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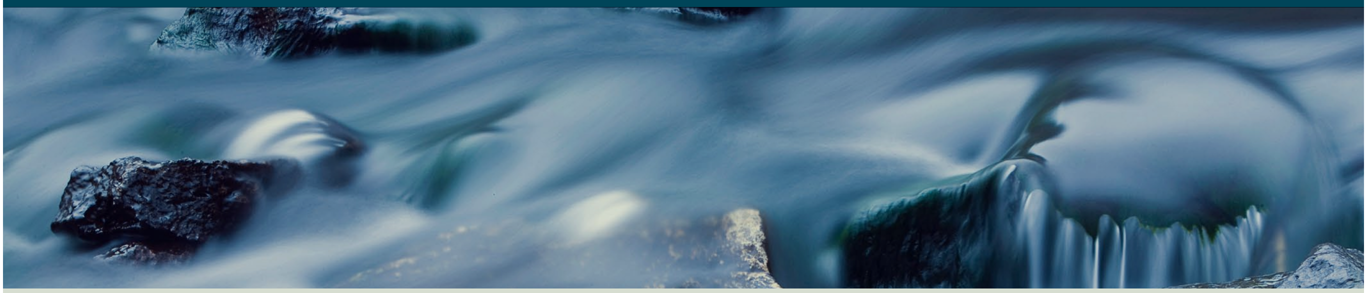

Laxá Hydropower Scheme, Iceland

Review of Sediment and Ice Challenges

Key Page

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Review of Sediment and Ice Challenges

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Prepared for: Landsvirkjun

Co operators: MultiConsult

Abstract: The report contains information on the Laxá Hydropower Scheme in Iceland, collected during the field visit to Laxá in June 2013 carried out by Haakon Støle from Multiconsult. Focus is on sediment and ice related problems at the three hydropower plants in the Laxá Scheme and recommendations for further actions on short term and long term basis.

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Andri Gunnarsson

Field Report

PROJECT
Laxá Hydropower Scheme, Iceland

SUBJECT
Review of Sediment and Ice Challenges

DOCUMENT CODE
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REPORT

PROJECT	**Laxá Hydropower Scheme, Iceland**	DOCUMENT CODE	125214-100-HAST
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CLIENT	**Landsvirkjun**	RESPONSIBLE UNIT	1087 Hydrologi
CONTACT	Andri Gunnarsson		

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	2013.09.20	Final Report			
	2013.09.07	Draft Report	Haakon Støle	Harald A. Simonsen	Odd Adler-Gjerde
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TABLE OF CONTENTS

REFERENCES

[1] Gunnarsson, A.: *Summary of Sediment problems Laxá II and III HEP*, Memorandum Landsvirkjun 2012.10.19

[2] Landsvirkjun: *LAX Laxávirkjun Gagnagrunnur 2010*. LV-2010/102. Landsvirkjun October 2010

[3] Landsvirkjun: Photos and video recordings from closedowns of the plants for flushing, inspection and maintenance etc. received from Landsvirkjun during the field visit.

[4] Gunnarsson, A. et al.: *Sniðmælingar í inntakslónum Laxárvirkjana*, Landsvirkjun, September 2012

1 Introduction

Laxá Hydropower Scheme is located on Laxá River in Northern Iceland, east of Akureyri. The hydropower scheme in Laxá was constructed by the town of Akureyri and the Government of Iceland before it was taken over by Landsvirkjun in 1983. The Laxá Hydropower Scheme is now owned and operated by Landsvirkjun. Landsvirkjun has experienced sever operational problems related to sediment loads as well as ice which are withdrawn together with the water from Laxá River for power generation in the three power plants in the Laxá scheme. Landsvirkjun initiated a comprehensive refurbishment programme for the Laxá Hydropower Complex three years ago. Many components of the Laxá 2 hydropower plant has been upgraded, including a new penstock and a renovated surge chamber and powerhouse. The field visit and this report is a part of Landsvirkjun's refurbishment plan for the Laxá Hydropower Complex, in which Multiconsult is happy to be able to contribute.

1.1 Objectives

The objectives with this study are to assess the sediment and ice related problems at the Laxá hydropower plants through a visit to the site and through the information made available to the Consultant during the visit to Iceland and to recommend possible measures aimed at reducing the impact of these problems on both short term basis and on long term basis.

1.2 Contractual Arrangements

The contact between Landsvirkjun and Multiconsult was established through an e-mail from Andri Gunnarsson to Haakon Støle on 2012.10.03. The scope of work was discussed via e-mail correspondence over some time leading to a Confirmation of Order sent from Multiconsult on 2013.01.22 signed by Odd Adler-Gjerde on behalf of Multiconsult, followed by Purchase Order No: 20131312 from Landsvirkjun dated 2013.03.20 signed by Guðmundur Björnsson on behalf of Landsvirkjun. These documents are given in Appendix 1.

2 The Laxá Hydropower Scheme

Laxá Hydropower Scheme is complex, both with respect to the history of its development; the way the scheme has been designed and constructed as well as the operational conditions. A brief introduction to the power scheme is therefore given below to give some reasons why the scheme is as it is today and to provide a basis for the recommendations for further actions as well as to safeguard that the Consultant understand the history, the design and the operation of components of the scheme correct.

2.1 Laxá Hydropower Scheme in Brief

The Laxá hydropower development includes two intake dams and three run-of-river hydropower stations. The upstream dam is referred to as the Laxá III dam which creates the intake pond to Laxá 1 and Laxá 3 hydropower plants. The downstream dam is referred to as Laxá II dam and the pond created by the dam serves as tailwater pond for Laxá 1 and Laxá 3 hydropower plants and it is also the headwaters for Laxá 2 hydropower plant. The overall layout of the Laxá hydropower scheme is shown in Figure 1 in Ref. [1]. This Memorandum *Summary of Sediment Problems Laxá II and III HEP* by Andri Gunnarsson is presented is Appendix 2.

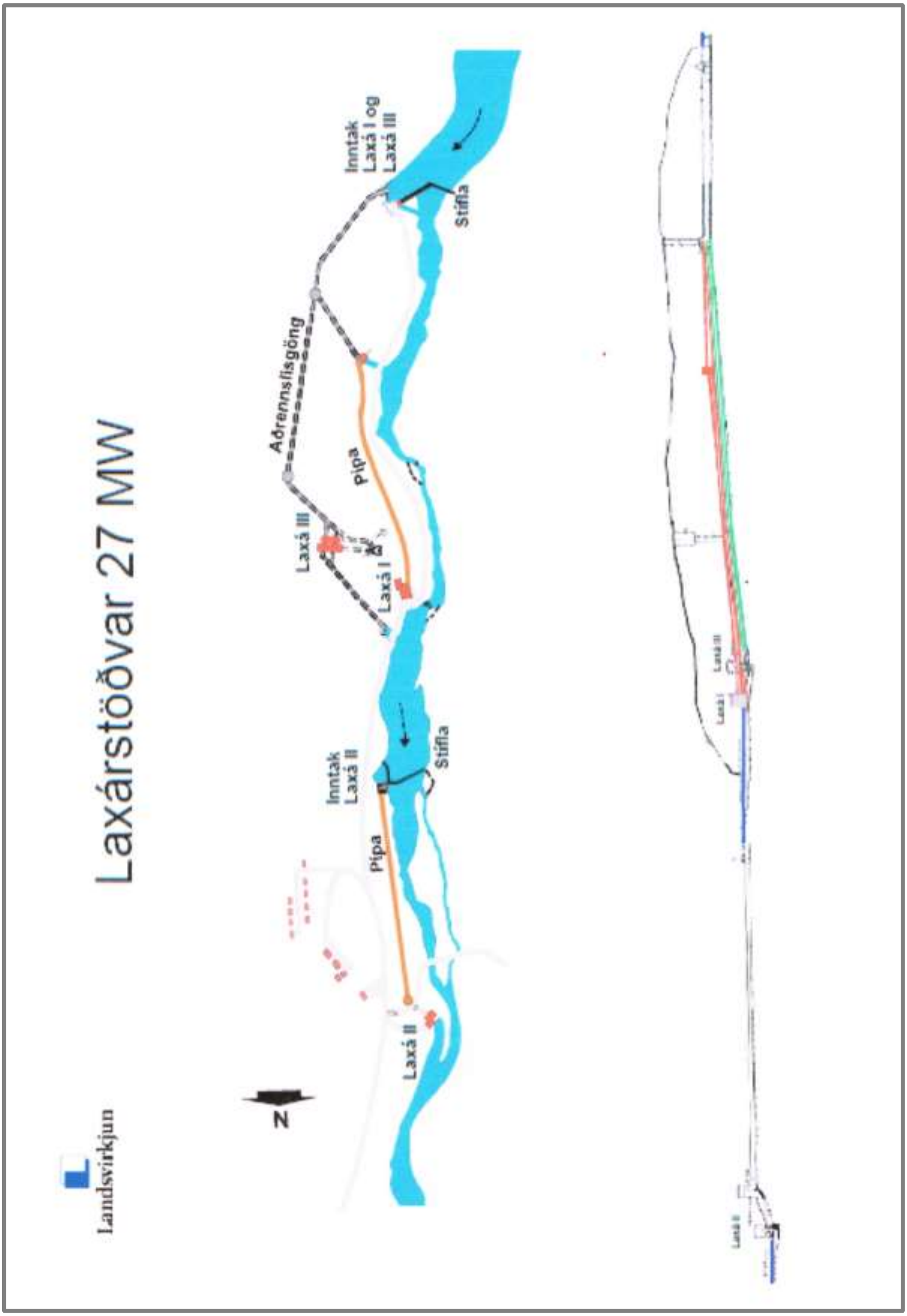

Figure 1: Layout and longitudinal section through the Laxá Hydropower Scheme with Laxá III and Laxá II dams and Laxá 1, Laxá 2 and Laxá 3 hydropower plants (Ref. 2).

2.2 Laxá III Dam and Intake

Laxá 1 hydropower plant was commissioned in 1939. The layout of the dam and the intake arrangement was then different from how it is today. The layout of the combined Laxá 1 and Laxá 3 hydropower plants is shown in Figure 2. The Laxá III dam, as it is today, is an “unfinished” dam. The layout is shown in Figure 3. When the first phase of Laxá 3 hydropower plant was built, it was assumed that a new and higher dam should be constructed downstream of the present diversion dam as shown in Figure 4. The present dam together with the bypass tunnel branch of the headrace tunnel should first of all serve as bypass during the construction of the high dam and later facilitate flushing of the reservoir.

The present dam represents a temporary design which has become permanent. When the Laxá 3 hydropower plant was constructed, it was designed to serve the dam shown in Figure 4 with a highest regulated water level at 138.5 masl. It has been decided that the high dam will not be constructed. It is now the time to finalize the design and finish the construction of the dam with an upstream water level close to what it is today. It is important that the final design of the dam includes robust and efficient facilities for sediment and ice handling.

It was not possible to find detailed as-built drawings of the existing dam-design during the field visit. Figure 3 is extracted from a drawing dated Sep 74 in scale 1:1000. Figure 5 and 6 show the layout of the intake arrangement with focus on the surface arrangements in Figure 5 while the underground arrangements are included in Figure 6. See also Figure 6 through Figure 8 in Appendix 2 which illustrates the present arrangements at Laxá III head-pond, dam and intake.

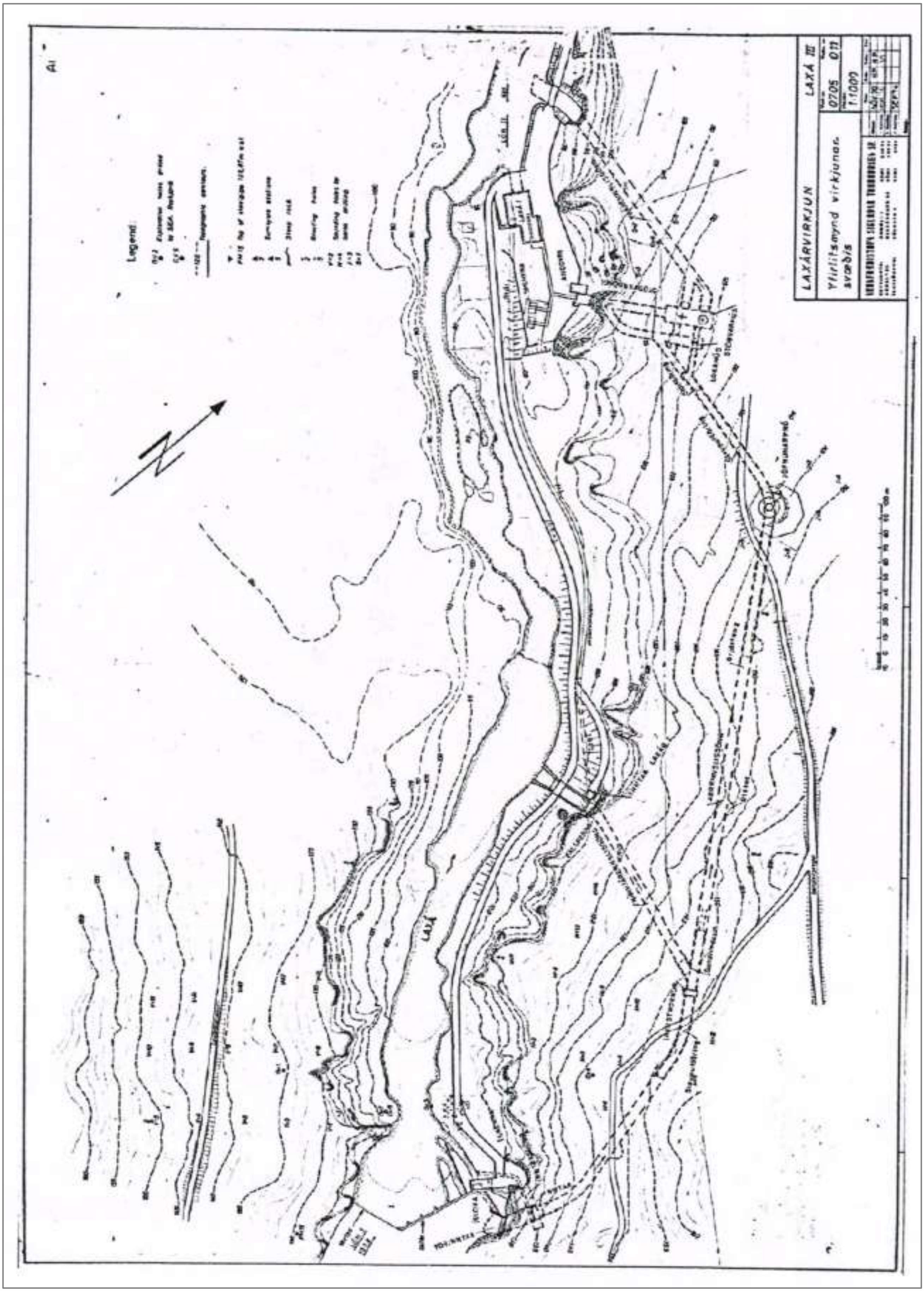

Figure 2: General layout of Laxá 1 and 3 Hydropower Plants (Ref. 2)

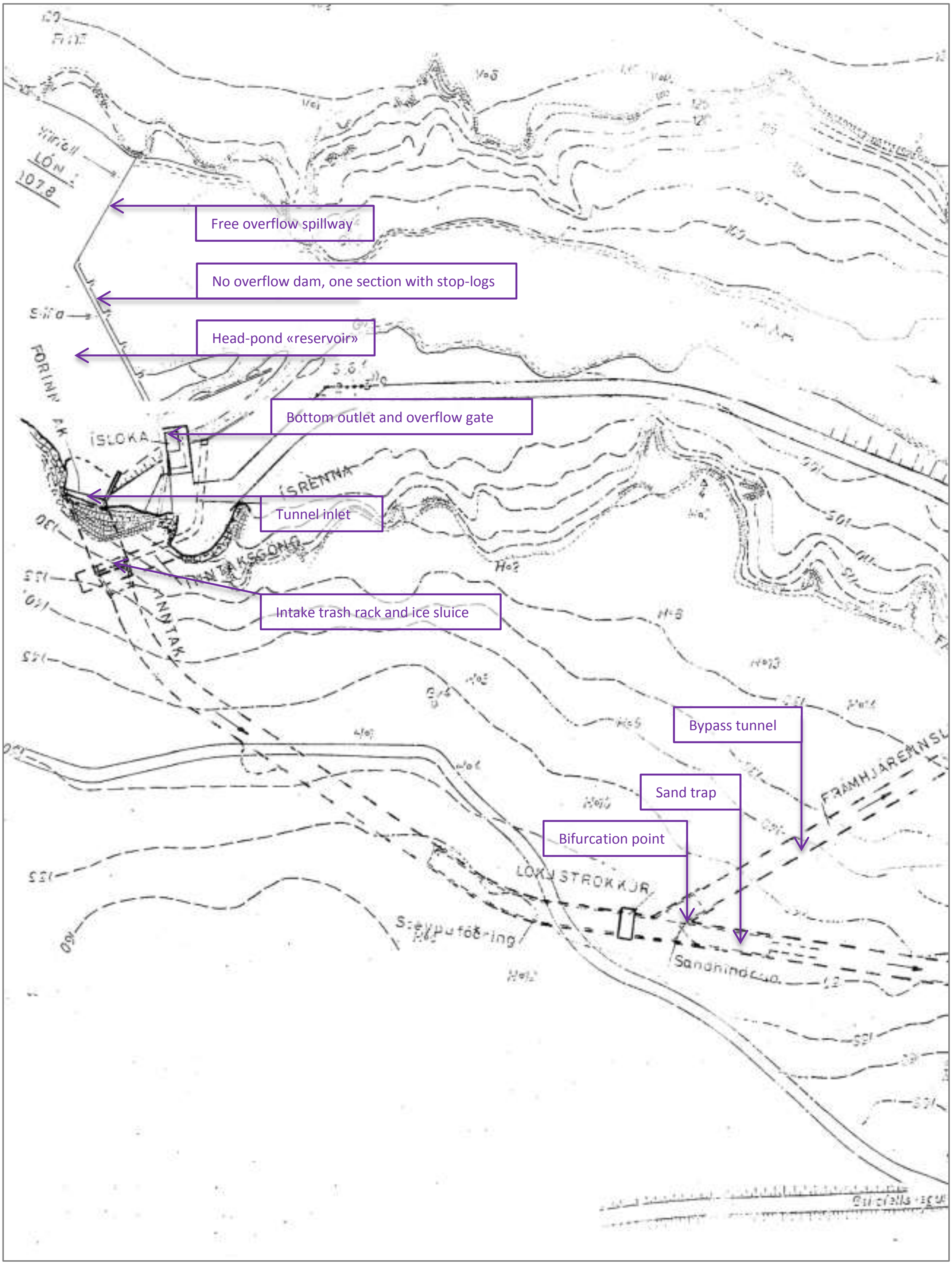

Figure 3: Layout of Laxá III Dam and Intake to Laxá 1 and Laxá 3 Hydropower Stations (Sep 74)

Figure 4: Layout planned high dam, the "New" Laxá III rockfill dam (March 67)

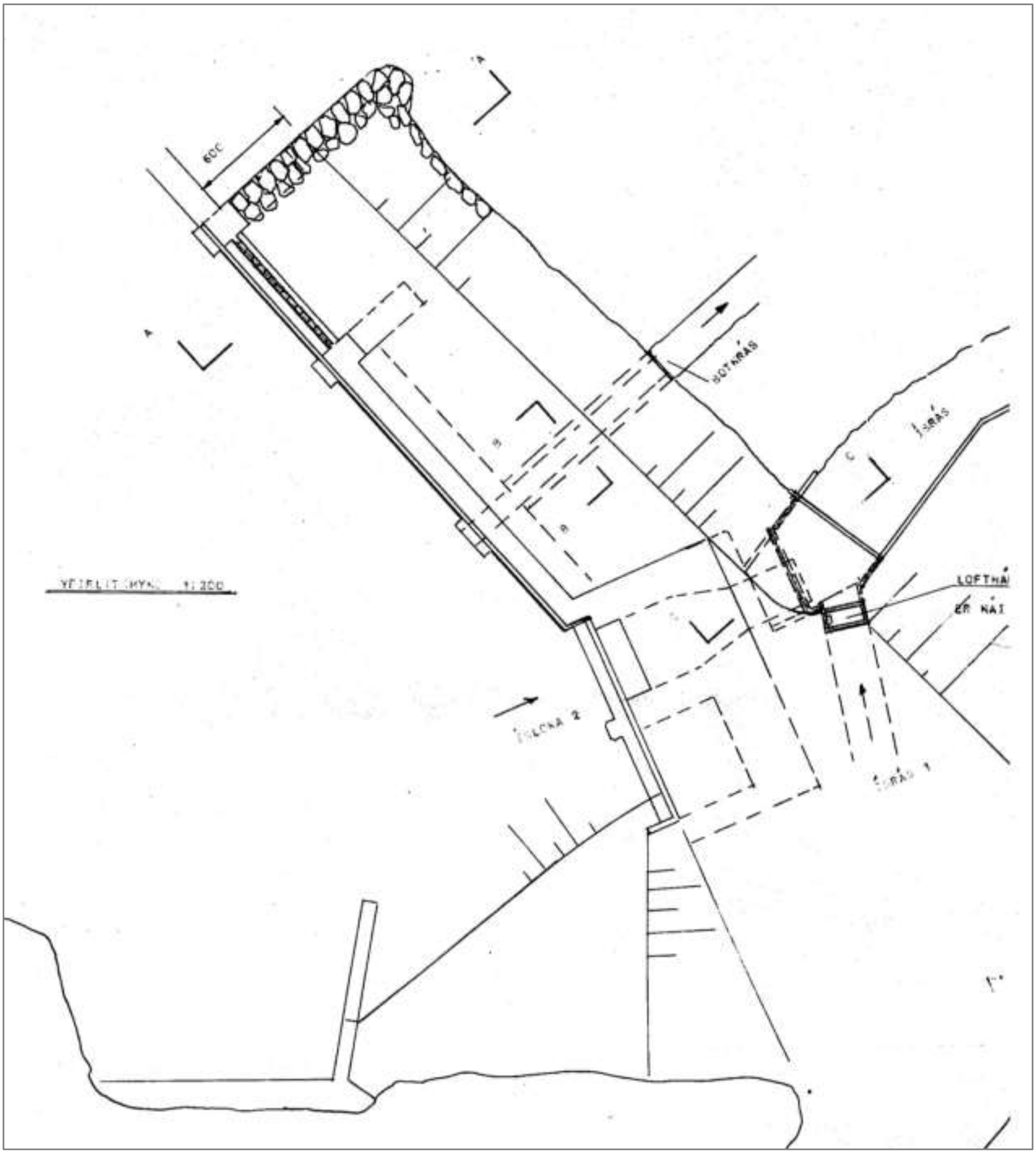

Figure 5: Layout Intake and part of Laxá III dam (more or less as-built)

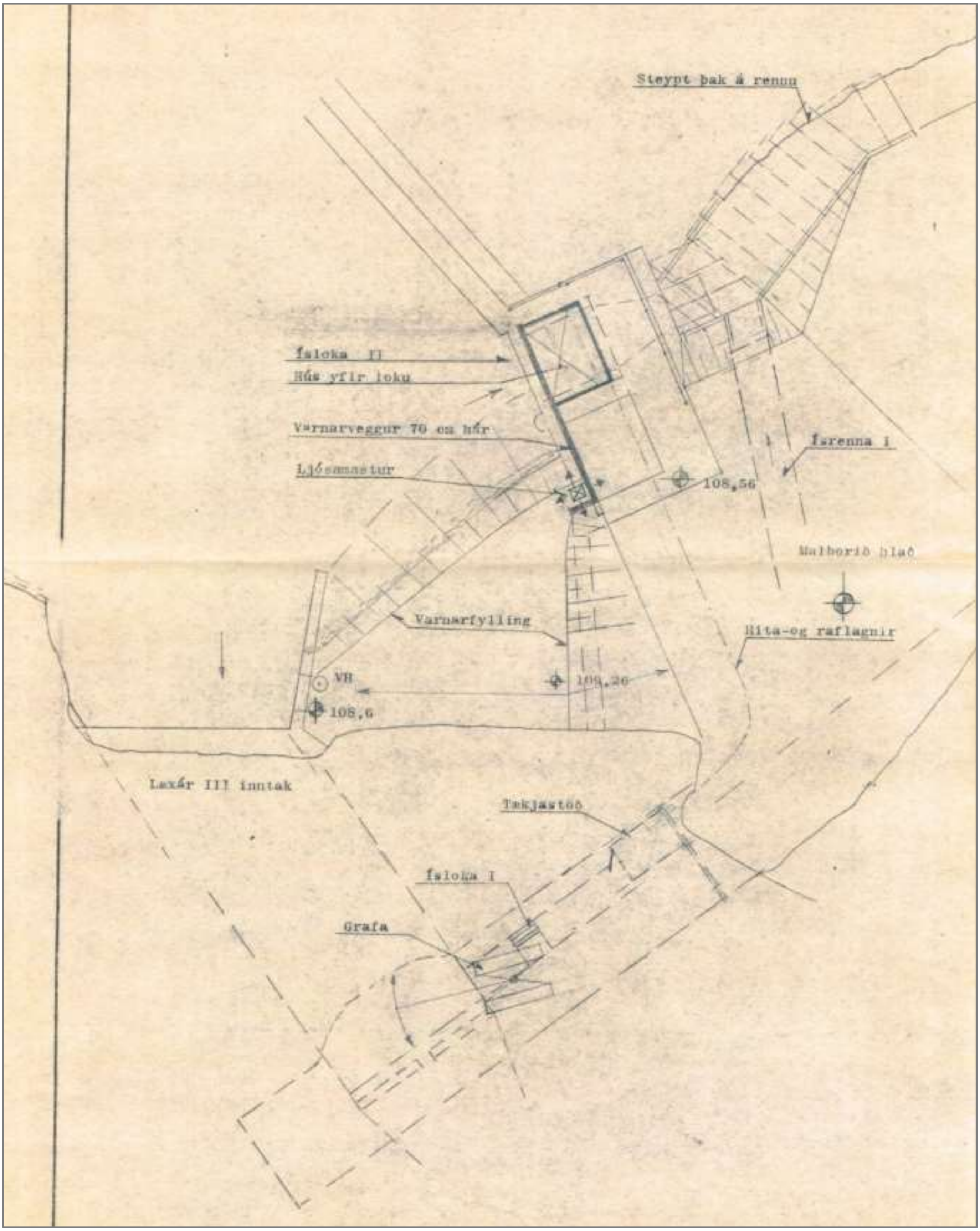

Figure 6: Layout Intake of Laxá I and III (more or less as-built)

The intake to Laxá 1 HEP was initially located where the overflow gate is located today, labelled "Isloka II" in Figure 6. The remains of the penstock are seen from the downstream side in Figure 9. It is believed that there was a plan to build new units in parallel with the original Laxá I with surface penstocks and surface power house as for Laxá I when the demand for power increased. New intakes would then be located in the bays along the longitudinal no-overflow section of the dam upstream of the original intake to Laxá I hydropower plant. These bays were closed by use of vertical stop logs. Some of them have later been closed permanently by concrete walls to replace the stop logs and an embankment has been constructed on the downstream side, see also Figure 30. The free overflow spillway shown in Figure 7, closing the left side of the dam, was as far as we understand constructed later. The terrain here was initially above the pool level.

Figure 7: Left side of the dam with free overflow spillway and the existing bay with vertical stop logs, seen from the right bank

Figure 8: Bay with vertical stop-logs upstream of concreted bays with downstream embankment

Figure 9: Overflow gate for passage of ice at the old intake location to Laxá 1 HEP

The overflow gate hoisting arrangement, with a hydraulic cylinder located under the gate as shown in drawings, was not in place. The gate is kept in position by use of two steel wires as shown in Figure 9.

The bottom outlet gate (width: 1.25 m, height: 2.00 m) just upstream of the overflow gate at the original intake site is shown in the drawing in Figure 5, but not on Figure 6. The hoisting mechanism was damaged as seen in Figure 10, and it was not clear if the gate could be operated again. The downstream side was closed by an embankment. It is not clear whether it is possible to reactivate this gate and use it for sediment flushing, see also Figure 30.

Figure 10: Hoisting arrangement for the bottom outlet gate, possible sediment flushing gate?

2.3 Laxá II Dam and Intake

The Laxá II dam and intake is shown in Figure 4 and 5 in Appendix 2. The dam and intake arrangement is shown with low water level during a reservoir flushing event in Figure 11. Drawings of the dam with layout and sections are shown in Figure 12.

Figure 11: Laxá II Dam and Intake to Laxá 2 Hydropower Plant (Ref. 3)

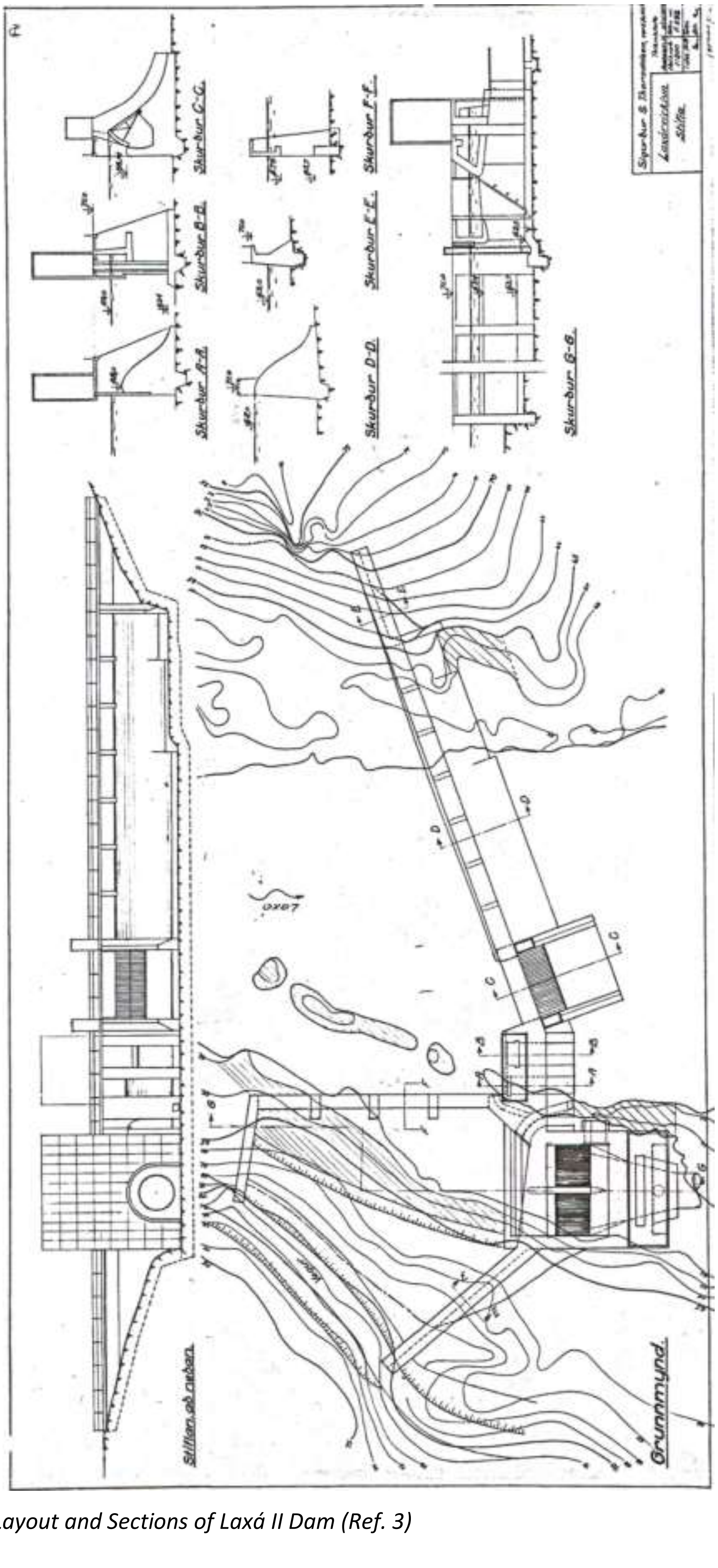

Figure 12: Layout and Sections of Laxá II Dam (Ref. 3)

Figure 13: Laxá II head-pond during draw-down and flushing (Ref. 3)

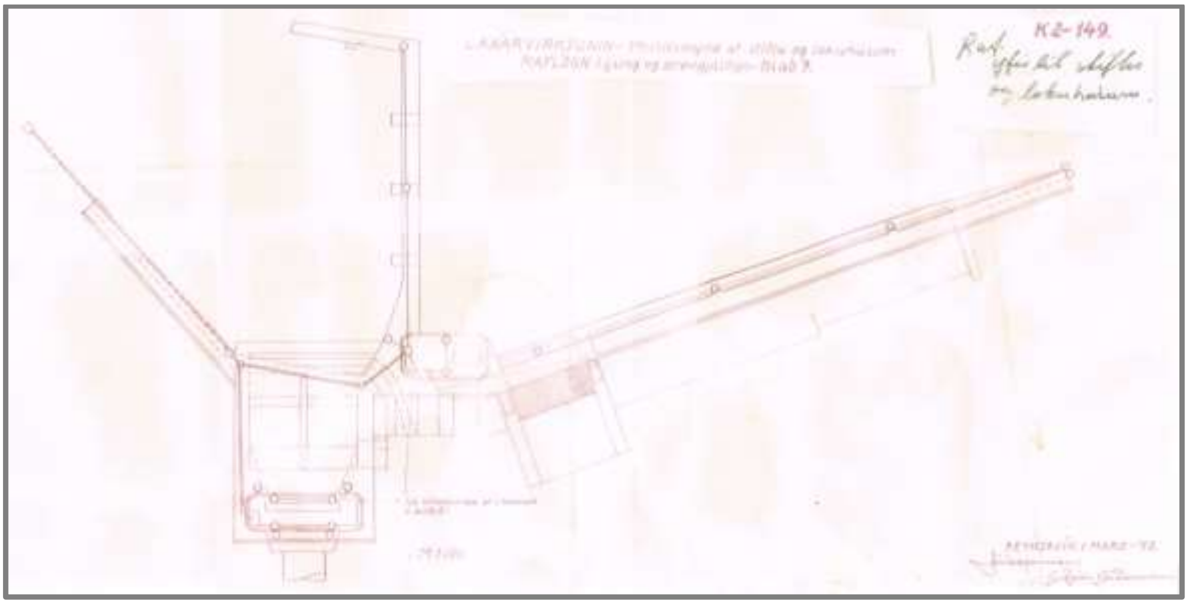

Figure 14: Layout of Laxá II Dam

Figure 13 shows the head-pond and the dam during draw down and a reservoir flushing event. The layout of the dam and intake structures (without any terrain information) is shown in Figure 14.

Laxá II dam is furnished with an overflow gate (flood gate) between the gate house and the free overflow crest, a high level gate and a low level gate under the gate-house and one small gate drawing water from a trench just upstream of the trash rack. The intake gate is located downstream of the trash rack. A “skirt wall” separates the intake bay from the head-pond. Vertical steel bars are located under the “skirt wall” to prevent large floating objects and ice to pass under the “skirt wall”. There is also a surface outlet, controlled by stop logs, in the corner between the trash rack and the “skirt-wall” through which surface water from the intake bay can be passed downstream.

Figure 15: Dam, intake bay with "skirt-wall" and water and ice passage arrangements at Laxá II Dam

There is no facility for letting the entire river flow by-pass the intake in an "as-before-situation" for normal to higher river discharges. Efficient sediment flushing, which requires a low upstream water level and a closed intake, can therefore not be implemented with higher river discharges.

The flip bucket of the spillway on the dam has damages as it can be observed in Figure 16. This is most likely caused by freezing action and not by cavitation or sediment wear. It seems that it is concentrated on one section of the dam which may have had poorer concrete quality than the other sections initially.

Figure 16: Damages at the flip bucket of spillway at Laxá II dam

3 Sediment Related Problems at Laxá Hydropower Scheme

The sediment related problems at Laxá Hydropower Scheme are addressed by *(Gunnarsson, 2012)* reference is made to Chapter 2 in Appendix 2 where the findings prior to the field visit are summarized. The bulk of the sediment load which is transported by the river into the head-pond of the Laxá III dam is passing through the intake, the headrace tunnel and the turbine as there is no efficient and "easy to operate facility" for bypassing the sediment load of the river. Sediment-induced erosion has been observed in both Laxá 3 and Laxá 2 turbines as shown in Figure 17.

Figure 17: Upper: replaced runner from Laxá 2 with signs of sediment-induced wear. Lower: the runner of Laxá 3 from an inspection of the turbine on 5th April 2011 (Ref. 3).

3.1 Sediment sources and sediment transport in Laxá

The documentation from sediment sampling as well as reports from the operation of the power-plants reviles that both relatively fine sediment load (sand and silt) as well as large particles as gravel and stones have passed through the turbines.

3.1.1 Sources of Finer Sediment, i.e. Sand and Silt

It is believed that the main sediment source is the steep slopes along the Laxá valley. The erosion is believed to take place during heavy rains and snow melt. Snow avalanches as well as mass wasting (slow land-slides) may also play an important role with respect to feeding the river with sediment from the valley slopes. The slopes shown in Figure 18 and 19 are very subjective to erosion and an unlimited sediment source to Laxá.

Figure 18: Valley slopes on the eastern side of the Laxá valley upstream of the Laxá III dam

Figure 19: More sediment yielding valley slopes in the Laxá valley upstream of the Laxá III dam

The discharge of the Laxá river is more constant than for most rivers due to the subsurface inflow from Mývatn through porous lava rocks. So even if the discharge of the main river varies very little, the discharge in the streams draining the catchment downstream of Mývatn is expected to vary from close to nothing to substantial discharges during snow melt and heavy rains. The fluctuations in the discharge of Laxá river is mainly contributed by these tributaries and the variation in discharge in Kráká river. The surface outlet from Mývatn is controlled by the outlet works, but the variation in release here is rather small and slow.

Figure 20: Sediment deposits in a small right bank tributary to Laxá River close to the dam

Figure 21: Sediment deposits along the bank of Kráká River upstream of Mývatn

Even if large floods are rare in Laxá, the river carries the sediment load supplied to it as there are no lakes or reservoirs where it can settle for a long time. Floods may play a smaller role than normal, but ice may play a larger role than normal, in the sediment transport pattern in Laxá. When the river is partly frozen and small ice dams are formed, the velocities in the opening between the ice and the bottom may increase drastically locally, causing local scour and bringing bed sediment into suspension.

Suspended sediment has been sampled at Helluvað gauging station, which is located just downstream of the confluence between the outlet of Mývatn and Kráká river. The sampling site is the bridge crossing the river upstream of Helluvað. A rating plot of all observed suspended sediment concentrations and the corresponding river discharges is shown in Figure 22. To illustrate the poor or non-existent correlation there is between discharge and concentration it is seen that the lowest observed concentration of 3 mg/l has the same or slightly higher corresponding river discharge as the highest observed concentration of about 300 mg/l in this data population.

The observed particle size distribution of the suspended sediment is shown in Figure 23, which reveals that nearly 60% of the observed suspended load is sand.

The gauging station at Helluvað is located where the sediment rich water from Kráká is mixed with the sediment free water from Mývatn. It is believed that observed concentrations both upstream in Kráká as well as further downstream in Laxá close to Laxá III dam would show higher average concentrations in general.

Bed sediment may also freeze and thus bound to larger ice-blocks which will be transported downstream when the ice cover brakes up. This mechanism is believed to be the way large gravel and stones are transported into the head-pond of Laxá III dam.

It is not easy to determine the sediment yield in Laxá, due to the mixed sediment transport pattern. Sediment yield estimates based on suspended sediment sampling campaigns will most likely underestimate the sediment load. This is due to the poor correlation between the sediment load and the river discharge, and that the sediment supply mechanisms are guided by very local conditions in many small tributaries along the valley. Large quantities of sand may also be transported as bed load and thus not be measured by a suspended sediment sampling programme.

It is impossible to prevent sand and silt from entering the Laxá III head-pond. From a practical hydropower operations point of view, it is more important to design a robust sediment and ice handling arrangement for the Laxá hydropower scheme than to study the sediment transport pattern in great depth. We know that the sediment load is too high to accept that it passes through the turbines. At the same time we know that close to 100% of the sediment load of Laxá upstream of the dam will end up in the river downstream of the power plants in the long run. It is not realistic to extract a substantial amount of the sediment load and deposit it on land. The challenge is to minimize the amount of the sediment load passing through the turbines of the power scheme and maximize the amount which by-passes the turbines.

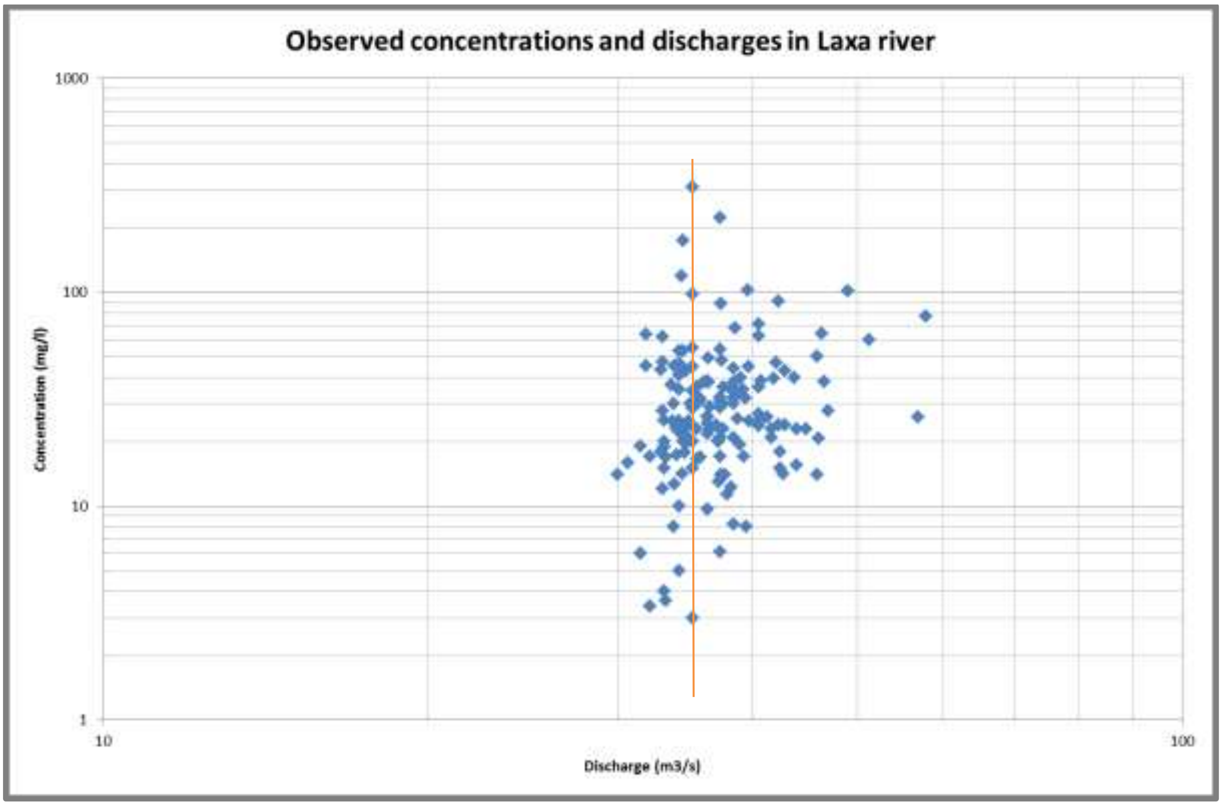

Figure 22: Observed suspended sediment concentrations and river discharges at Helluvað in Laxá

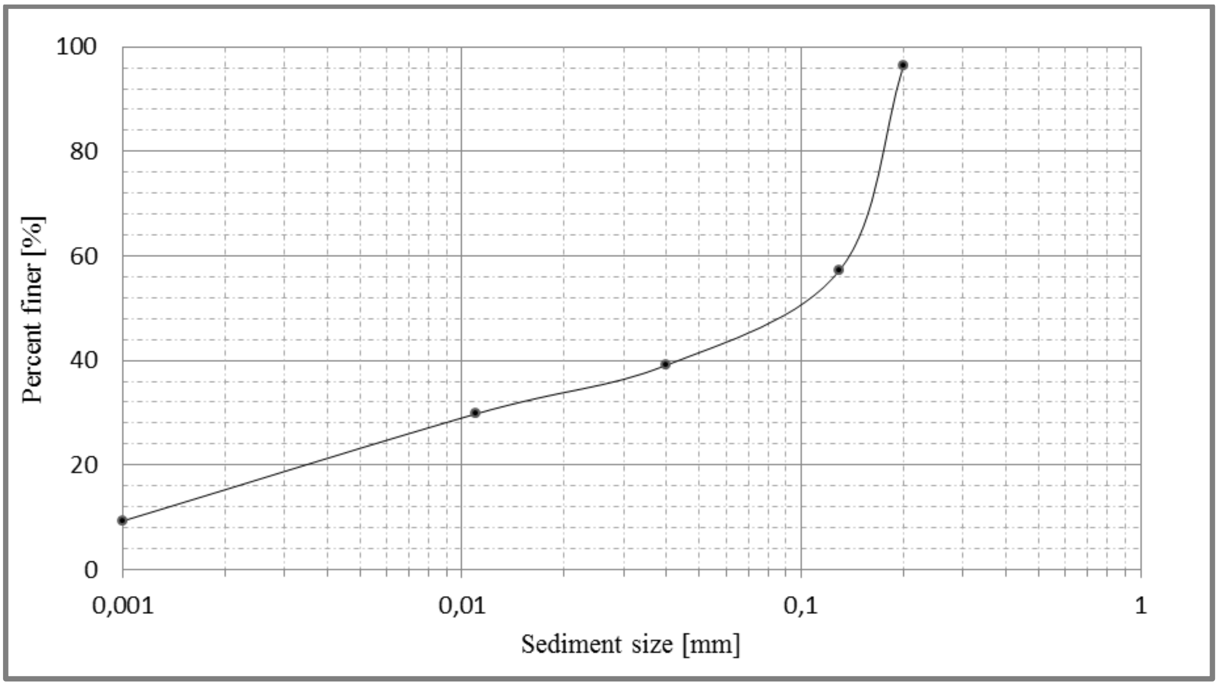

Figure 23: Observed particle size distribution of suspended sediment at Helluvað in Laxá

3.1.2 Sources of Larger Sediment, i.e. Gravel and Boulders

Boulders have been observed in the waterways of both Laxá 3 and Laxá 2 hydropower plants. More than ten stones were found in the spiral-casing of the turbine itself at Laxá 3 on the event 22nd March 2011. These stones are estimated to be in the range from about 50 mm to 300 mm, based on the video recorded on the event. These particles may have been transported all the way from the head-pond to the turbine, but it is more likely that they come from the surge shaft. The mechanisms which have transported these stones to the turbine is addressed below.

Hypotheses 1: Large particles enters the waterway through the intake from the head-pond

The same intake structure is serving as the intake to Laxá 3 and Laxá 1 hydropower plant and as a flushing channel for the reservoir. While the velocities are small and unable to transport gravel and boulder during normal operation of the intake, the velocities are high and enabling transport of gravel and stones when it is operated in flushing mode. The trash rack at the intake has an open section in the bottom. This allows particles larger than the light opening of the trash rack to pass under the trash rack. The reasoning behind this design is most likely linked to the high velocities which will occur during flushing. If the entire section was furnished with a trash rack, it would most likely clog up during flushing. Photos from inspections of the tunnel between the intake gate and the bifurcation point reveals that the concrete tunnel floor has been severely damaged. This is believed to be caused by the flushing operations.

Ice blocs containing gravel and stones may have a density close to the density of water. Blocs containing large particles and ice may therefore be transported as bed load throughout the headrace tunnel and end up in the turbine even though these particles would not be transported individually due to their weight.

Hypotheses 2: Large particles enters the waterway through the surge shaft

The drawing Figure 4 is extracted from shows also a longitudinal section through the waterway. This is shown in Figure 24. The plan included a "superstructure" on top of the surge shaft which would prevent surface water to enter into the surge chamber. Figure 25 shows the present situation on top of the surge chamber which also is an unfinished structure. There is no structure to prevent material from sliding into the surge chamber during snow melt or heavy rains. Ground water is furthermore drained into the surge chamber through cracks in the rock. The ground water will freeze as it is subjected to the air temperature during winter and ice bodies will form and be hanging from the side walls until they become so heavy that they break off and fall into the surge chamber. Pieces of rock may break off and fall into the surge chamber together with the ice.

The water standing in the surge chamber will be exposed to the air temperature as well as to radiation to the sky during the long winter nights. When the surface temperature is below 4 degree centigrade, the density is lower than the somewhat warmer water below and the temperature gradient will prevent the surface water from mixing with the heavier water below. If the water withdrawn from the river contains ice, the ice will tend to accumulate in the upper part of the tunnel as it has a lower density than the rest of the water in the tunnel. The gradient of the tunnel increases from the point where the surge chamber is connected with the headrace tunnel. There is therefore hydraulically a high break here where ice will tend to accumulate as air also would do when the plant is operated normally.

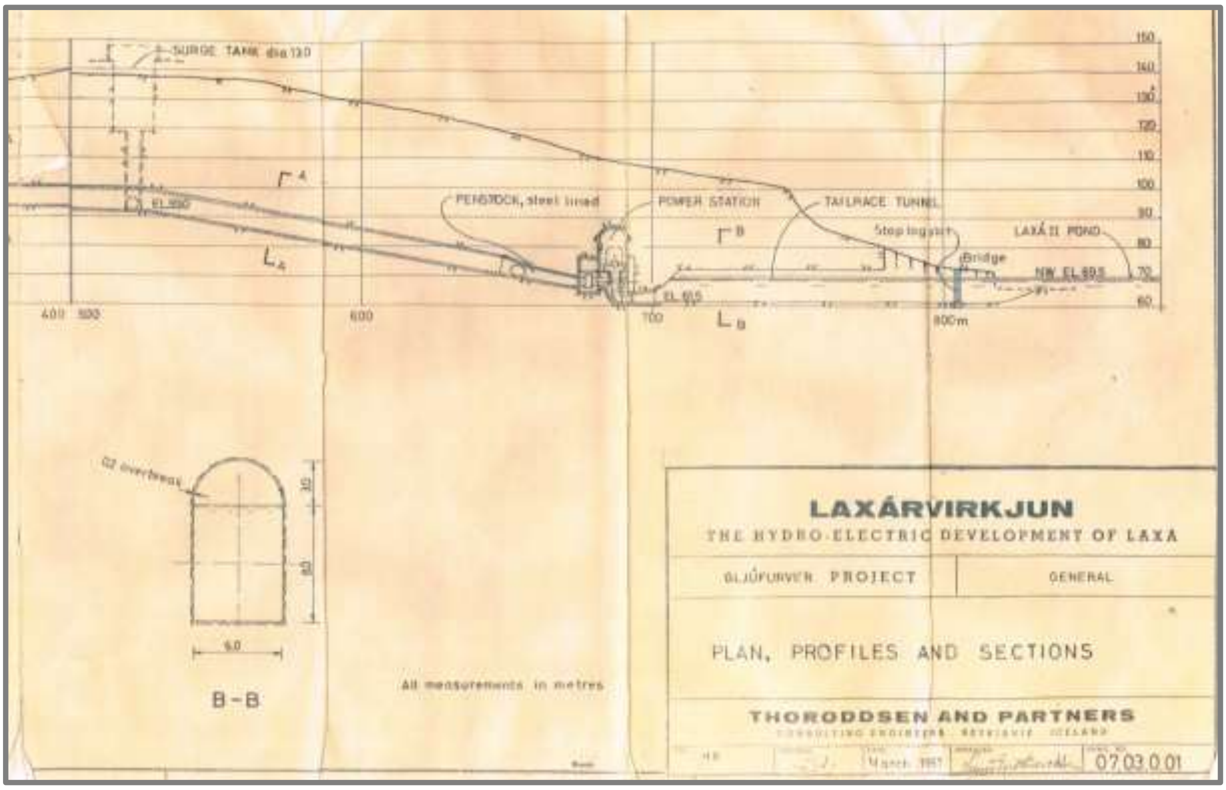

Figure 24: Longitudinal section of the waterway as designed for the Laxá III high dam

Figure 25: Surge shaft opening as it is today

Some of this ice may settle sideways and upwards into the surge chamber and give momentum to the formation of an ice cover in the chamber. This ice cover will bind itself to the rock surface in the chamber and break down the rock as the water in the cracks in the rock will expand and slowly cause fragmentation of the rock. Large forces will occur when the ice surface starts to move up and down due to surges in the water ways when the load changes. Pieces of rock will break off and sooner or later be transported into the tunnel and the turbine due to surges or together with ice blocks.

Laxá II Dam

Large particles in the range 0.2 to 0.5 m are also found just upstream of the trash rack at the Laxá II intake. These particles can only pass the trash rack if they are subjected to very high velocities or bound to ice. The trash rack bars had initially a spacing of 100 mm, but they were replaced by new racks (with bars cc 500 mm) after the first winter due to ice-production on the rack itself. The sediment flushing arrangement with the trench and the small gate can only have a chance to move these particles when the water level is close to the bottom of the forebay and there is open channel flow in the trench, which never happens.

These large particles are most likely transported by ice. They may come from the river upstream, but it is more likely that they are eroded from the banks of the forebay and the head-pond. Figure 24 shows that the stone masonry lining of the bank of the forebay is damaged and many stones have been removed also from the stone-lined right bank of the head-pond as shown in Figure 25 as well as Figure 13.

Figure 26: Damages of the stone masonry lining along the right bank of the forebay

Figure 27: Damages of the stone masonry lining along the right bank of the head-pond

Ice in action in the head-pond and the forebay of Laxá II dam is shown in Figure 28. This is the most likely mechanism to transport stones and gravel from the banks of the head-pond to the intake trash rack.

Figure 28: Ice action in the head-pond and the forebay of Laxá II dam (Ref. 3)

3.2 Experiences with Sediment Handling at Laxá

The Consultant has only visited the Laxá hydropower scheme for two days and has no experience from sediment handling at the plant. The comments given below is based on his interpretation of information given to him from Landsvirkjun via documents, drawings, photos, videos and from talking with the staff at Laxá in addition to the information he has deducted from the observations he made at the site. This does therefore not represent the full picture and additional information and corrections are welcomed. This presentation of the present situation is first of all a basis for the recommendations given in the next chapter on how sediment handling at Laxá can be improved.

3.2.1 Laxá III Dam

There is no facility to continuously abstract the sediment rich bottom flow as the flow approaches the intake and thus exclude a substantial part of the sediment load, especially the coarser sediment fractions, from the flow at the intake site. The only way to exclude sediment load is therefore to periodically flush the head-pond (i.e. “the reservoir”).

The trapping ability of the head-pond of Laxá III is initially significant, but the storage ability for trapped sediment is limited and considerably smaller than for Laxá II dam. The velocities through the head-pond are much higher at Laxá III then in Laxá II. If the head-pond is not flushed relatively often, the major part of the sediment load, sand and coarse silt, will travel through the head-pond and be transported to the power plants in operation, Laxá 1 and/or Laxá 3. The sediment load contains little fines, i.e. fine silt and clay, so the water may look relatively clear even though it is transporting considerable amount of sand and coarse silt.

The low level gate in the dam (shown in Figure 10 and Figure 30), which is the simplest and to most outsiders, the first choice for flushing sediment deposits from the head-pond of Laxá III dam, has not been used to flush sediment deposits during the time Landsvirkjun has operated the plant, may be never(?). Since Laxá 3 was constructed, the diversion tunnel has been the designated tool to flush sediment because the high dam would come sooner or later and the bottom outlet gate in the dam could then not be used. So it has been deactivated rather than upgraded for flushing purposes.

The diversion tunnel has been used to successfully flush some of the deposits in the upstream reservoir through the intake. The damages to the floor in the tunnel as well as the sediment induced wear of the flow-splitters at the downstream end of the spillway-chute downstream of the radial gate are proof of the large quantities of sediment which has been flushed at high water velocities.

The sand trap downstream of the bifurcation of the headrace tunnel has as far as we understand been less successful in abstracting substantial quantities of sediment because it is small with very limited trap efficiency, but also because there is no easy way to unload sediment which may be trapped there. When a sand-trap is filled with deposits, its trapping ability goes to zero. The sand trap has therefore had no significance except may be retarding or stopping some larger particles from moving downstream towards the turbines.

So even if large quantities of sediment has been flushed and thus bypassed the turbines, the erosion of the penstock, the butterfly valve, the spiral-casing, the stay vanes, the guide vanes, the runner and the labyrinth seals of the turbine gives evidence for the following statement: **The major part of the sediment load in Laxá river has passed through the turbine of Laxá 3 hydropower plant**. A Francis turbine with a head of only 30 m has normally a relatively high capacity to pass suspended sediment. The fact that the turbine is designed for a higher head and thus must operate far out of its best-point has made it more vulnerable to sediment-induced wear than what would have been the case if the turbine was designed for the actual head.

When it comes to passage of ice, the Laxá III dam has several challenges. The tools the operators have to use are limited to the two small overflow gates, one outside (ísloka II) and one underground at the trash rack location (ísloka I). None of them have favourable hydraulic conditions, they are small and the gap between the water surface and concrete structures above are very narrow. It requires a substantial work force and machinery to pass ice through these sluices and thus keep the plant running and prevent the intake trash rack to clog up during severe weather conditions. The free overflow section of the dam is located far from the intake and has limited impact on ice conditions at the intake site as long as the plant is in operation and consumes the bulk of the river flow.

3.2.2 Laxá II Dam

There is no facility to continuously abstract the sediment rich bottom flow as the flow approaches the intake and thus exclude a substantial part of the sediment load, especially the coarser sediment fractions, from the flow at the intake site. The low level gate under the gatehouse and the sediment flushing arrangement at the trash rack location can only remove sediment very locally near the gates when the plant is operated at normal water levels and these gates are open. The water velocity in the pond generated by these gates will only be sufficient to transport sediment in the vicinity of the gates where the water is accelerated towards the gate. Almost all water passing through the trash rack will be out of reach of these two gates. The only way to exclude sediment load is therefore to periodically flush the head-pond (i.e. “the reservoir”).

In *(Ref. 4)* it is reported that a net volume of 1,300 m^3 of deposits were flushed during a flushing operation in 2012, based on bathymetric surveys of the reservoir before and after a flushing. If flushing of Laxá III dam took place at the same time, the amount of sediment removed from Laxá III dam shall be added to these 1,300 m^3 which was removed from Laxá II reservoir.

The capacity of the bottom outlets are limiting the flushing efficiency of Laxá II dam as sediment eroded from the upper part of the pond will deposit in the downstream part as soon as the water level rises. According to (ref. 2) the outlet capacity is 63.4 m^3/s when the upstream water level is at elevation 66.5 masl.

There are several facilities for release of surface water at Laxá II dam when the water level is just below the crest of the dam. Two of them are gated sluices. These are shown in Figure 12 in Section A-A which, is one of the two gates under the gate-house and referred to as ísyfirfall in [2], and Section C-C, referred to as Flóðgátt in [2]. These gates will be referred to as the ice-sluice which has a sill at elevation 68.0 masl and a width of 2 m, and the flood-sluice with a sill at elevation 66.5 masl and a width of 8 m. Reference is also made to Figure 15 where these outlets can be seen in the upper left corner. The flood-sluice gate is an overflow gate while the ice-sluice gate is an underflow gate.

The ice-sluice is located next to the downstream end of the skirt-wall which is a good location for passage of drifting ice. It is, however, narrow and must be fully open to pass water in free-surface flow mode. Larger pieces of floating ice may therefore easily bridge over the sluice and clog the sluice with respect to ice passage.

The flood-sluice is also located in a good position for passage of ice. The width is 8 m and water and ice can pass over it. As far as the Consultant understands, it is not used for passage of ice, which is understandable.

Figure 29: The flood-sluice-gate with damaged downstream apron made of wood-staves

As seen in Figure 29, the gate is in a poor condition. The steel frame supporting the downstream apron is damaged and many wood-staves are removed. If water is running over this gate for passage of ice when the air temperature is well below zero and the water temperature is close to zero, the temperature of the structures and the gate itself will also be below the freezing point. Water will therefore freeze as it hits the steel and concrete structures. Ice blocks will jam the wood staves and the hoisting mechanism of the gate. The cracks in the steel structure under the wood staves indicate that large forces have occurred from ice directly or as a result of an attempt to manoeuvre the gate in a frozen condition. As it is today, the flood-sluice-gate is therefore not an appropriate tool for passage of ice.

4 Recommendations

4.1 General

Laxá hydropower scheme is very special. It is most likely the most complicated hydropower scheme in Iceland with many components and a lot of operational and maintenance difficulties, but it remains relatively small with a capacity of 27 MW. Many components are old and in need of maintenance and rehabilitation. It is, however, not advisable to just rehabilitate the scheme component by component. An overall plan for upgrading of the scheme is required based on a holistic design approach. This issue is addressed further under the recommendations under the long term perspective below.

4.2 Short-term Perspective

The framework for the recommendations given within the short term perspective is as follows:

- No re-design and reconstruction of the dams are done
- The plants shall not be closed down for more than a couple of days to inspect and investigate crucial components and/or install new sediment measurement and handling facilities
- Data, information and experience needed for a comprehensive upgrading study of the plant shall be collected

4.2.1 As built drawings

It was not possible to find complete drawings and other relevant information on the Laxá III dam as it is today. Ref. 2 includes no drawings of the dam and the intake arrangement, except the overall layout drawing shown in Figure 1 and 2 and a section drawing of the ice-sluice. It is likely that more information are available somewhere in the system (as shown in Figure 30), but undocumented modifications has most likely been implemented, the hoisting arrangement at ísloka II shown in Figure 9 which is different from the drawing shown in Ref. 2 is an example of that. Two drawings of components of the Laxá III dam found at Landsvirkjun's office in Reykjavik are shown in Figure 30.

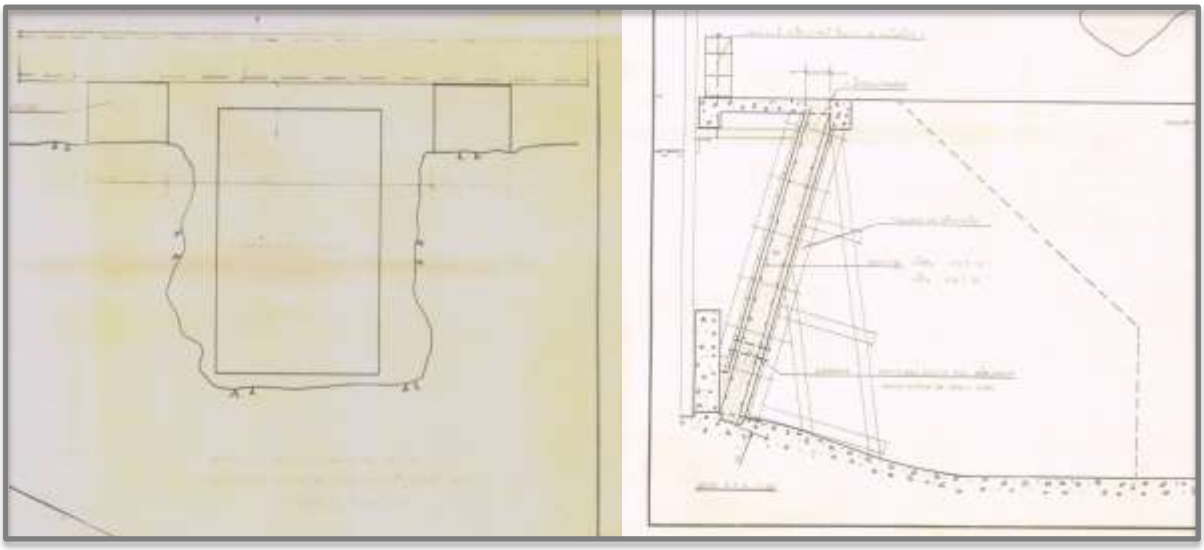

Figure 30: Drawings of bottom outlet gate and a closed bay in the Laxá III dam

4.2.2 Inspection and/or testing of important components

It is recommended to collect all available information and thereafter inspect the following components.

- The surge chamber at Laxá 3 hydropower plant
- The bottom outlet of Laxá III dam, including the geometry of the bed upstream

When the surge chamber is inspected, arrangements for removal of stones and gravel which may be found on the platform where the diameter of the surge chamber changes from 13 m to 4-6 m as well as in the tunnel system connecting the surge chamber with the headrace tunnel should be made. The geometry of the connection between the surge chamber and the headrace tunnel shall also be documented as this is important for how ice and air moves in the tunnel system. Each stone which may end up in the turbine is a potential risk for the turbines safety and efficiency as such, but also a possible generation loss risk which may lead to an emergency closedown of the plant.

4.2.3 Sediment and Discharge Measurements

It is not so easy to find a site with good accessibility where representative water samples for sediment analysis can be retrieved with a high frequency, also during the winter. It is therefore recommended to install an arrangement in the manhole between the butterfly valve and the turbine in Laxá 3 hydropower plant. The location is shown in Figure 31. We would recommend that manual samples are taken initially and that a laboratory for analysis of the suspended sediment content by use of the filtration method is established at the site. This will make it possible to take frequent samples for a time to see if the concentration varies rapidly or not. Samples for particle size distribution analysis and mineral content analysis can be taken to Reykjavik or another place for analysis. The sampling pipe arrangement installed in the manhole should however be prepared for continuous indirect measurement by use of the SMOOTH technology in a branch flow. The concentrations observed at Helluvað are too low for the SMOOTH measurement concept. If the manual sampling programme reveals that the concentrations at the Laxá 3 turbine is frequently above 500 mg/l, it would then be interesting to monitor the sediment concentration continuously and get data in real-time.

Figure 31: Location for installation of a SMOOTH sediment sampler for manual and automatic sediment measurements

In order to compute the sediment load through the turbine and in the Laxá river in total, it is recommended to arrange for corresponding measurement of the turbine discharge and the river discharge. The turbine discharge can be recorded indirectly through the generator output. It may be necessary to calibrate this through discharge measurements in the tailrace canal or at the intake. The river discharge can be observed at Laxá II dam *(ref. 2)*. Landsvirkjun have in-house expertise for quality control of the discharge measurement arrangements. Multiconsult can assist in establishing sediment measurement programme and if needed, also provide quality control on the discharge measurement programme.

A similar sediment monitoring arrangement, installed at Nathpa Jhakri (1500 MW) hydropower plant in India, is shown in Figure 32.

Figure 32: Installation of a SMOOTH sediment monitoring rig at a high head Francis turbine in India

4.2.4 *Experimental Sediment Handling*

Landsvirkjun has already carried out sediment flushing from the two head-ponds and followed it up with some quantitative research *(Ref. 4).* It would be of great interest to test out alternative ways to evacuate sediment from Laxá III reservoir. The most attractive technologies are conventional reservoir flushing and hydro-suction which is addressed below.

A) Reservoir Flushing

Reservoir flushing at Laxá III dam has so far only be carried out by use of the intake and the diversion structure as described earlier. This arrangement has several disadvantages and it would be of great importance to find a way to flush the head-pond without taking the sediment load through the intake and the upstream part of the headrace tunnel.

There are two existing facilities which could be used for this, i.e. the bottom outlet gate and the bay closed with stop logs shown in Figure 8. The efficiency of using these two low level openings to flush sediment around and not through the intake will be very important information for designing a permanent and robust sediment handling method for Laxá III dam.

Before these outlets are opened, it is important that preparations are done so it is sure that it will be possible to close these facilities again properly after the flushing operation is completed.

B) Sediment Removal by use of Hydro-Suction

Hydro-suction is an attractive method for removal of deposits from a reservoir while it remains in normal operation. The hydro-suction sediment removal technique is presented in Appendix 3. This text is taken from another report where sediment hydro-suction has been proposed for a much larger hydropower scheme where several dams with sizable reservoirs are planned for a cascade development in a heavy sediment-loaded river.

It would be possible to design a hydro-suction rig for the Laxá III dam with a pipe connection through the vertical stop logs close to the upstream end of the non-overflow section of the dam. It should be possible to cover an area within 200 m from this point, which is most of the reservoir. It, is, however, recommended to start with a rig with about 100 m operational radius.

A hydro-suction rig at Laxá II dam will have more head available and can therefore cover a larger area. A 250 long rig will cover most of the reservoir.

4.2.5 Safeguarding Actions

There are some components of the scheme which can be upgraded more or less immediately as they will safeguard the plants and prevent further degradation. We believe that it should be done as soon as possible and that it can be done independent from a more comprehensive study of the entire scheme.

The Surge Shaft

We recommend Landsvirkjun to start the work as soon as possible on safeguarding the surge chamber and thus prevent intrusion of snow, ice and sediment into the chamber and the waterway of the plant which may cause an emergency shutdown of Laxá 3 hydropower plant.

Scour protection of the banks of Laxá II head-pond

We do also recommend Landsvirkjun to carry out works to protect the banks of the Laxá II pond from further erosion and degradation. This is most important for the eastern slope inside the forebay, but also for the slope along the road further upstream on the eastern side of the pond.

Upgrading of the flood gate at Laxá II dam

The flood-sluice-gate at Laxá II dam should also be upgrade so it can be used for passage of ice.

4.3 Long-term Perspective

In the long term perspective, permanent facilities for efficient handling of sediment and ice at the Laxá hydropower scheme should be developed. This will give the operators of the plant robust tools to handle these challenges efficiently and cost effective. This will require larger investments and should therefore be studied in the context of a general upgrading and rehabilitation of the scheme.

4.3.1 Conceptual Design of Sediment and Ice Handling Facilities at Laxá

A conceptual hydraulic design of sediment and ice handling at both Laxá III and Laxá II dam should be carried out. It will most likely be useful to test some aspects of the conceptual design in a hydraulic model study to secure high performance. This is more important at Laxá III than Laxá II as the head-pond is shallower and the influx of ice and larger sediment particles are not restricted by an upstream dam as the case is for Laxá II dam.

Multiconsult would be happy to carry out this study in cooperation with experts within Landsvirkjun. This can be done as a part of the feasibility study addressed below or as a separate study to provide input to the feasibility study.

4.3.2 Feasibility Study on an Upgrading of the Laxá Hydropower Scheme

We recommend that a feasibility study is carried out to make sure that an upgrading is technically, economically and environmental feasible and thus economically more attractive than to allow the scheme to fadeout in a planned and safe manner.

Sediment and ice handling are important issues in order to secure the income side through minimization of generation losses. When an overall plan is approved and adopted, then the upgrading of the scheme can be done component by component or as a more concentrated reconstruction programme.

Multiconsult will gladly cooperate with Landsvirkjun in this respect. We can carry out complete studies on all levels or take part in a study together with experts within Landsvirkjun in various fields.

The most important disciplines where Multiconsult has top qualified staff on international level, relevant to a feasibility study of the Upgraded Laxá Hydropower Scheme, are:

- Civil & hydropower engineering with expertise in planning, design and optimization of hydropower plants
- Hydraulic engineering with expertise in ice and sediment handling
- Dam & dam safety assessment engineering
- Mechanical engineering with expertise in design and upgrading of turbines and gates
- Electrical engineering with expertise in generators and power plant control systems
- Geotechnical engineering with experience from cold climate conditions

Multiconsult does also have experts within associated fields like physical and numerical hydraulic modelling, hydrology, hydrometric systems, engineering geology & tunnelling, economy, environment, construction planning, costing & scheduling, small hydropower, construction supervision etc. We would all be happy to continue our cooperation with Landsvirkjun on Laxá as well as other hydropower plants in Iceland.

Appendix 1: Contract Documents

MULTICONSULT

Landsvirkjun
Att: Guðmundur Björnsson
Háaleitisbraut 68
103 Reykjavík
Iceland

Your ref.: Mr. Guðmundur Björnsson   Our ref.: Odd Adler-Gjerde   Oslo, 2013-01-22.

Confirmation of Order - Sediment challenges at Laxá power station; field visit and field report with recommendations for further actions.

With reference to previous email correspondence between Mr. Gunnarson and Mr. Støle, and offer and acceptance by email on the 30. Nov. 2012 and 7. Jan. 2013 respectively, we hereby confirm the order.

The scope of work will consist of preparations, field visit to Iceland and Laxá power station, estimated at 5 days including travel days from Norway. The resulting delivery will be a brief field report including observations made and recommendations for further actions. All tasks will be performed by Mr. Støle.

Fixed price contract amount: NOK 100 000.-.

The client will be responsible for all transport in Iceland. The consultant will cover all costs for our staffs fooding and lodging in Iceland.

Time schedule: To be further agreed upon, but tentatively during April. Price is based on project completion by June 2013.

Terms:
The assignment is subject to Multiconsult's Conditions of Contract, dated October 28, 2011 (attached).

For more information about our firm and services please visit our website www.multiconsult.no and www.norplan.com

We hope that the Confirmation of Order is in alignment with your expectations. If you have any comments or concerns, please contact us immediately.

Sincerely Yours
For MULTICONSULT

Odd Adler-Gjerde
Head of section Hydrology
Norplan / Multiconsult AS

MULTICONSULT
Nedre Skøyen vei 2 · P.b. 265 Skøyen · 0213 Oslo · Tel.: 21 58 50 00 · Fax: 21 58 50 01 · www.multiconsult.no · NO 910 253 158 MVA

Standard Conditions of Contract for Multiconsult AS

1. Introduction

Standard Conditions of Contract for Multiconsult AS. In the following Company is used for Multiconsult AS.

2 General

Unless otherwise agreed, the Company carries out all commissions in accordance with the following contract documents, in the listed order of priority:"

1. The relevant contract as signed
2. These Standard Conditions of Contract for Multiconsult AS.
3. The Norwegian Standard NS 8402:2010 Standard Conditions of Contract.

When requested, the NS 8402:2010 will be forwarded by the Company.

3. Remuneration

Depending on the assignment, the remuneration may comprise

- Fees
- Equipment rental
- Expenses

3.1 Fees

Work executed by the Company is normally invoiced on a time charge basis (incl. any travel time) according to standard hourly rates. This also applies to additional work in the case of fixed price contacts.

The standard hourly rates are based on 8 hrs. workdays. Overtime is charged at the same standard rates.

For assignments requiring shift or night-work, or stationing outside the permanent office premises, special rates may be agreed to.

General expenses incurred by the Company are charged by a mark-up on the fee, ref. clause 3.4.

3.2 Equipment rental

Unless otherwise agreed, the use of field and laboratory equipment, measuring instruments, IT-equipment for special tasks, etc., is charged according to standard unit rates.

Unless otherwise agreed, site investigation equipment rental and man-hours are charged according to the time spent by the operator in the field, including travels, mobilization and demobilization time.

Loss of equipment caused by unforeseen ground conditions will be charged to the Customer at cost.

3.3 Adjustment of rates and unit prices

Unless otherwise agreed, the rates for personnel, equipment and laboratory tests are adjusted annually the 1st of July, in accordance with the increase in wages paid by the Company.

3.4 Expenses

Unless otherwise agreed, the following expenses are charged to the Client:

- External copying of drawings, reports, tender documents, etc. for the use of others, e.g., the Client, contractors, authorities, etc.
- Advertisements and expenses related to the publication and distribution of competition and tender documents.
- Public fees and taxes
- Insurance costs, if non-standard insurance cover is requested by the Client
- Travel and accommodation, invoiced according to the official guidelines for travel for Norwegian government account
- Other expenses related to the stationing of personnel outside the Company's offices

Whenever the expenses are paid in advance by the Company on behalf of the Client, a mark-up of 5 % is charged.

To cover general expenses on behalf of the Customer like telecommunication services, postage, administrative work, etc., a mark-up of 5 % of the total fee and equipment charges for technical services is added.

4. Payment

Unless otherwise agreed, our work is invoiced monthly. Invoices are due for payment within 30 days of issuance.

For overdue payments a penal interest is charged according to law regarding late payment, and the Company may withhold produced results.

The Client must specify and justify any objections to the invoice of the Company without undue delay.

5. Copy right. Professional secrecy

The Company has the rights to all material it produces.

The Client has the right to the use of this material in the specific project for which it was produced. The Client may not use the material in other projects, or make it available to others without the written consent of the Company.

The parties are mutually obliged to observe professional secrecy.

6. Liability

The Company's liability versus the Client for losses incurred due to the Company's consulting services is limited to:

a) 60 times the national incurance amount (G) in the case of liability that is not covered by the Company's insurance; and

b) 150 times the national insurance basic amount (G) in the case of liability that is covered.

The Company is insured to cover the above liabilities. A copy of the insurance policy is available upon request. An increased liability and insurance cover may be agreed upon before the start of the assignment. Any such increase of the Company's liability, and any work outside the Nordic countries, require a separate liability agreement. The additional premium will be charged to the Customer as a project expense, ref. clause 3.4.

The Company cannot be held liable for circumstances and losses arising due to errors in its quantity estimates or omitted activities in the bill of quantties, where such losses arise because the Customer has concluded binding agreements with a third party concerning prices and quantities.

The Company is not responsible for any claim of compensation that have been based on information given that has been shown to be insufficient regarding building time or the amount of costs of the building project.

7. Delays

Unless otherwise agreed, the Company may only be held responsible for fineable delays caused by the Company.

Standard fine upon delays is NOK 1000,- per workday.

The total payable fine due to delays is limited to 20 % of the Company's remuneration for the assignment.

The Company is to be awarded additional time and payment for extra work caused by circumstances for which the Client is responsible, such as changes, regulatory delays, etc.

8. Duties and taxes

All agreed remuneration will be subject to the addition of VAT, according to the current regulatory requirements.

9. Choice og law and venue

This agreement shall be governed by and construed in accordance with the laws of Norway, and the Company's venue shall be the venue for any and all disputes arising out of the agreement.

Landsvirkjun

Purchase Order No: 20131312

NORPLAN AS/Multikonsult AS
Nedre Sköyen vei 2
021 Oslo
Norway

Att........: Odd Adler-Gjerde
Telephor
Fax.......:
Email....: odd.adler.gjerde@multiconsult.no

Date.................................: 26.3.2013 Page: 1 of 1
Payment terms.................: Net 30 days ag. orig. invoice/shipping documents
Delivery time.....................: June 17th to June 21st 2013
Delivery date.....................:
Delivery terms...................:
Mode of delivery ....:

Contact ....: Guðrún Steinarsdóttir
Telephone.........................: 515 9024
Email.................................: gudruns@lv.is

Delivery address: Landsvirkjun
Laxárstöð
641 Húsavík
Iceland

According to your e-mail dated 22.1.2013:

Del.date	Item number	Description	Qty	Unit	Unit price	Amount
	VARA	Sediment challenges at Laxá Power Station, field visit and field report with recommendations for further actions: The scope of work will consist of preparations, field visit to Iceland and Laxá Power Station, estimated at 5 days including travel days from Norway. The resulting delivery will be a brief field report including observations made and recommendations for further actions. All tasks will be performed by Mr. Stöle.	1,00		100.000,00	100.000,00 NOK

Landsvirkjun will be responsible for all transport in Iceland. Multiconsult will cover all costs for their staffs fooding and lodging in Iceland.

Please confirm our order and delivery date by fax or e-mail.

Original invoice shall be sent to Landsvirkjun, Háaleitisbraut 68, 103 Reykjavík, Iceland.
Order number must be referred to on all documents and shipments.

Round-off	Total
0,00	100.000,00 NOK

Appendix 2: Memorandum

SUMMARY OF SEDIMENT PROBLEMS

LAXÁ II AND III HEP

MEMORANDUM

DATE.: 19-10-2012
NR.:

AUTHOR: Andri Gunnarsson, Landsvirkjun
DISTRIBUTION: MultiConsult
VERSION: 1

Issue: Summary for MultiConsult

1 Introduction

The three Laxá hydro power tations harness a 70 m head on an 1800 m strecth of River Laxá to produce a total of 27.5 MW of electricity. The inflow to Lake Mývatn is mostly underground, through layers of lava, largely immune from seasonal fluctuations and ideal for harnessing hydropower. Laxá I and II are low head hydro stations that harness the natural flow of River Laxá. Station III, the latest addition, utilizes the same head as Laxá I but runs its water through a tunnel to the power station, 60 metres inside the rock. The town of Akureyri and the Icelandic Government built the Laxá Stations which joined Landsvirkjun in 1983.

Table 1 – Main parameters for Laxá power plants

	Laxá I - 1939	Laxá II - 1953	Laxá III - 1973
Installed capacity	5 MW	9 MW	13.5 MW
Turbine type	2 x 2.5 MW Francis	1 x 9 MW Francis	1 x 13.5 MW Francis
Generation capacity	3 GWh / a	78 GWh / a	92 GWh / a
Total head	39 m	29 m	39 m

Figure 1 – Overview of Lake Mývatn and the small rivers which contribute to it. One of these contributories, Kráká River, is the main source of sediment transport in Laxá. Notice the power plants can not be seen on the figure.

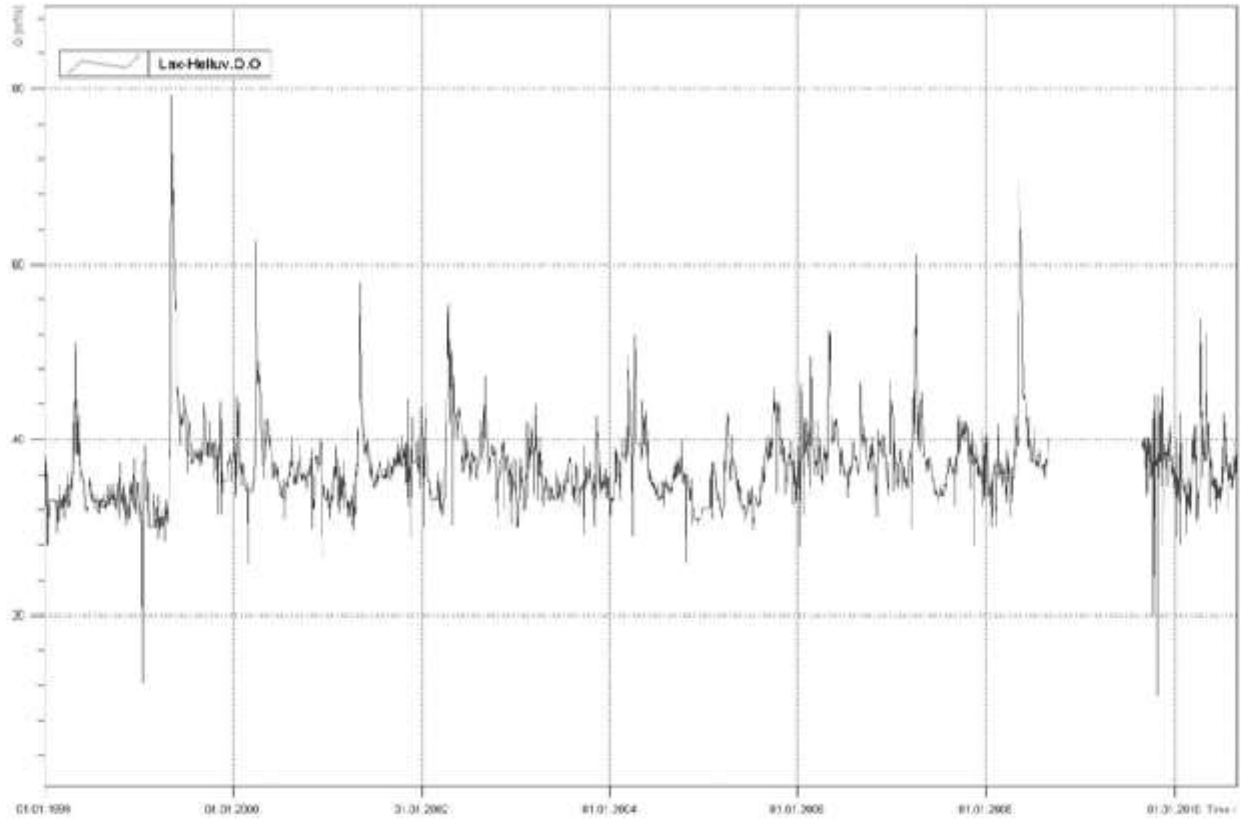

Figure 2 – Measured discharge at Helluvað gauging site in Laxá. This shows the characteristics of the river which is mainly groundwater fed. A stable annual mean discharge of 37.0 m^3/s is observed but in the spring time flood peaks are observed ranging from 50-60 m^3/s.

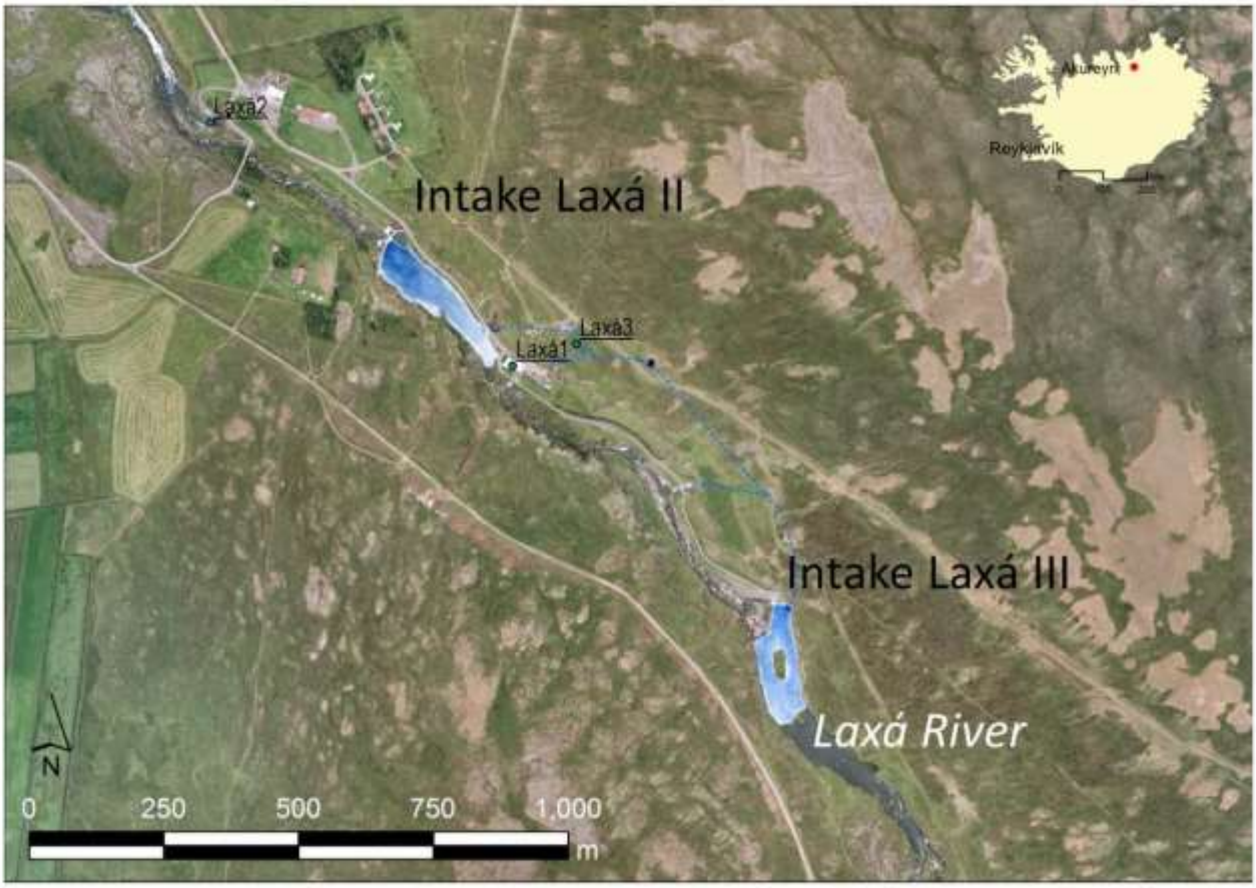

Figure 3 – overview of Laxá II and Laxá III sitting. Blue dotted lines show tunnels from the upstream pond to the downstream.

1.1 Laxá Stations I and II

The Laxá I Station is the oldest power plant in the river Laxá. From the dam at the top of the canyon, the water is first diverted through an underground tunnel and then through a channel approximately 670 m in length, leading to the power station. The station operates two turbine units, coming on-line in 1939 and 1944. For the Laxá II Station, the river is dammed 300 metres below Laxá I, diverting the water 380 metres to the power station via a penstock and a surge tank.

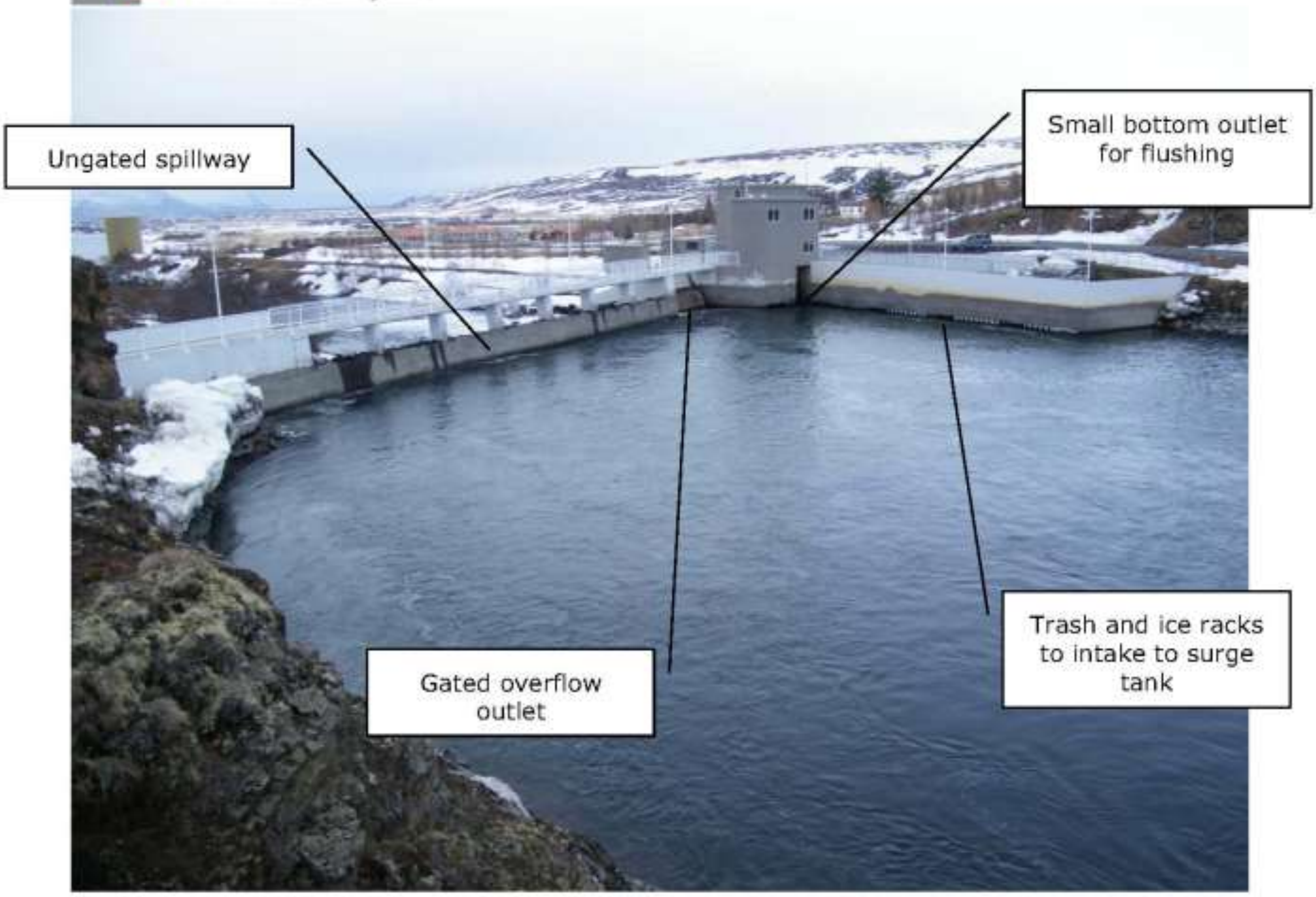

Figure 4 – The intake pond for Laxá II during normal operating conditions.

Figure 5 – Laxá II intake pond during flushing.

1.2 Laxá III Station

The Laxá III Station is the most recent power station in the river Laxá. The underground vault housing the station's turbine unit was initially designed for two 25 MW turbines. The plans called for the construction of a 56 m high dam in the upper part of the canyon, making the total head 83 m. The Laxá III Hydropower Station was inaugurated in 1973 with one turbine instead of two, and further plans for the region were shelved. The project as initially designed was to address sediment problems by a bigger reservoir capable of flushing. Today, the reservoir is full of large diameter material and has no capabilities to store additional material. Flushing of the reservoirs is very limited due to insufficient size of bottom outlets.

Figure 6 – top view of the Laxá III intake pond. Almost all the discharge flows by the far bank. Accumulation of sand can clearly been seen at stabilized operating conditions.

Figure 7 shows the upstream view of the intake pond at Laxá III. There the ungated spillway crest can be seen but the intake is to the left and can not been seen on the figure.

Figure 7 – overview of the intake pond at Laxá III. 80% of the flow though the pond is by the left bank. This is the location of the original main river bed.

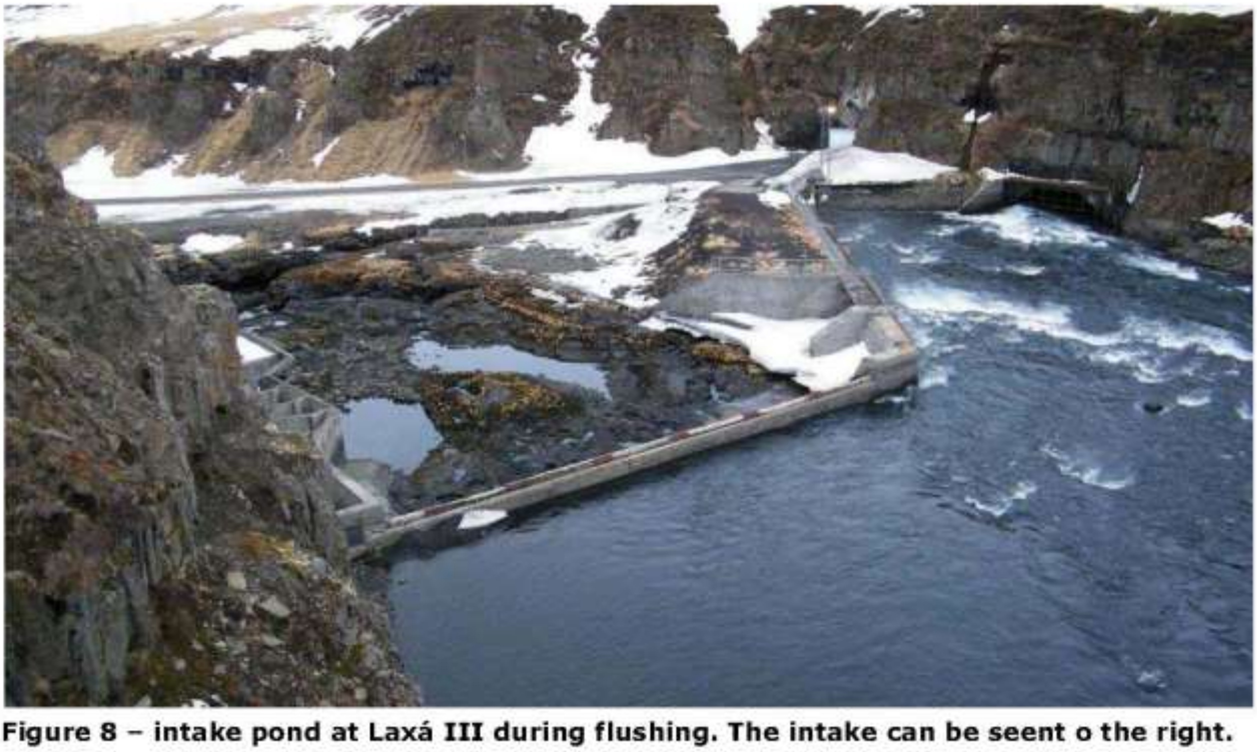

Figure 8 – intake pond at Laxá III during flushing. The intake can be seent o the right.

2 General description of the problems

From commission of the power plant problems in association with sediment transport, and mainly coarse sediments such as sand and coarse silt have been influencing the operation, manly the turbine assembly by abrasion and erosion of runners, covers and other critical parts of the turbines. Another problem is also experienced, slush and ice transport in the river, an because the intake structure at Laxá III has a free surface ice and slush can travel into the headrace tunnel.

A measurement program to assess the transport of material has been conducted with sampling from a site upstream of the power plant with annual measurements of 8-12 samples from 1997 to 2010 at Helluvað gauging site (see Figure 1) aimed at estimating the total transport of material through the system. Based on the 13 year available data from sediment measurements the average size distribution indicates that up to 60 % of the sediment sample is larger than 0.06 mm on average. On average up to 40 % of the samples are larger than 0.2 mm in diameter. Particle size distribution plot based on average values is shown below. Observations indicate that total sediment transport is not evenly distributed annually but high values of sediment concentration are associated with spring floods and snow melt floods. Between 40.000 60.000 kg of material are estimated to be transported by Helluvað gauging site.

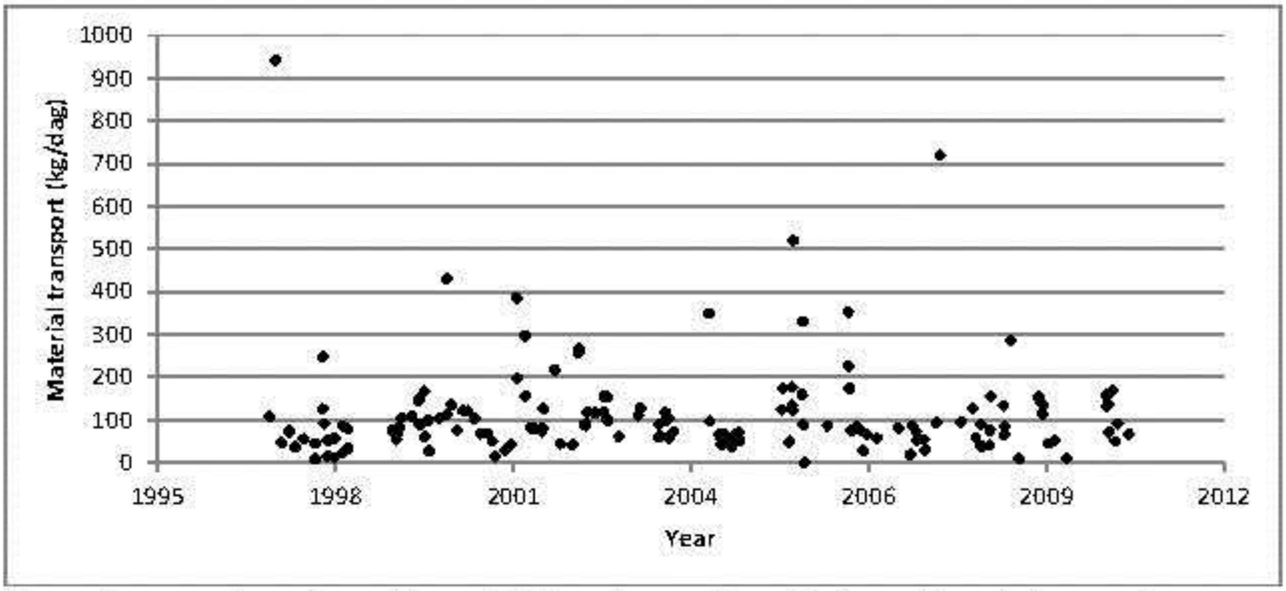

Figure 9 – overview of gaugings at Helluvað sampling site for sediment transport.

Sphericity, particle shape factors or hardness have not been estimated for the samples.

The main sampling site is at Helluvað and measurements are conducted from a bridge. Helluvað is located upstream of the Laxá power plant but the site layout indicates that all material transported through Helluvað is transported through the power plant, either through the turbines or by the spillway when excess water is in the system. Methods of sampling are discussed below but the flow at Helluvað is assumed fully turbulent to ensure full mixing of the material over the water column.

Based on the measurements over the period from 1997 2010 data in Table 2 is presented. Because the river is spring fed distribution of sediment concentration is limited in relation to the discharge. Average values are calculated and there statistical properties.

Table 2 – average values from the data sampled from 1997 – 2010 at Helluvað. Values are in percent larger and calculated from all available samples shown in the appendix, sediment measurement data.

	Percent larger %				
	< 0.002	***0.002 - 0.02 mm***	***0.02 - 0.06 mm***	***0.06 - 0.2 mm***	***> 0.2 mm***
Mean	9.3	20.5	9.3	18.2	39.1
Std.	10.0	13.8	8.3	10.7	20.5
Min.	0.0	0.0	0.0	0.0	0.0
Max.	68.0	61.1	62.9	65.0	84.0

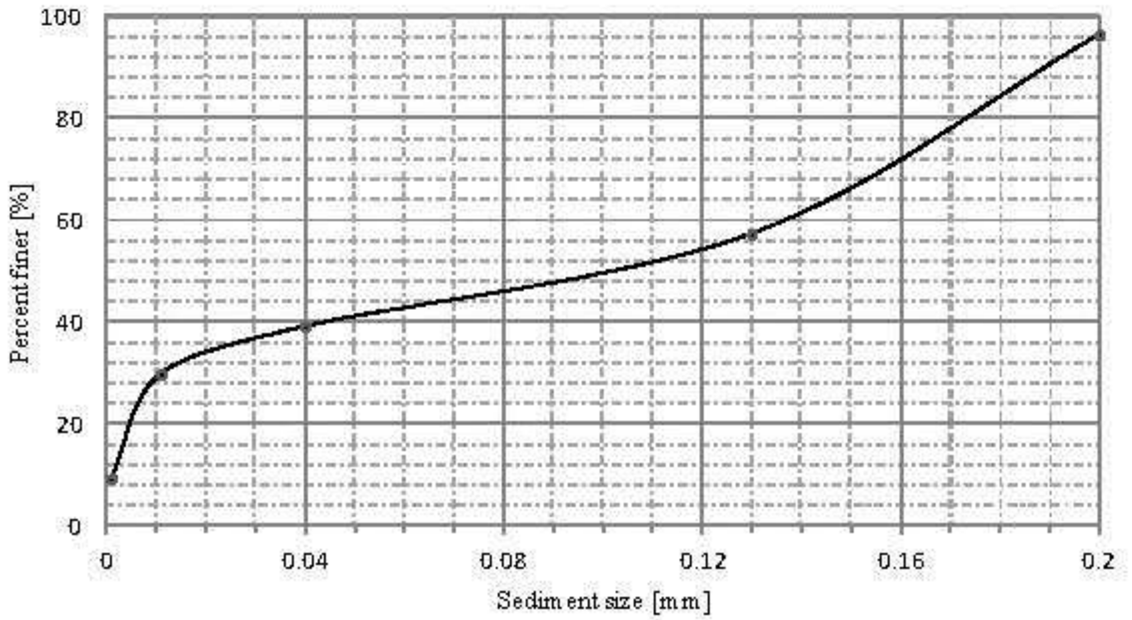

Figure 10 – average particle size distribution calculated from the data acquired over the period from 1997 to 2010.

3 The task

As described briefly here above the two main problems at Laxá power plants is large diameter sediment transport and ice through the system. The ice transport is a much smaller problem and could maybe be resolved by operation of the power plants. We would like to arrange a field visit for an expert from MultiConsult to address this problem with us and advise on further research and solutions to the problems described. At this point all options are open, from strategically operating the power plant to avoid transport through the system to building a new intake with flushing capabilities.

I hope we can collaborate on solving this problem,

Best regards,

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4 Appendix 1 – Sediment measurement data

						Size fraction - %					
Loaction	Date	Time	Discharge	Concentration	TDS	Coarse sand	Fine sand	Coarse silt	Fine silt	Clay	Biggest particle
#	yyyy.mm.dd	hh:mm	m3/s	mg/l		> 0.2 mm	0.06 - 0.2 mm	0.02 - 0.06 mm	0.002 - 0.02 mm	< 0.002	-
Laxá, Helluvað	1997-07-20	11:10	33.6	37	102	15	16	30	20	19	0.8
Laxá, Helluvað	1997-08-24	18:00	35.2	310	109	6	36	33	22	3	0.7
Laxá, Helluvað	1997-09-27	17:30	32.1	17	102	28	26	11	22	13	0.9
Laxá, Helluvað	1997-11-08	20:30	34.2	25	102	73	20	1	0	6	1.7
Laxá, Helluvað	1997-12-09	21:00	30	14	117	54	16	5	23	2	1.7
Laxá, Helluvað	1998-01-28	13:00	45.9	14	121	15	65	13	7	0	0.5
Laxá, Helluvað	1998-04-02	11:45	35.2	15	81	68	15	9	8	0	1.9
Laxá, Helluvað	1998-04-02	11:55	35.2	3	91	5	11	34	50	0	0.5
Laxá, Helluvað	1998-05-14	16:15	40.5	71	84	46	20	13	17	4	2.3
Laxá, Helluvað	1998-05-14	16:30	40.5	36	84	15	30	13	28	14	0.6
Laxá, Helluvað	1998-05-23	23:00	36.5	29	90	26	20	22	31	1	1.3
Laxá, Helluvað	1998-06-10	12:20	31.5	19	85	70	22	7	1	0	1.3
Laxá, Helluvað	1998-06-10	12:35	31.5	6	86	21	50	13	15	1	0.4
Laxá, Helluvað	1998-07-18	11:15	33.1	20	95	70	15	4	10	1	1.5
Laxá, Helluvað	1998-07-18	11:25	33.1	4	99	27	46	22	5	0	0.3
Laxá, Helluvað	1998-09-04	10:58	33.8	30	94	45	11	11	32	1	1.6
Laxá, Helluvað	1998-09-04	11:20	33.8	8	91	14	26	5	45	10	0.6
Laxá, Helluvað	1998-10-03	14:20	33	28	89	46	18	5	19	12	1.7
Laxá, Helluvað	1998-10-03	14:45	33	12	90	28	39	3	12	18	0.7

						Size fraction - %					
Loaction	Date	Time	Discharge	Concentration	TDS	Coarse sand	Fine sand	Coarse silt	Fine silt	Clay	Biggest particle
#	yyyy.mm.dd	hh:mm	m3/s	mg/l		> 0.2 mm	0.06 - 0.2 mm	0.02 - 0.06 mm	0.002 - 0.02 mm	< 0.002	-
Laxá, Helluvað	1999-06-09	18:45	41.6	21	86	64	16	4	15	1	1.1
Laxá, Helluvað	1999-07-03	11:30	42.4	15	98	78	15	6	1	0	1.5
Laxá, Helluvað	1999-07-03	12:00	42.4	18	89	14	9	3	6	68	0.6
Laxá, Helluvað	1999-07-19	10:35	41.6	23	97	44	14	5	20	17	1.8
Laxá, Helluvað	1999-08-01	16:10	38.4	32	94	37	11	9	23	20	1.8
Laxá, Helluvað	1999-09-28	14:45	39.4	32	100	49	17	4	17	13	3
Laxá, Helluvað	1999-11-03	19:45	38.4	44	102	42	31	5	13	9	0.8
Laxá, Helluvað	1999-11-11	09:00	43.7	40	93	29	33	12	14	12	2.1
Laxá, Helluvað	1999-11-12	21:00	44.8	23	98	27	47	7	16	3	0.7
Laxá, Helluvað	1999-12-08	21:30	35.2	55	108	59	18	4	14	5	3.3
Laxá, Helluvað	1999-12-09	09:35	35.2	20	109	38	32	6	19	5	0.8
Laxá, Helluvað	1999-12-27	13:45	37.3	31	113	65	13	2	17	3	1.9
Laxá, Helluvað	2000-01-03	20:15	38.4	8	116	49	21	7	19	4	1.2
Laxá, Helluvað	2000-03-03	14:10	35.2	35	126	66	23	4	4	3	1.7
Laxá, Helluvað	2000-04-10	13:50	49	102	90	73	9	5	5	8	4.5
Laxá, Helluvað	2000-04-11	12:30	47	28	99	51	12	5	24	8	1.2
Laxá, Helluvað	2000-05-08	17:00	35.2	45	83	51	15	7	20	7	1.5
Laxá, Helluvað	2000-06-07	14:15	36.3	24	89	38	26	9	19	8	1.0
Laxá, Helluvað	2000-07-12	16:20	34.2	41	102	27	45	10	9	9	1.3
Laxá, Helluvað	2000-08-09	15:45	36.3	39	92	4	17	14	41	24	0.5
Laxá, Helluvað	2000-09-14	14:30	37.3	32	84	34	16	2	29	19	1.7
Laxá, Helluvað	2000-10-17	14:20	36.3	22	105	20	23	7	23	27	1.0
Laxá, Helluvað	2000-11-21	14:15	38.4	21	112	30	26	10	7	27	1.6
Laxá, Helluvað	2000-12-22	14:00	34	17	115	6	3	27	25	39	1.0

						Size fraction - %					
Loaction	Date	Time	Discharge	Concentration	TDS	Coarse sand	Fine sand	Coarse silt	Fine silt	Clay	Biggest particle
#	yyyy.mm.dd	hh:mm	m3/s	mg/l		> 0.2 mm	0.06 - 0.2 mm	0.02 - 0.06 mm	0.002 - 0.02 mm	< 0.002	-
Laxá, Helluvað	2001-01-06	09:20	34.2	5	110	25	39	20	16	0	0.7
Laxá, Helluvað	2001-03-03	08:15	34.2	10	102	68	25	4	3	0	1.1
Laxá, Helluvað	2001-04-06	12:35	33.1	15	116	83	12	3	2	0	3
Laxá, Helluvað	2001-05-09	12:00	57.9	77	88	71	20	6	2	1	2.5
Laxá, Helluvað	2001-12-10	12:45	40.5	62	92.5	35	16	4	15	30	1.75
Laxá, Helluvað	2001-05-13	20:15	45.9	50	89	73	17	4	1	5	2.6
Laxá, Helluvað	2001-06-25	13:20	35.2	98	96	60	12	6	6	16	3.5
Laxá, Helluvað	2001-06-29	15:00	34.2	53	107	77	20	2	1	0	2.1
Laxá, Helluvað	2001-07-30	17:45	36.3	26	90.5	21	24	8	24	23	1.3
Laxá, Helluvað	2001-08-15	17:10	36.3	26	127	37	8	3	36	16	1.6
Laxá, Helluvað	2001-09-26	14:05	37.3	23	102.5	55	17	2	19	7	1.4
Laxá, Helluvað	2001-10-02	09:52	40.5	24	115	62	28	6	4	0	2.3
Laxá, Helluvað	2001-10-08	12:30	38.4	38	121	42	16	4	29	9	3.4
Laxá, Helluvað	2002-01-11	14:40	37.3	14	100	49	33	0	14	4	9
Laxá, Helluvað	2002-03-19	17:20	30.6	16	123	42	39	11	7	1	18
Laxá, Helluvað	2002-04-21	12:30	46.3	64	84	36	16	13	24	11	27
Laxá, Helluvað	2002-04-25	17:00	51.3	60	93	47	18	11	21	3	23
Laxá, Helluvað	2002-05-30	19:05	42.3	24	104	81	17	2	0	0	17
Laxá, Helluvað	2002-06-02	19:35	41.3	26	93	63	25	3	1	8	16
Laxá, Helluvað	2002-06-11	20:35	36.4	38	84	46	12	9	23	10	23
Laxá, Helluvað	2002-07-23	12:40	38.2	35	103	27	14	2	42	15	12
Laxá, Helluvað	2002-07-25	22:30	37.6	36	110	48	29	10	12	1	11
Laxá, Helluvað	2002-09-12	16:30	39.2	35	97	32	30	10	23	5	10
Laxá, Helluvað	2002-09-13	13:10	37.5	48	93	39	30	5	13	13	10
Laxá, Helluvað	2002-10-02	20:10	39.6	45	105	35	17	6	30	12	15
Laxá, Helluvað	2002-10-03	09:45	38.41	30	102	50	20	2	11	17	11

						Size fraction - %					
Loaction	Date	Time	Discharge	Concentration	TDS	Coarse sand	Fine sand	Coarse silt	Fine silt	Clay	Biggest particle
#	yyyy.mm.dd	hh:mm	m3/s	mg/l		> 0.2 mm	0.06 - 0.2 mm	0.02 - 0.06 mm	0.002 - 0.02 mm	< 0.002	-
Laxá, Helluvað	2002-12-05	14:20	35.2	20	95	17	19	14	17	33	0.5
Laxá, Helluvað	2003-03-24	20:10	35.5	36	92	37	16	7	24	16	1.9
Laxá, Helluvað	2003-04-08	18:15	34.7	43	97	48	17	4	24	7	0.9
Laxá, Helluvað	2003-07-19	11:10	34.8	20	98	42	17	7	30	4	1.1
Laxá, Helluvað	2003-07-21	15:00	35	30	95	35	8	3	37	17	1.5
Laxá, Helluvað	2003-07-24	11:30	37.2	20	103	18	22	8	45	7	1
Laxá, Helluvað	2003-08-23	18:12	35.7	32	110	22	25	11	34	8	1.1
Laxá, Helluvað	2003-08-24	17:00	36	38	91	26	32	11	21	10	1.5
Laxá, Helluvað	2003-09-10	17:30	34.2	35	100	37	27	18	18	0	1.6
Laxá, Helluvað	2003-09-11	10:12	34.5	20	103	22	24	7	38	9	1
Laxá, Helluvað	2003-10-01	18:00	35.5	23	93	46	28	4	20	2	1.3
Laxá, Helluvað	2003-10-07	20:00	36.5	23	87	38	30	3	11	18	0.9
Laxá, Helluvað	2004-04-27	10:30	39.6	102	90	84	5	2	7	2	3.4
Laxá, Helluvað	2004-04-30	21:15	37.6	30	104	45	19	3	25	8	1.1
Laxá, Helluvað	2004-06-22	18:40	34.4	23	98	64	22	7	7	0	1.1
Laxá, Helluvað	2004-06-29	17:35	34.8	20	85	42	10	10	32	6	1.1
Laxá, Helluvað	2004-07-03	16:50	34.4	14	111	44	14	16	26	0	1.5
Laxá, Helluvað	2004-07-22	23:12	34.8	21	98	50	8	7	11	24	3.1
Laxá, Helluvað	2004-07-28	18:15	34.2	22	95	25	13	10	32	20	1.2
Laxá, Helluvað	2004-08-25	21:15	34.6	18	103	20	14	10	33	23	0.9
Laxá, Helluvað	2004-08-30	14:45	33.9	13	105	38	16	18	28	0	1.7
Laxá, Helluvað	2004-09-16	19:15	37.1	20	91	16	9	5	47	23	1.2
Laxá, Helluvað	2004-10-10	19:10	34.9	24	99	37	20	3	17	23	2.2
Laxá, Helluvað	2004-10-16	11:05	35.8	17	93	76	17	3	4	0	2.4

						Size fraction - %					
Loaction	Date	Time	Discharge	Concentration	TDS	Coarse sand	Fine sand	Coarse silt	Fine silt	Clay	Biggest particle
#	yyyy.mm.dd	hh:mm	m3/s	mg/l		> 0.2 mm	0.06 - 0.2 mm	0.02 - 0.06 mm	0.002 - 0.02 mm	< 0.002	-
Laxá, Helluvað	2005-06-08	23:22	31.9	45	89	9	5	10	20	3	0.8
Laxá, Helluvað	2005-06-15	16:15	31.9	64	98	13	4	17	26	5	2.3
Laxá, Helluvað	2005-07-22	14:10	33.2	17	95	6	3	1	2	5	1.4
Laxá, Helluvað	2005-07-24	18:30	32.9	18	97	5	1	2	3	7	1.35
Laxá, Helluvað	2005-08-04	09:30	33	62	97	11	6	16	29	1	1.85
Laxá, Helluvað	2005-08-06	10:45	33	47	101	8	2	12	23	1	2.1
Laxá, Helluvað	2005-08-09	15:30	32.9	44	107	6	4	10	17	7	1
Laxá, Helluvað	2005-08-13	11:25	34.5	175	94.5	23	24	63	61	4	2.5
Laxá, Helluvað	2005-09-29	16:30	42.8	43	112	33	4	1	4	1	3.75
Laxá, Helluvað	2005-10-06	19:35	42.3	91	91	32	25	6	17	11	1.65
Laxá, Helluvað	2005-10-09	08:08	42.8	24	105	10	7	1	5	1	1.1
Laxá, Helluvað	2005-10-13	08:15		21	108	9	7	1	2	2	1.1
Laxá, Helluvað	2006-02-21	18:00	44.0	23	104	52	19	6	18	5	2.9
Laxá, Helluvað	2006-06-16	20:10	34.4	119	92	8	5	29	47	11	1.1
Laxá, Helluvað	2006-06-18	21:15	38.5	68	90	11	5	24	54	6	1.6
Laxá, Helluvað	2006-06-24	13:20	37.3	54	85	18	6	22	44	10	1.5
Laxá, Helluvað	2006-07-05	12:15	34.9	25	102	45	15	10	20	10	1.1
Laxá, Helluvað	2006-08-03	15:10	39.7	25	98	18	32	25	17	8	0.9
Laxá, Helluvað	2006-08-28	13:00	37.6	23	92	23	27	9	19	22	1.5
Laxá, Helluvað	2006-09-10	23:40	39.5	8	99	38	26	8	23	5	2.5
Laxá, Helluvað	2006-09-28	09:53	37.1	1253	91	0	0	5	55	40	1.0
Laxá, Helluvað	2006-09-29	16:32	37.3	21	88	19	10	8	43	20	1.5
Laxá, Helluvað	2006-11-28	14:00	39.2	17	108	39	23	16	13	9	1.0

						Size fraction - %					
Loaction	Date	Time	Discharge	Concentration	TDS	Coarse sand	Fine sand	Coarse silt	Fine silt	Clay	Biggest particle
#	yyyy.mm.dd	hh:mm	m3/s	mg/l		> 0.2 mm	0.06 - 0.2 mm	0.02 - 0.06 mm	0.002 - 0.02 mm	< 0.002	-
Laxá, Helluvað	2007-03-27	20:00	46	21	103	65	20	4	9	2	2.1
Laxá, Helluvað	2007-05-31	17:30	37.3	6	91	22	8	19	45	6	3.3
Laxá, Helluvað	2007-06-13	01:30	35.2	29	102	59	12	7	12	10	1.9
Laxá, Helluvað	2007-07-03	17:45	33.1	25	96	44	18	8	16	14	1.7
Laxá, Helluvað	2007-07-11	16:10	33.1	19	87	70	15	5	7	3	2.0
Laxá, Helluvað	2007-08-16	18:00	37.3	17	111	53	20	7	18	2	2.5
Laxá, Helluvað	2007-08-23	17:00	36.3	10	109	46	18	7	25	4	1.1
Laxá, Helluvað	2007-10-24	23:15	37.3	29	105	38	13	4	21	24	2.1
Laxá, Helluvað	2007-10-27	11:33	40.5	27	111	46	18	8	23	5	1.2
Laxá, Helluvað	2007-11-15	21:00	37.3	223	113	63	13	9	14	1	2.5
Laxá, Helluvað	2008-03-12	18:30	35.8	31	118	37	4	4	33	22	1.75
Laxá, Helluvað	2008-05-18	18:01	56.9	26	86	55	20	7	13	5	1.35
Laxá, Helluvað	2008-06-04	14:00	43.9	16	91	26	26	11	30	7	1
Laxá, Helluvað	2008-06-28	19:15	38.2	12	88	70	24	1	5	0	1
Laxá, Helluvað	2008-07-04	15:40	40.7	26	84	43	4	4	37	12	1.5
Laxá, Helluvað	2008-07-13	16:00	37.9	11	93	31	10	24	33	2	0.8
Laxá, Helluvað	2008-08-21	18:20	37.2	13	118	26	20	4	30	20	0.8
Laxá, Helluvað	2008-08-22	15:01	37.0	24	121	30	7	15	17	31	1.9
Laxá, Helluvað	2008-08-26	15:45	36.4	49	129	42	36	11	10	1	1.5
Laxá, Helluvað	2008-11-05	17:30	39.0	40	111	34	10	5	26	25	2.2
Laxá, Helluvað	2008-11-12	20:20	38.9	19	168	16	11	7	51	15	0.7
Laxá, Helluvað	2008-11-14	14:24	38.7	26	108	4	6	6	54	30	0.5
Laxá, Helluvað	2008-12-15	17:20	37.4	89	125	35	20	34	8	3	1.45

						Size fraction - %					
Loaction	Date	Time	Discharge	Concentration	TDS	Coarse sand	Fine sand	Coarse silt	Fine silt	Clay	Biggest particle
#	yyyy.mm.dd	hh:mm	m3/s	mg/l		> 0.2 mm	0.06 - 0.2 mm	0.02 - 0.06 mm	0.002 - 0.02 mm	< 0.002	-
Laxá, Helluvað	2009-02-03	17:30	32.1	3	117	57	29	9	5	0	1.0
Laxá, Helluvað	2009-05-21	11:15	46.6	38	77	58	18	9	14	1	1.2
Laxá, Helluvað	2009-06-02	09:45	41.8	39	86	81	10	6	1	2	2.1
Laxá, Helluvað	2009-06-15	16:20	38.7	34	107	50	12	10	25	3	1.9
Laxá, Helluvað	2009-06-18	07:20	40.7	39	78	47	22	10	14	7	1.5
Laxá, Helluvað	2009-07-20	17:32	37.7	14	147	50	9	7	28	6	0.8
Laxá, Helluvað	2009-08-19	21:50	42.7	14	153	50	16	9	23	2	1.1
Laxá, Helluvað	2009-10-29	13:30	33.2	4	112	58	41	1	0	0	1.0
Laxá, Helluvað	2010-06-09	17:20	33.9	45	91	16	6	20	49	9	0.9
Laxá, Helluvað	2010-06-10	10:30	34.5	53	93	22	8	19	48	3	1.05
Laxá, Helluvað	2010-06-19	22:00	34.2	47	112	56	9	9	21	5	3
Laxá, Helluvað	2010-06-25	12:50	33.8	25	96	79	11	4	6	0	2.25
Laxá, Helluvað	2010-07-13	17:00	42.0	47	84	48	15	5	11	21	2.05
Laxá, Helluvað	2010-07-29	17:35	35.5	17	100	36	9	5	32	18	1.1
Laxá, Helluvað	2010-08-11	22:40	35.5	30	108	54	7	6	25	8	2.6
Laxá, Helluvað	2010-10-12	19:10	34.0	23	102	11	13	25	46	5	0.75

Appendix 3: Sediment Handling by Hydro-suction

Dredging and Hydro-suction

Under-water excavation of bed deposits by use of mechanical equipment of various kinds is synonymous with dredging in this report. Various methods are applied for the excavation part as well as the transport and deposition of the excavated material. The difference between dredging and hydro-suction is the energy source for the excavation process, but there is definitely overlapping between them. The main power source for hydro-suction is the hydraulic energy head created by the dam while dredging has external power source both for cutting and transportation of the excavated sediment. Some will argue that hydro-suction is one speciality within the dredging technologies. The dredging technologies are mainly developed within the fields of costal engineering, marine offshore engineering and the mining and mineral processing industries. Hydro-suction has been developed mainly for use in water storage reservoirs behind dams.

Pipeline

Several methods can be adopted for cutting deposited sediment as well as transport and deposition of the excavated sediment load. Deposition of excavated sediment on land is not realistic within the context of sediment handling at most reservoirs. Transport of sediment and water slurry in pipes to the river downstream of the dam is referred to as hydro-suction. Re-deposition of excavated sediment inside the dead storage of the reservoir is referred to as dredging. Nevertheless, a hydro-suction rig can be furnished with a mouthpiece from the dredging industry where the mouthpiece is referred to as a cutter head or a jetting head.

Advantages

Sediment removal from a reservoir by use of dredging or hydro-suction has several advantages compared with reservoir flushing. The most important is that it is not necessary to empty the reservoir before sediment removal takes place as it is with conventional reservoir flushing. Sediment removal can furthermore take place during all normal operation water levels.

Economy

The sediment concentration in the water used to excavate deposits and release the slurry in the river downstream of the dam is high. The water consumed by a hydro-suction rig is therefore limited. The water losses associated with reservoir flushing is within another order of magnitude. Hydro-suction can work at all water levels in the reservoir and use minimum release flow or more than that in periods where water will be spilled anyhow during the spillway of the plant.

Environment

As the excavation of deposits by hydro-suction is controlled; sediment load can be fed into the river downstream of the dam to obtain an acceptable sediment concentration in the river further downstream. Sediment can also be temporarily deposited downstream of the dam where it can be picked up by flood water released through the spillway of the dam. That will secure a more normal sediment concentration in the flood water and reduce the risk of degradation of the river bed and scouring of river banks downstream of the dam during flood events.

Sustainability

The prospect of having a sustainable water storage reservoir is the most attractive feature of a reservoir with an efficient sediment removal system both in economic terms as well as environmental terms.

Adopted Approach to Reservoir Sediment Handling

There is no well-proven technology which can guarantee long term sustainability and cost-effective sediment handling at the reservoirs. Nevertheless it is likely that this can be achieved through up-scaling and further development of known technologies.

The study approach has been to provide the operator of the power plants with all available tools for sediment management within a realistic technical, economic and environmental context. The plants will then be able to make use of the best available technologies today and develop the most attractive ones further for the benefit of the project in the long term.

Objective

The objective with the adopted sediment management strategy is to obtain long term sustainability of the scheme with optimum sediment handling as well as operation of the reservoirs within a context of the best technical and environmental practice, not only today, but for years to come.

Alternative

The recommended alternatives for sediment management in the reservoirs are therefore to maintain the possibility of implementing conventional reservoir flushing by converting the diversion tunnels to relatively sizable bottom outlets which facilitates reservoir flushing if possible and to make all necessary preparations for using hydro-suction. Hydro-suction is seen as the most promising technology for sediment management at all plants. In the following part of this document, the hydro-suction sediment removal system is addressed further.

General

Pipe-flow

Transportation of sediment suspended in water through a pipe is a well-known hydraulic phenomenon. It has been used for a long time in the mining industry as well as in costal engineering in connection with dredging and/or land reclamation. Free surface and supercritical flow condition is the most effective mode of transport while full face flow is the most flexible mode of transport as the pipeline does not have to run with a constant slope within the reservoir. The pipeline will furthermore not be subjected to varying buoyant forces due to various combinations of water, sediment and air inside the pipeline.

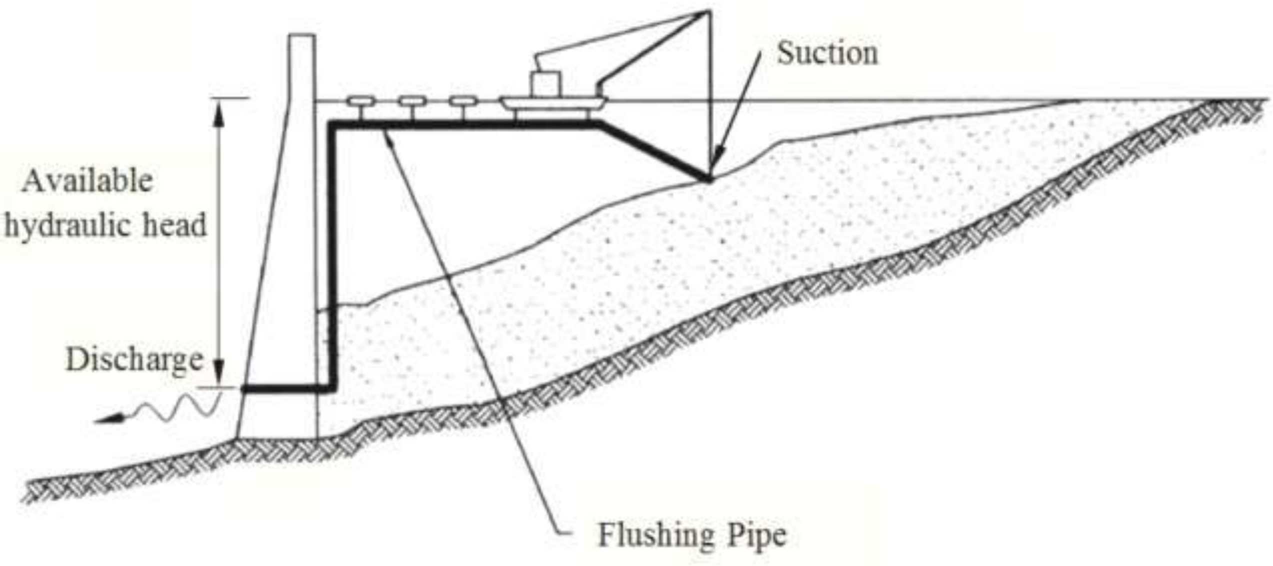

Figure 1: Conceptual Sketch of a Hydro-suction arrangement (H.S. Shrestha, 2012)

Concept drawings of a hydro-suction rig are shown in Figure 1 and Figure 2. The main components of a hydro-suction rig is the suction head or the mouth-piece with its system for positioning itself inside the reservoir, the flexible pipeline which connects the suction head with the fixed outlet arrangement and the downstream flow control arrangement from which the sediment rich water flow is released to the river downstream of the dam.

Status

Hydro-suction is a relative new and immature technology. Most of the available experience is from projects where hydro-suction has been used as a second option to improve the performance of reservoirs where sedimentation rates has proven to be higher than expected and where other methods has not performed satisfactorily.

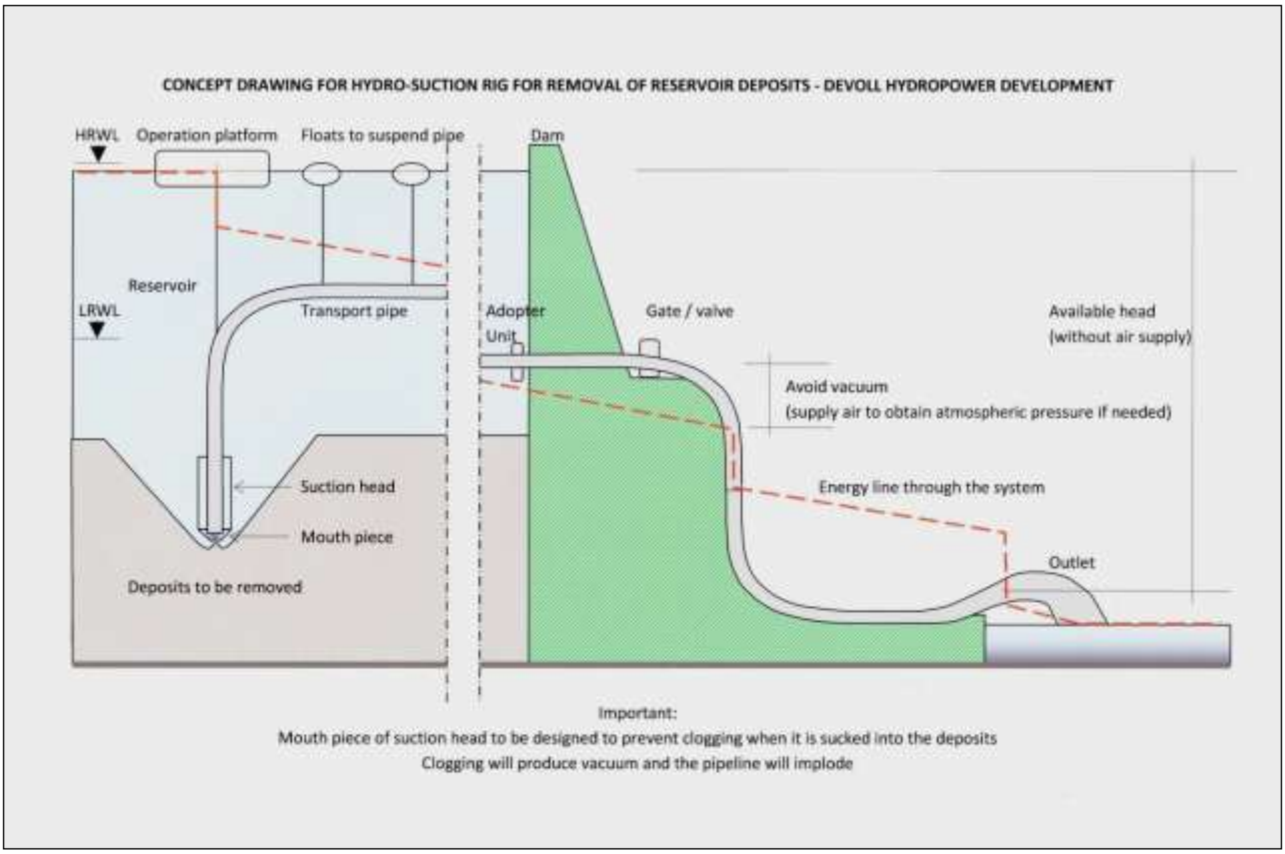

Figure 2: Concept drawing of a hydro-suction rig

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