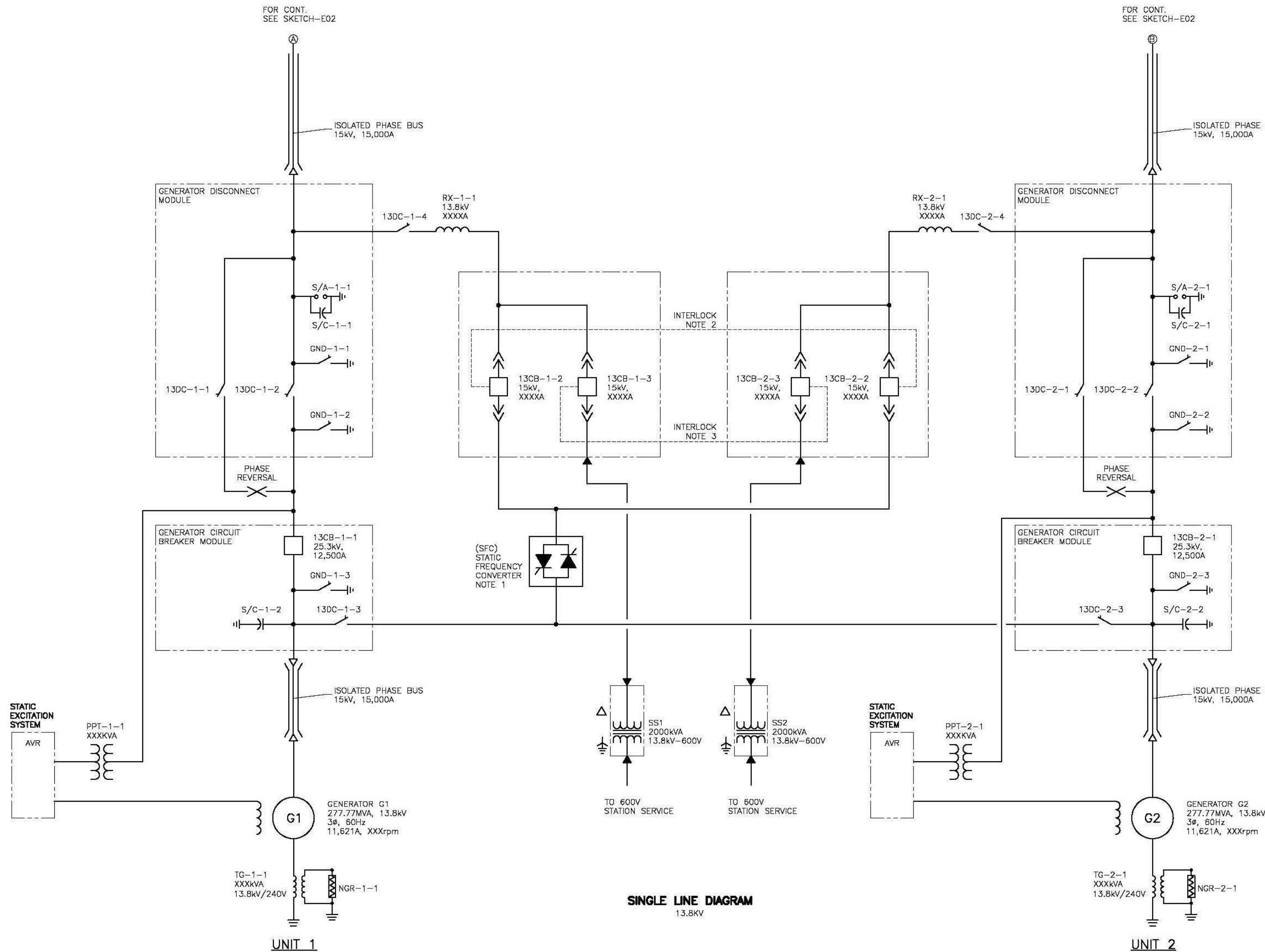
FIGURE 5.2
MICA DAM PUMP STORAGE OPTION - LEFT BANK 2-250 MW PUMP TURBINES
CONCEPTUAL LAYOUT USING DIVERSION TUNNELS - PLAN AND SECTIONS

HATCH

Plotted: Dec 01, 2010 – 10:06am
Drawing: P:\BCHYDRO\335793\CAD\C\335793 FIGURE 5.2.dwg

NOTES

1. STATIC FREQUENCY CONVERTER (SFC) RATED FOR SINGLE UNIT STARTING UNLOADED IN PUMP MODE ONLY.
2. 13CB1-2 AND 13CB2-2 INTERLOCKED SUCH THAT ONLY ONE BREAKER CAN BE CLOSED AT A GIVEN TIME.
3. 13CB1-3 AND 13CB2-3 INTERLOCKED SUCH THAT ONLY ONE BREAKER CAN BE CLOSED AT A GIVEN TIME. DUAL STATION SERVICE FEEDS ARE INTENDED TO BE BREAK BEFORE MAKE.
4. ALL EQUIPMENT RATINGS ARE PRELIMINARY ONLY.



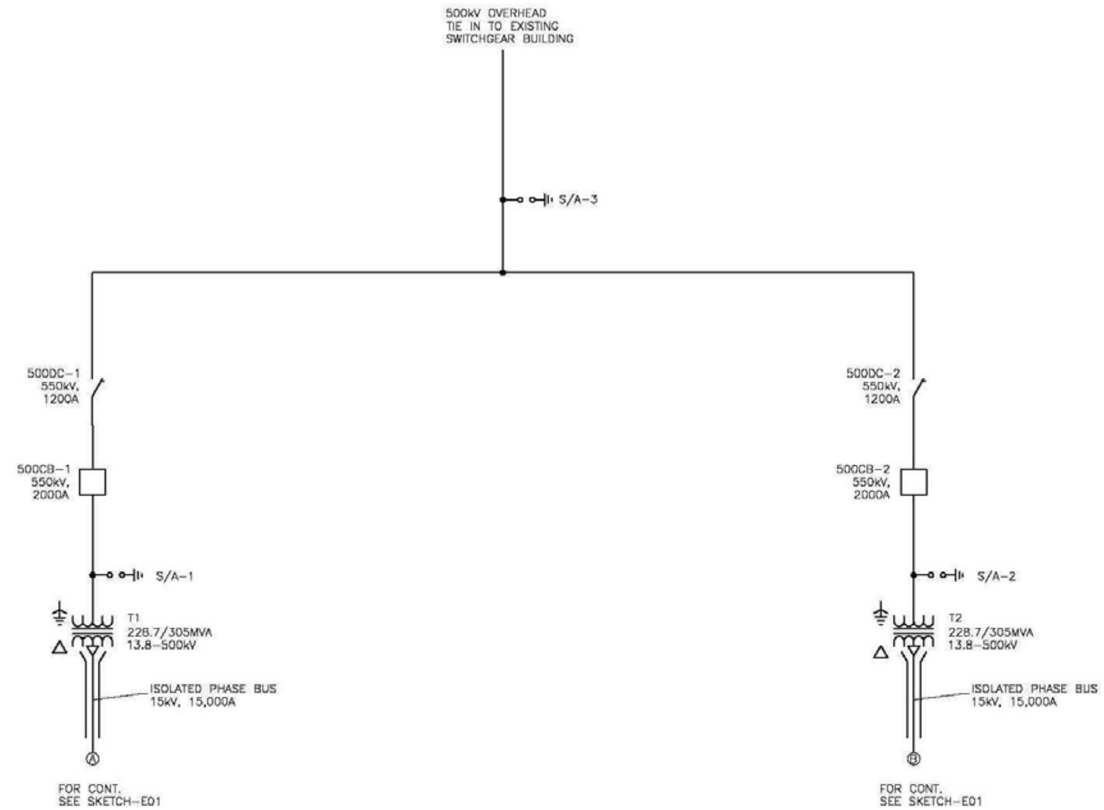
Plotted: Dec 01, 2010 - 1:06pm
Drawing: P:\BCHYDRO\336793\CAD\E\336793 FIGURE 5.3.dwg

FIGURE 5.3
MICA DAM PUMP STORAGE OPTION - LEFT BANK 2-250 MW PUMP TURBINES
CONCEPTUAL SINGLE LINE DIAGRAM - SHEET 1 of 2

HATCH

NOTE

1. ALL EQUIPMENT RATINGS ARE PRELIMINARY ONLY.



SINGLE LINE DIAGRAM
13.8/500KV

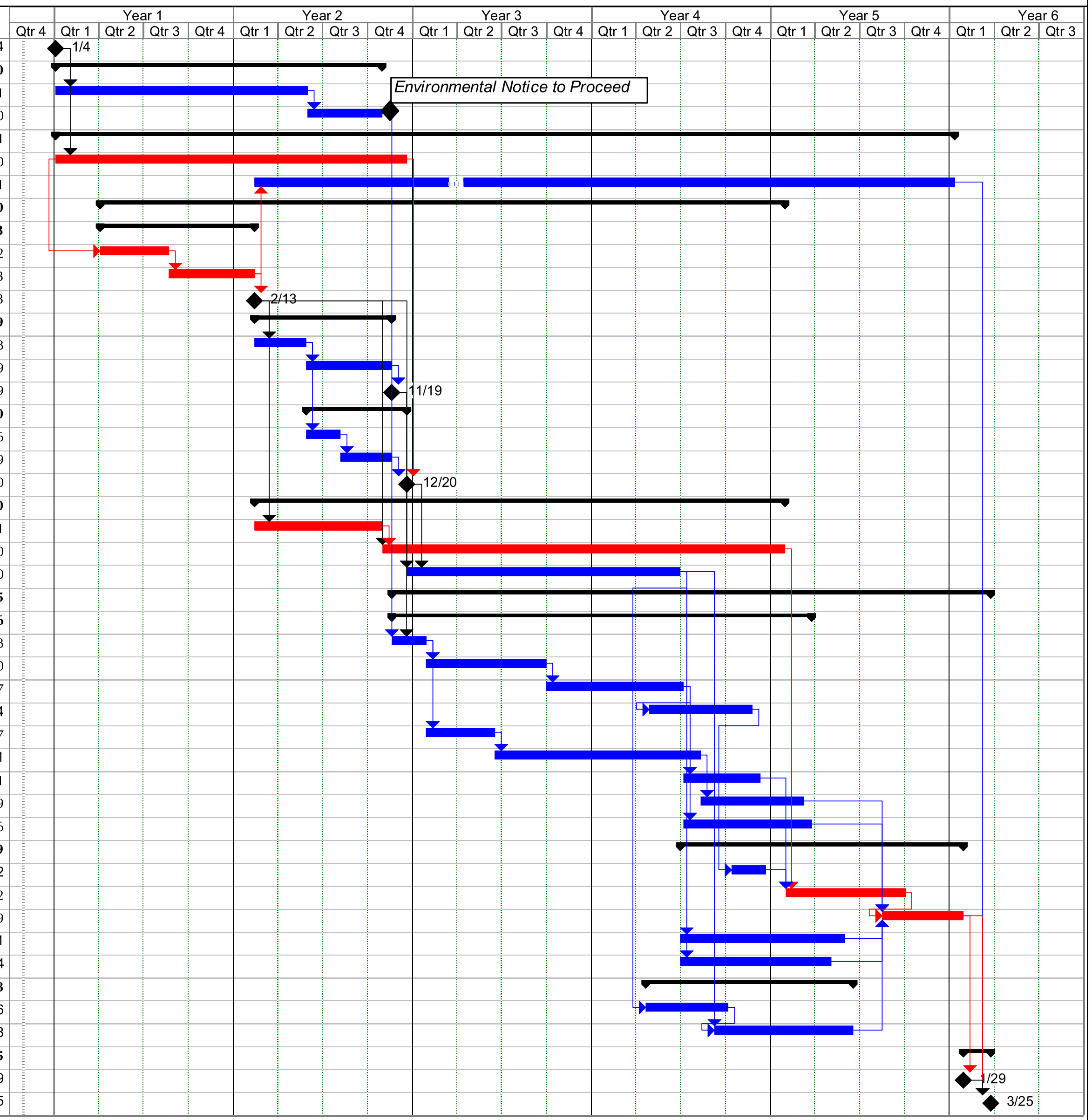
Plotted: Dec 01, 2010 - 1:07pm
Drawing: P:\BCHYDRO\336793\CAD\E\336793 FIGURE 5.4.dwg

FIGURE 5.4
MICA DAM PUMP STORAGE OPTION - LEFT BANK 2-250 MW PUMP TURBINES
CONCEPTUAL SINGLE LINE DIAGRAM - SHEET 2 of 2

HATCH™

Figure 8.1 Pumped Storage at Mica GS - Preliminary Project Schedule

ID	Task Name	Start	Finish
1	Project Start Date	Jan 4	Jan 4
2	**ENVIRONMENTAL PROCESS**	**Jan 4**	**Oct 30**
3	Environmental Activities	Jan 4	May 31
4	Permits and Approvals	Jun 1	Oct 30
5	**ENGINEERING & SITE INSPECTION**	**Jan 4**	**Jan 11**
6	Eng, Preliminary Design & Tendering Doc	Jan 4	Dec 20
7	Final Design & Engineering during Construction	Feb 14	Jan 11
8	**TENDERING PHASE**	**Apr 5**	**Jan 30**
9	**Pumping / Generating Units**	**Apr 5**	**Feb 13**
10	Preparation of Tender Documents	Apr 5	Aug 22
11	Tender Period, Evaluate Proposals/Negotiations	Aug 23	Feb 13
12	Contract Award	Feb 13	Feb 13
13	**General/Civil Contract (inc Gates)**	**Feb 14**	**Nov 19**
14	Preparation of Tender Documents	Feb 14	May 28
15	Tender Period, Evaluate Proposals/Negotiations	May 29	Nov 19
16	Contract Award	Nov 19	Nov 19
17	**Balance of Plant M&E & Swyd Equipment**	**May 29**	**Dec 20**
18	Preparation ofTender Documents	May 29	Aug 6
19	Tender Period, Evaluate Proposals/Negotiations	Aug 7	Nov 19
20	Contract Award	Dec 20	Dec 20
21	**Pump-Turbine/Motor-Generator Equip Manufacture**	**Feb 14**	**Jan 30**
22	Pump-turbine model tests	Feb 14	Nov 1
23	Design & Delivery Pump-Turbine/Motor-Generat	Nov 1	Jan 30
24	Balance of Plant M&E & Swyd Equipment	Dec 20	Jun 30
25	**CONSTRUCTION PHASE**	**Nov 20**	**Mar 25**
26	**Civil works**	**Nov 20**	**Mar 26**
27	Mobilization & Site Facilities & Roads	Nov 20	Jan 28
28	PH Access Tunnel	Jan 29	Sep 30
29	Powerhouse & Service Bay	Oct 1	Jul 7
30	PH & Service Bay Concrete	Apr 29	Nov 24
31	Div Tunnels Mod & Connecting Tunnels	Jan 29	Jun 17
32	Penstocks (Supply & Installation)	Jun 18	Aug 11
33	Discharge Gate House, Access Tunnel	Jul 8	Dec 11
34	Bus/Vent Shaft & Egress & Cable Tunnel	Aug 12	Mar 9
35	Draft Tubes & Gate Structure	Jul 8	Mar 26
36	**Mechanical & Electrical Works**	**Jul 1**	**Jan 29**
37	PH Crane & Hoisting Equipment	Oct 14	Dec 22
38	Erection of Pump-Turbine/Motor-Generator Units	Feb 2	Oct 2
39	Testing & Commissioning	Aug 17	Jan 29
40	BOP Mechanical Equipment & Services	Jul 1	Jun 1
41	BOP Electrical Equipment & Services	Jul 1	May 4
42	**500 kV Switchyard & 500 kV Transmission Line**	**Apr 22**	**Jun 18**
43	500 kV Switchyard	Apr 22	Oct 6
44	500 kV Transmission Line	Sep 9	Jun 18
45	**IN SERVICE (Unit 1 & Unit 2)**	**Jan 29**	**Mar 25**
46	Unit 1	Jan 29	Jan 29
47	Unit 2	Mar 25	Mar 25



Project: Mica PS- Schedule-R2
Date: Oct 28

Critical | Task | Split | Milestone | Summary

Page 1

FIGURE 9.1
MICA DAM PUMP STORAGE OPTION - LEFT BANK 2-250 MW PUMP TURBINES
Pump Performance - One Single Speed Unit
Gross Head, Overall Efficiency, Power Input vs Pump Discharge

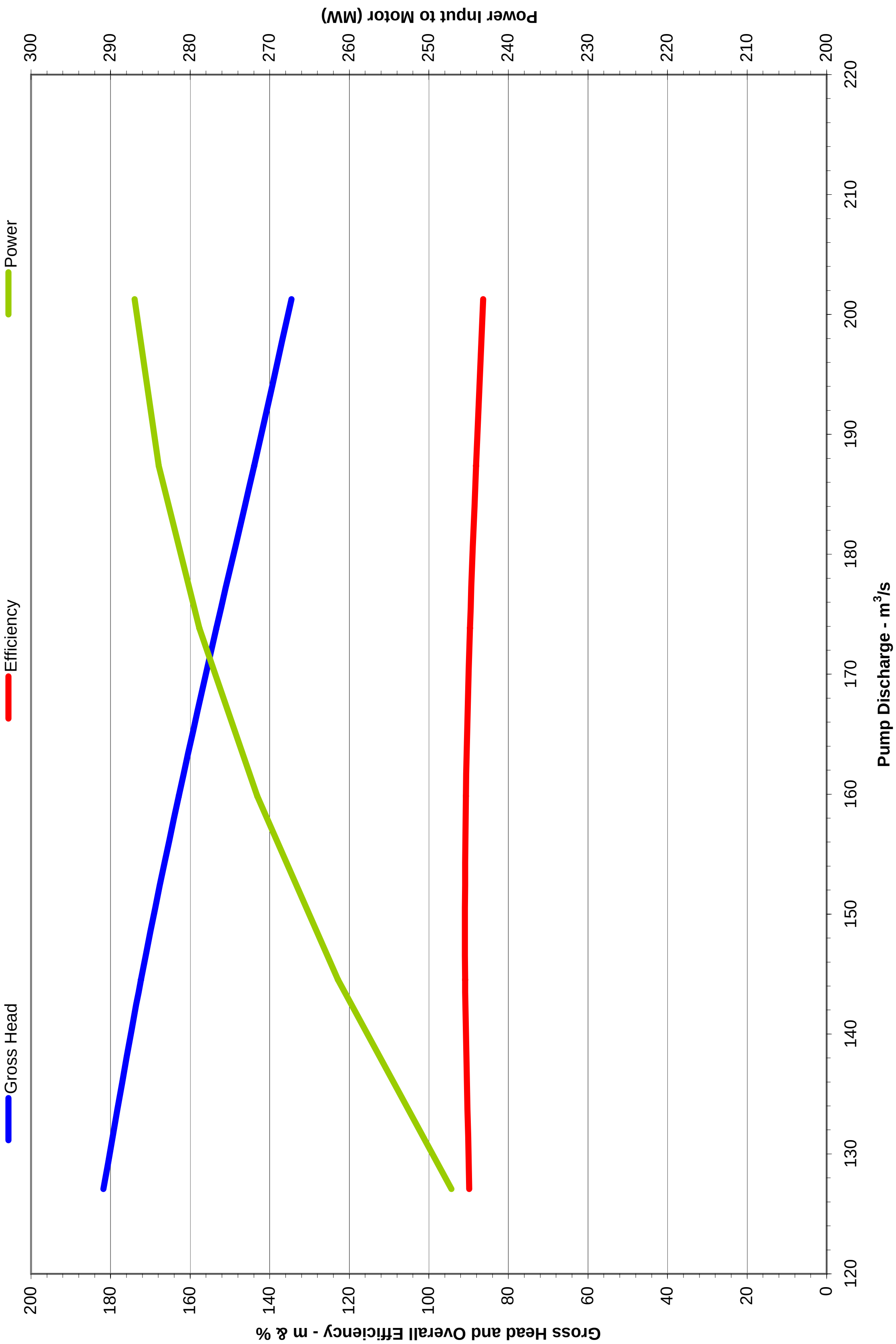
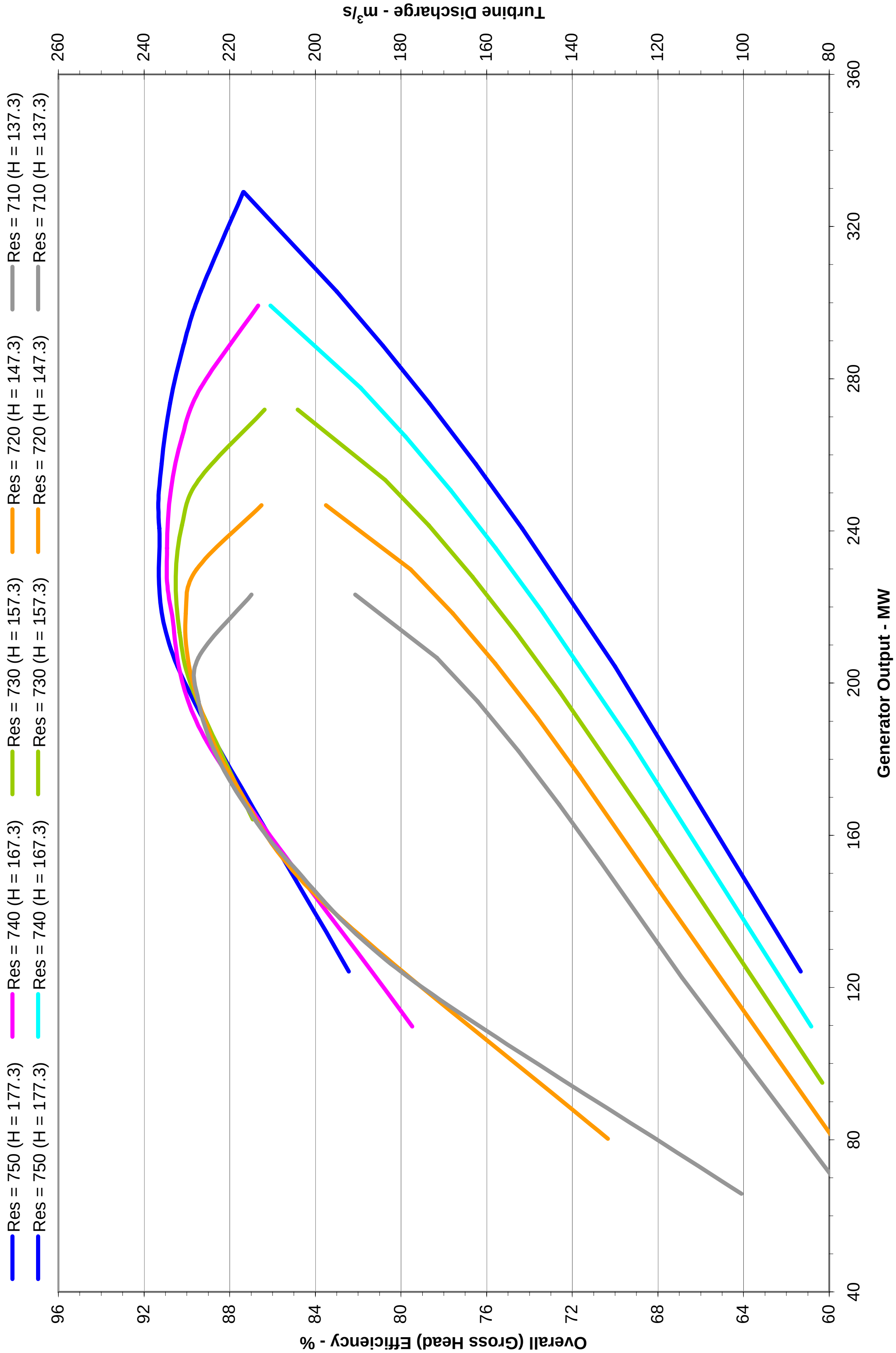


FIGURE 9.2

MICA DAM PUMP STORAGE OPTION - LEFT BANK 2-250 MW PUMP TURBINES

Generating Performance - One Single Speed Unit

Overall Efficiency, Turbine Discharge vs Generator Output



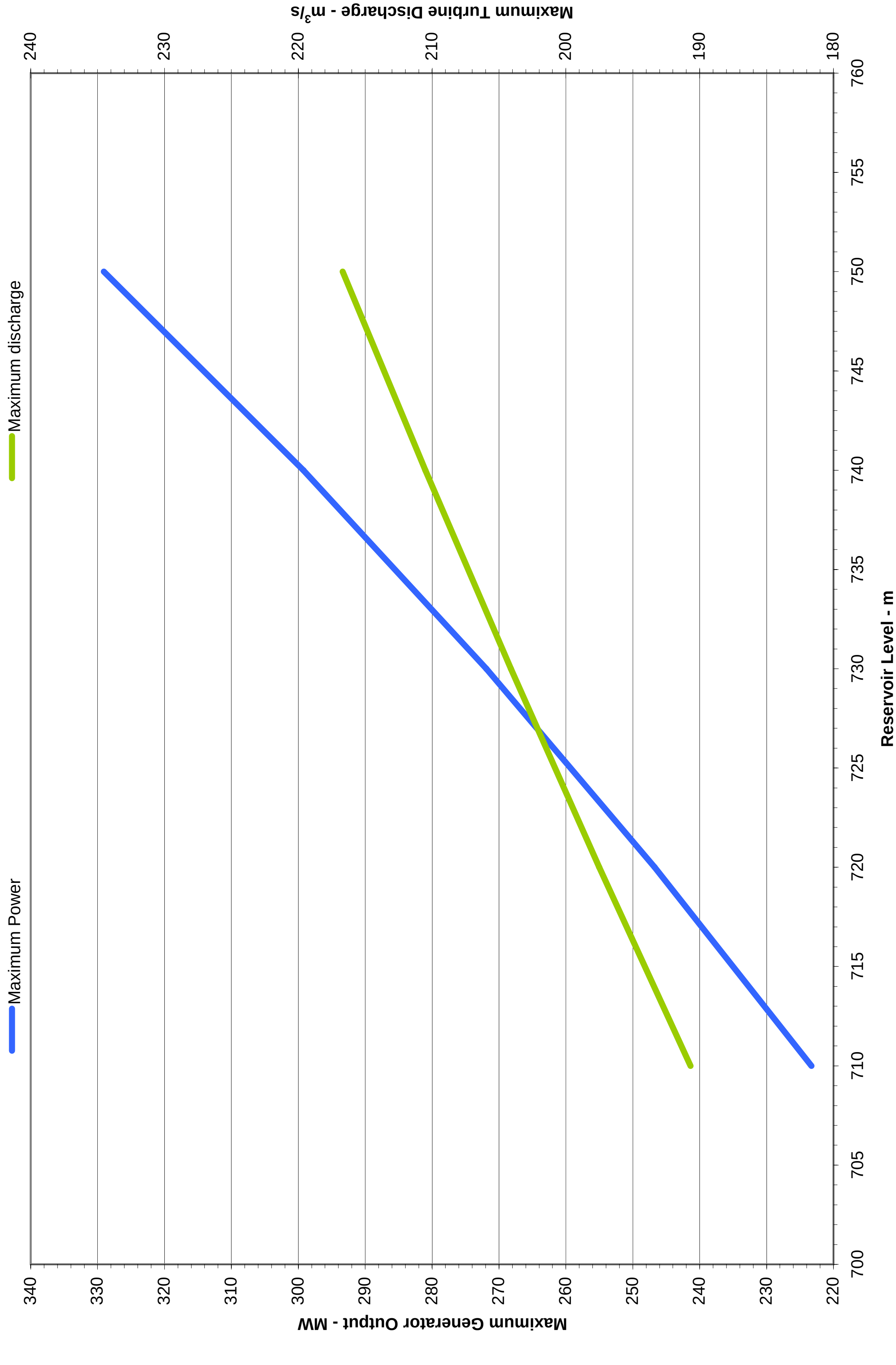


FIGURE 9.3

MICA DAM PUMP STORAGE OPTION - LEFT BANK 2-250 MW PUMP TURBINES

Generating Performance - One Single Speed Unit

Max. Generator Output, Max. Turbine Discharge vs Reservoir Level

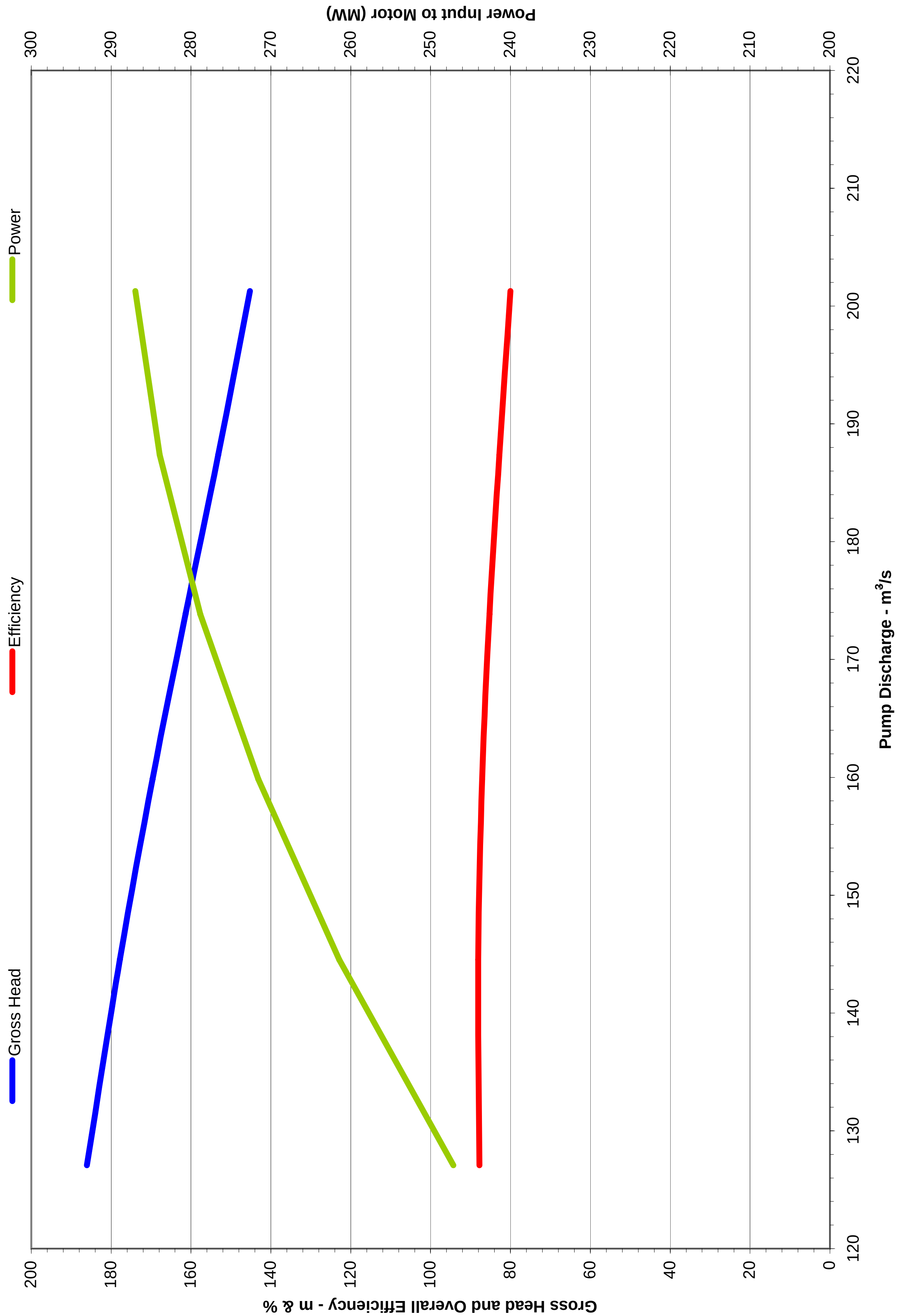


FIGURE 9.4

MICA DAM PUMP STORAGE OPTION - LEFT BANK 2-250 MW PUMP TURBINES

Pump Performance - One of Two Single Speed Units

Gross Head, Overall Efficiency, Power Input vs Pump Discharge

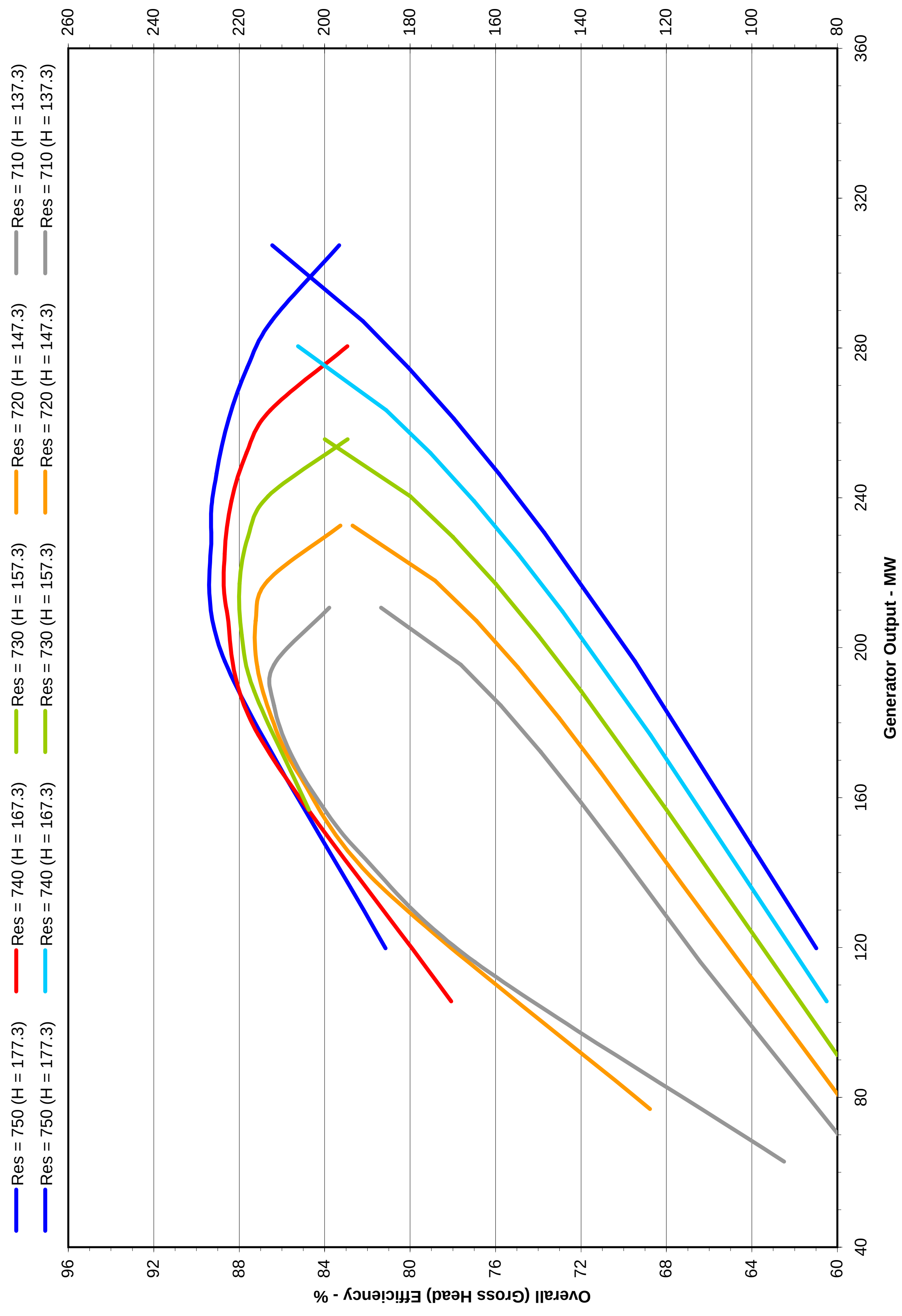


FIGURE 9.5
MICA DAM PUMP STORAGE OPTION - LEFT BANK 2-250 MW PUMP TURBINES
Generating Performance - One of Two Single Speed Units
Overall Efficiency, Turbine Discharge vs Generator Output

HATCH™

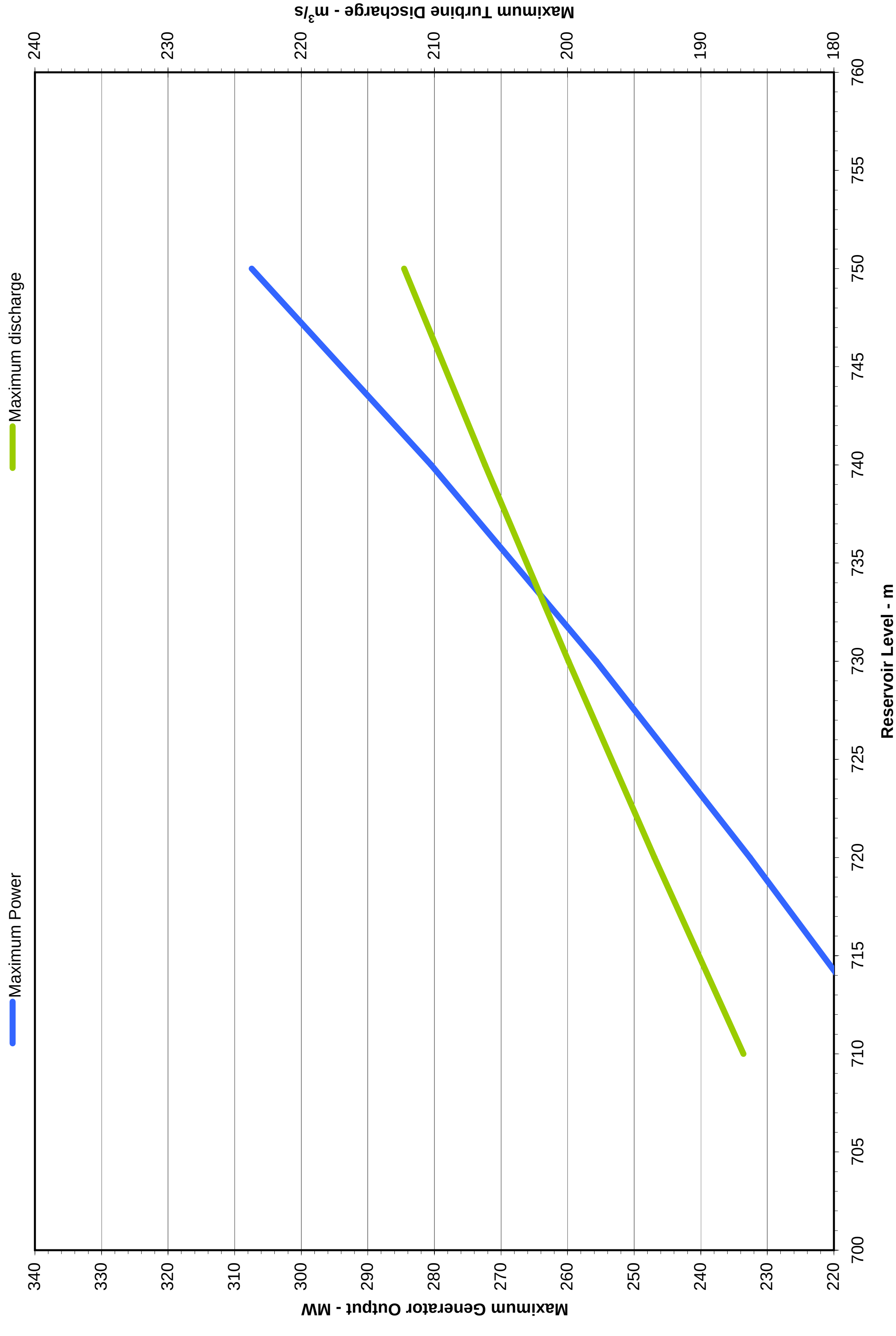


FIGURE 9.6
MICA DAM PUMP STORAGE OPTION - LEFT BANK 2-250 MW PUMP TURBINES
Generating Performance - One of Two Single Speed Units
Max. Generator Output, Max. Turbine Discharge vs Reservoir Level

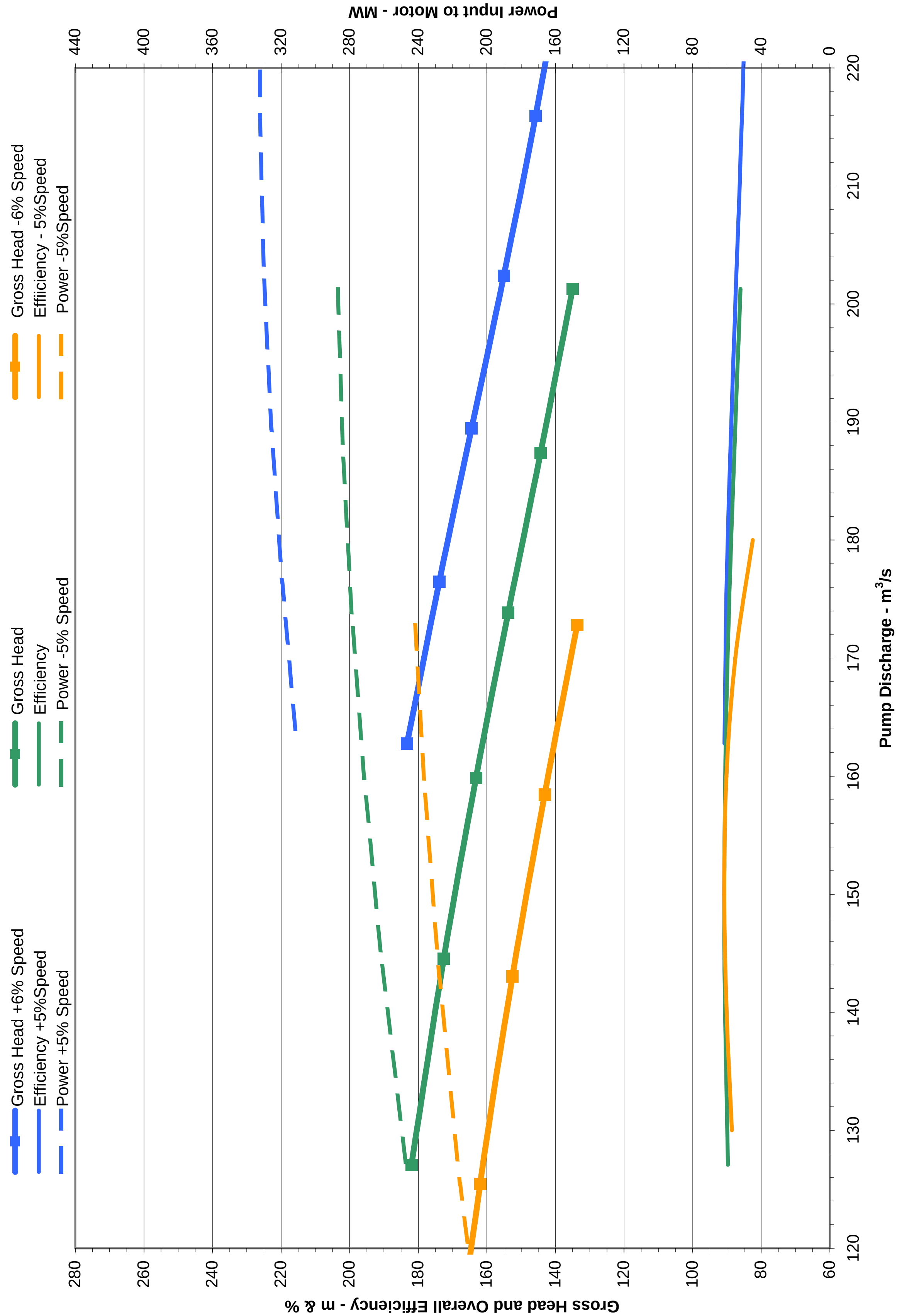


FIGURE 9.7
MMICA DAM PUMP STORAGE OPTION - LEFT BANK 2-250 MW PUMP TURBINES
Pump Performance - One Variable Speed Unit
Gross Head, Overall Efficiency, Power Input vs Pump Discharge

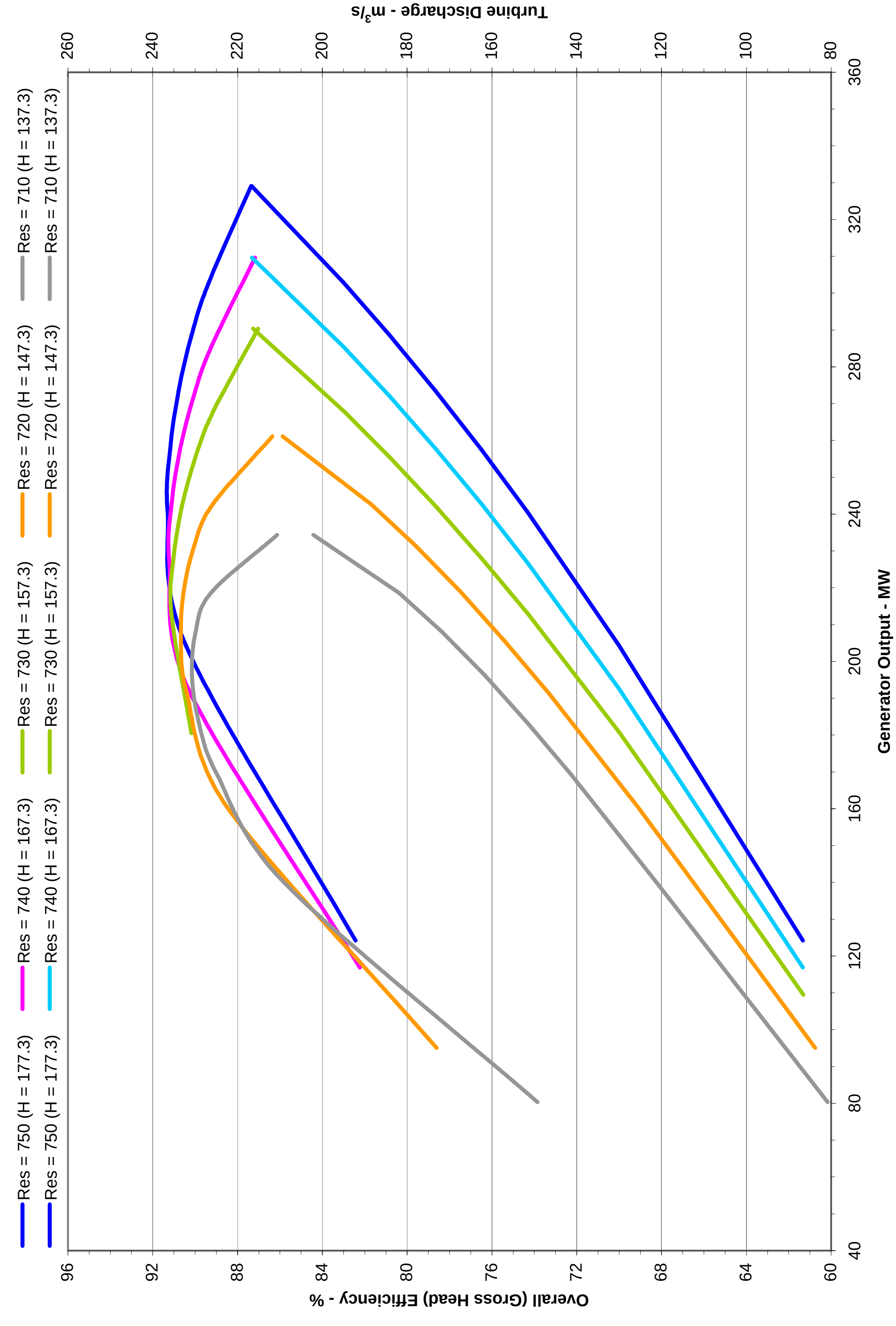


FIGURE 9.8
MICA DAM PUMP STORAGE OPTION - LEFT BANK 2-250 MW PUMP TURBINES
Generating Performance - One Variable Speed Unit
Overall Efficiency, Turbine Discharge vs Generator Output

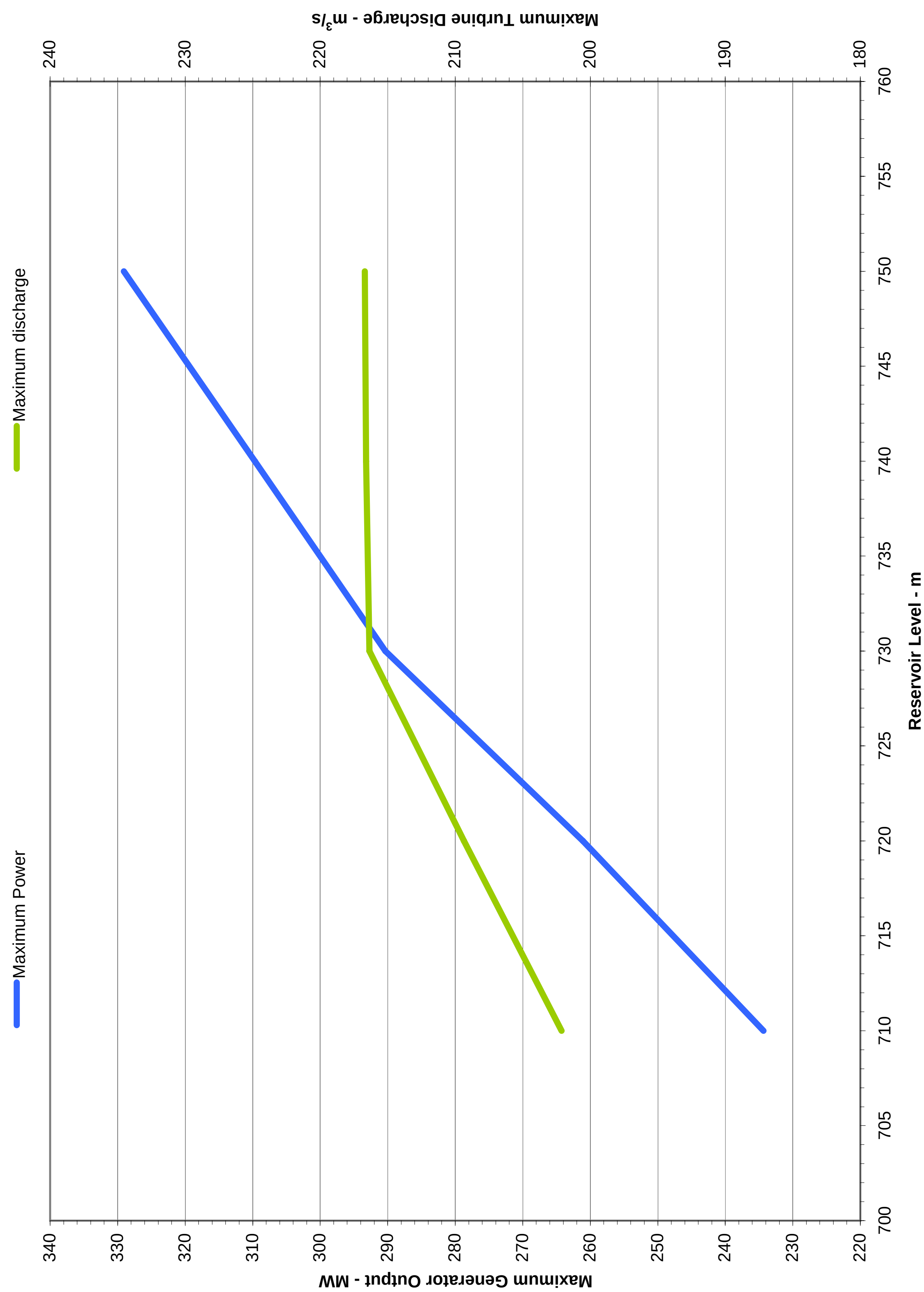


FIGURE 9.9
MICA DAM PUMP STORAGE OPTION - LEFT BANK 2-250 MW PUMP TURBINES
Generating Performance - One Variable Speed Unit
Max. Generator Output, Max. Turbine Discharge vs Reservoir Level

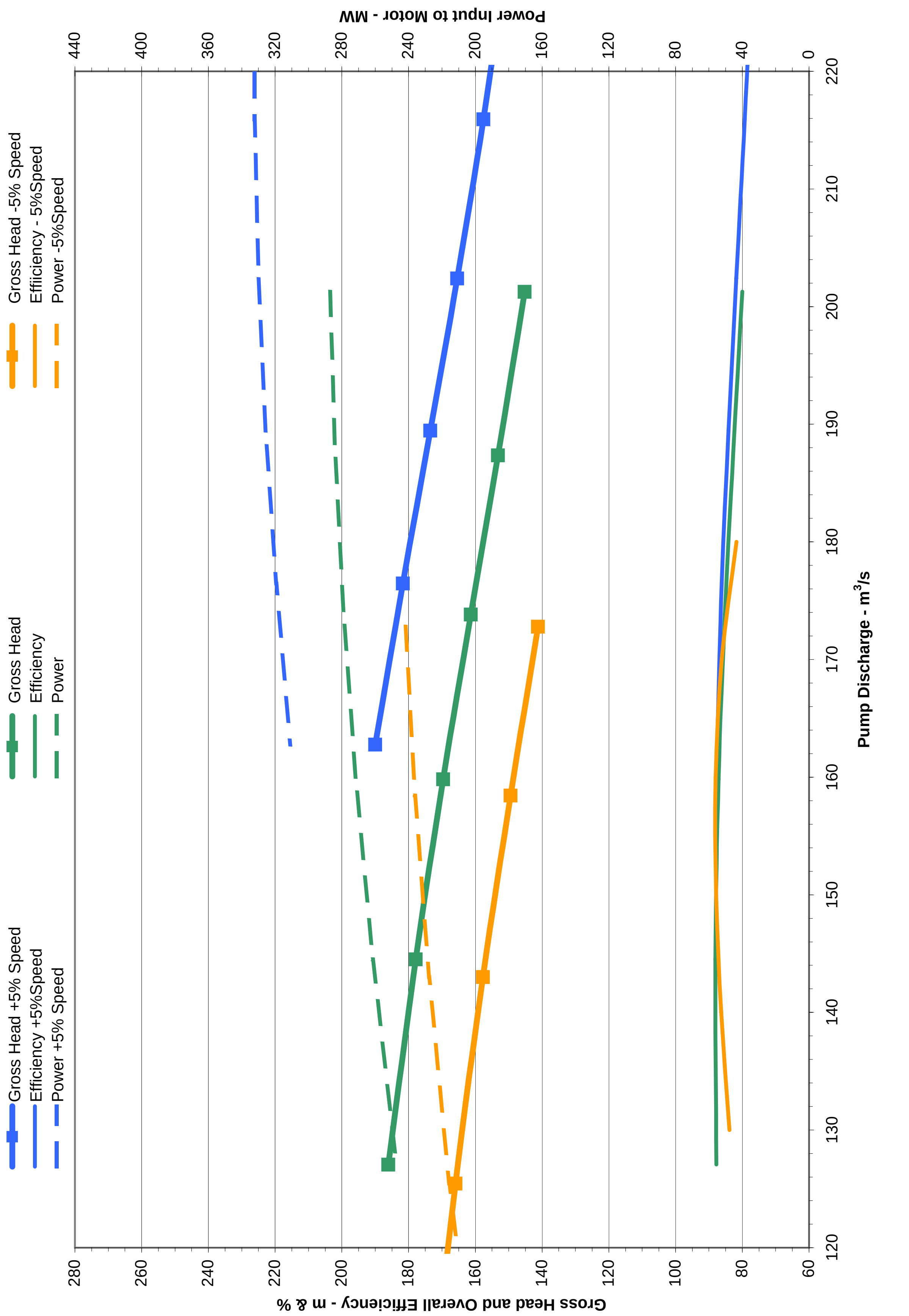


FIGURE 9.10
MICA DAM PUMP STORAGE OPTION - LEFT BANK 2-250 MW PUMP TURBINES
Pump Performance - One of Two Variable Speed Units
Gross Head, Overall Efficiency, Power Input vs Pump Discharge

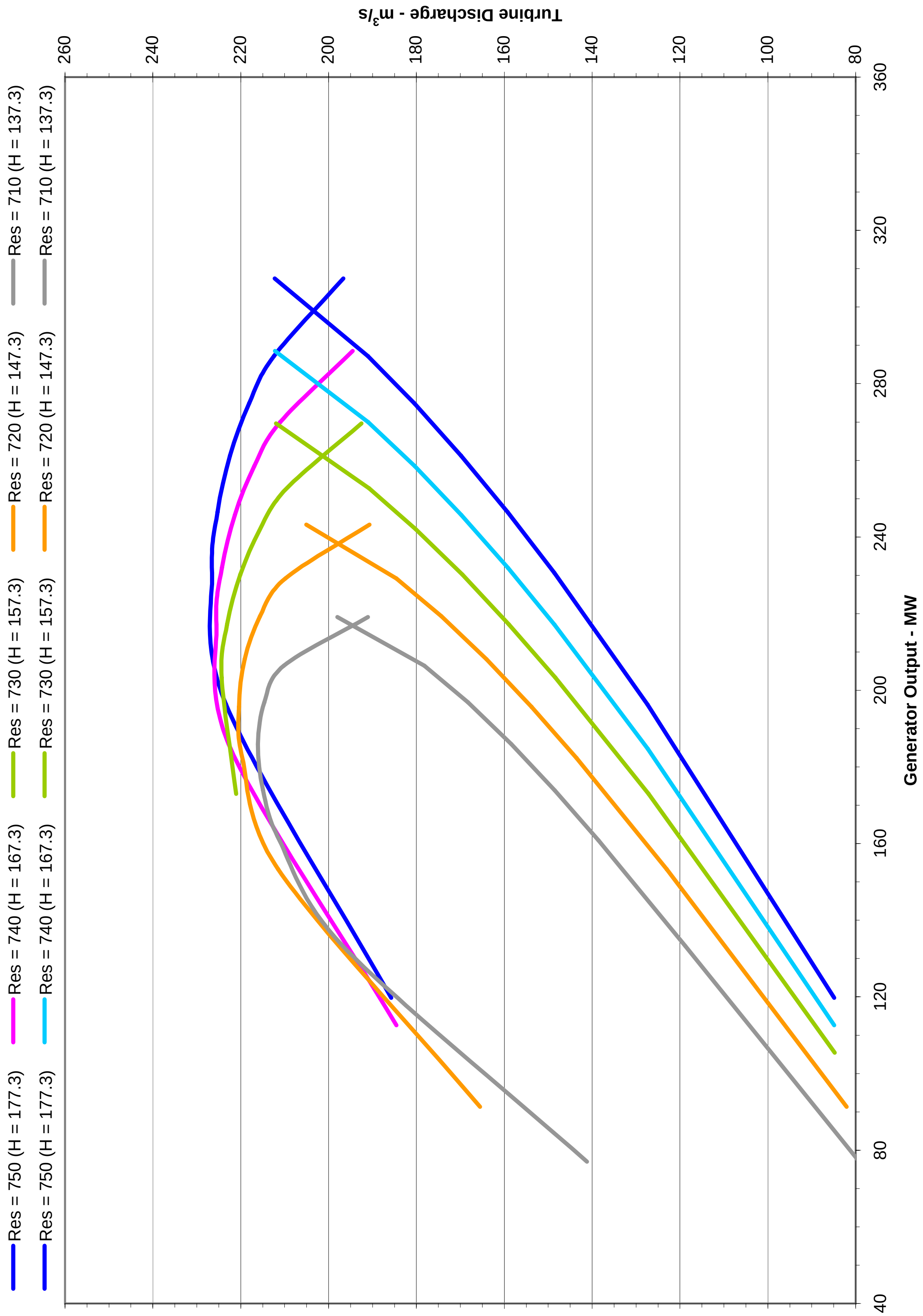


FIGURE 9.11

MICA DAM PUMP STORAGE OPTION - LEFT BANK 2-250 MW PUMP TURBINES

Generating Performance - One of Two Variable Speed Units

Overall Efficiency, Turbine Discharge vs Generator Output

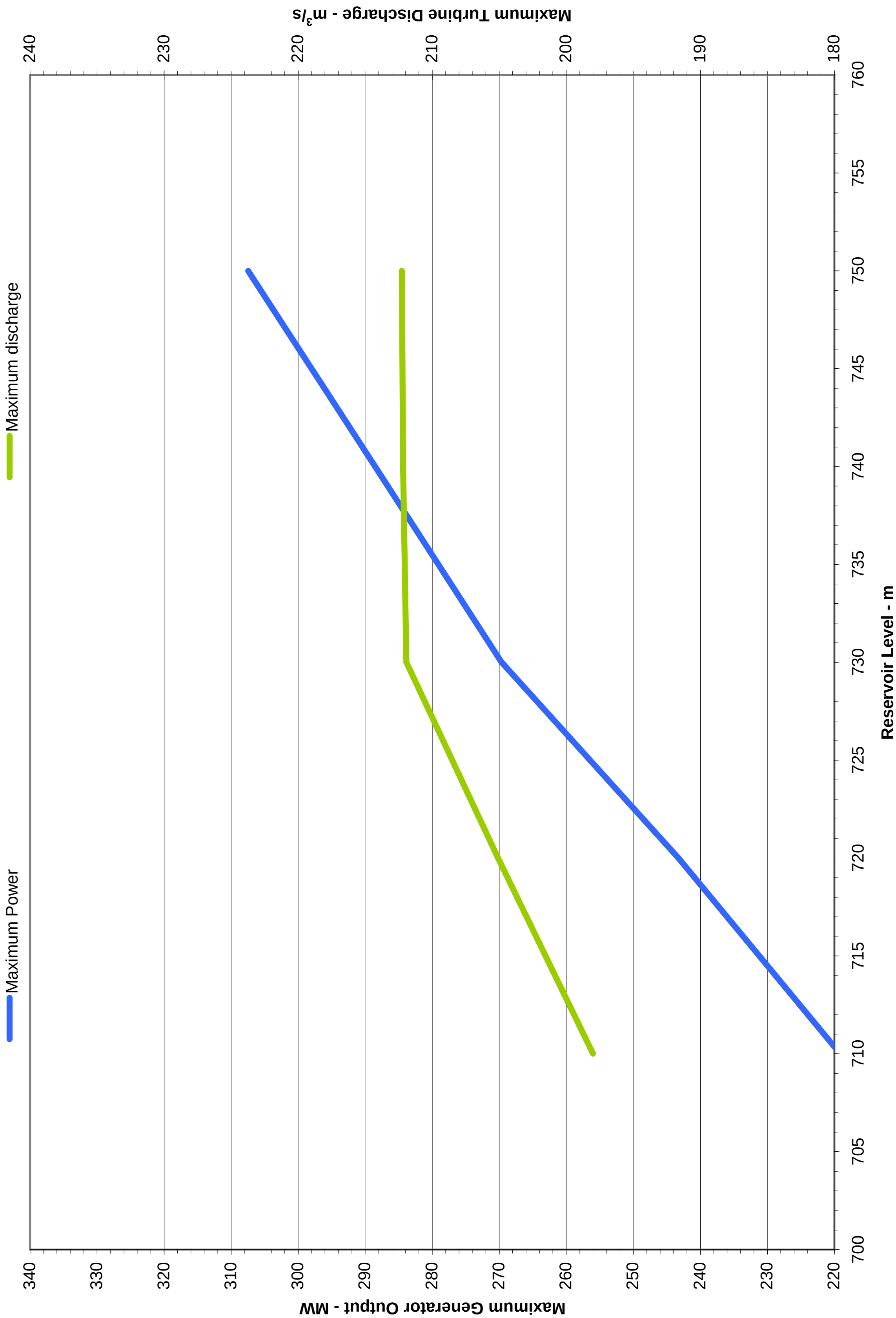


FIGURE 9.12

MICA DAM PUMP STORAGE OPTION - LEFT BANK 2-250 MW PUMP TURBINES

Generating Performance - One of Two Variable Speed Units

Max. Generator Output, Max. Turbine Discharge vs Reservoir Level

Appendix A

Photographs

Photo 1 Mica Dam Crest showing Outlet Works Structure Beaker Building and Trans Lines

Photo 2 Mica Dam Left Bank, Outlet Works Discharge Chute and Spillway

Photo 3 Mica Dam Left Bank Discharge Chute and Access Tunnel Portal to Diversion Tunnels

HATCH™

Suite 400, Oceanic Plaza, 1066 West Hastings Street
Vancouver, British Columbia, Canada V6E 3X2
Tel (604) 689 5767 ◆ Fax (604) 689 3918