Dam and intake remediation of the Laxá powerplant III, North Iceland

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The Laxá Power Plant III from 1973 (14 MW, discharge 44 m^3/s), is a run of the river plant that had severe operational and abrasional problems due to ice and sediment transport. In 2016/17, the dam and intake were rebuilt to reduce the operational problems. The changes, designed by Verkís Consulting Engineers, include a new outer intake with ice skimming spillway on top and two small sediment traps for flushing sediment (sand up to relatively large stones) past the power station's waterways.

The goal was to divert both ice and sediment, back to the river downstream of the dam. The plant started again in March 2017. The experience after two years in operation is good, even though the ice skimming has not been fully functioning and the gravel excluder has been inoperational during part of both winters. No operational problems affecting the power production have occurred due to ice and sediment transport around the intake area. Some sediment still passes through the turbine but very little compared to before and wear on mechanical parts seems normal.

This paper covers the original operational problems, environmental restrictions, the remediation concept and expectations as well as describing the gained experience after two years of operation.

1. Background

The Laxá Hydropower Plants, located in the north of Iceland, were constructed by the town Akureyri and the Icelandic Government. They were constructed in consecutive order; Laxá I in 1939 (5 MW, 39 m head), Laxá II in 1953 (9 MW, 29 m head) and Laxá III in 1973 (14 MW, 39 m head), which uses the same intake pond as Laxá I. These are run of the river plants with small intake ponds but relatively stable discharge with the exception of short periods with lower discharge due to ice formations. Landsvirkjun, the National Power Company of Iceland took the stations over in 1983.

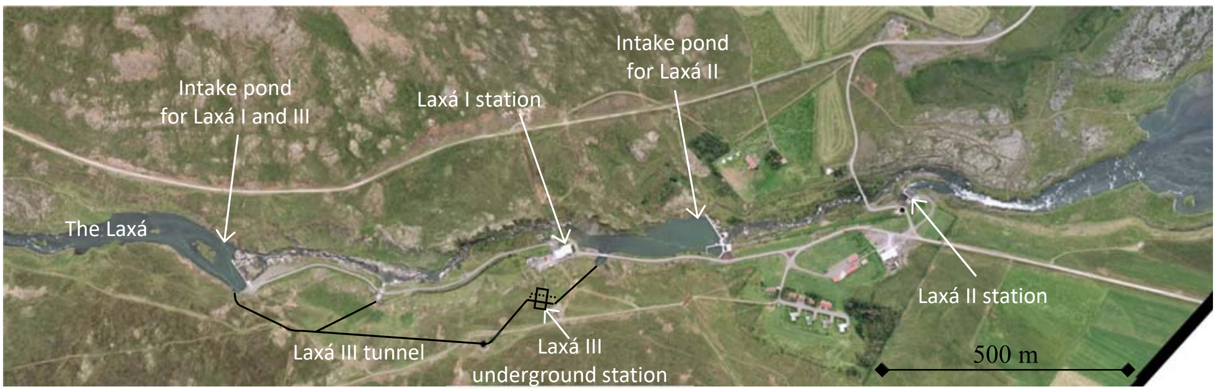

Fig. 1. Map showing the Laxá Hydropower Plants within the Laxá Canyon.

The Laxá is a spring fed river with origin in Lake Mývatn (about 35 m^3/s). The Kráká (about 7 m^3/s) is a tributary originating from the sand desserts in the Icelandic highlands. This tributary is the main source of sediment transported by the Laxá as Laxá itself runs on lava formations all the way from the lake to the power stations. The thalweg of the Laxá from Lake Mývatn to the power plants, is steep enough to prevent ice cover formation. There are a few exceptions from this, like the Birningsstaðaflói, a bay within the river located about 5 km upstream of the power plants. Because the river does not form an ice cover it can produce huge amounts of ice slush that can accumulate at and above the intake ponds. Additionally, anchor ice plus inflowing ice slush can form ice dams at various locations along the river (growing from the river bed and up). These will later break and cause ice surges of various sizes from small to very large ones. The ice creates another problem that is transport of stones with ice. All these factors contribute to severe operational problems in the Laxá power plants.

At the time of planning Laxá III those problems were well known, and the design took notice. The first phase of the project consisted of the waterways, the power station and the first turbine for a bigger power plant. The second phase, including a big dam that should have raised the water level some 45 m and created 60 million m^3 storage capacity, was never constructed due to the first major environmental protests (mainly local landowners) in Iceland. This resulted in continuation of the operational problems. The dam was the old dam built for Laxá I in 1939, raising the water level only about 3 m, leaving the intake for Laxá III partly above water.

The table below shows volumes of relevance to the left and discharges of relevance to the right.

Approximate volume of the	Thousand m^3		Discharge in the Laxá in Laxá Canyon	m^3/s
Intake pond for Laxá II	40		Through power plants	44
Intake pond for Laxá III	30		Flood (500 year return period)	200
Originally planned reservoir for Laxá III	60 000		Estimated size of the biggest ice surge (approximately 5 minutes duration time)	300
Birningsstaðaflói (bay)	100-200			

1.1 Previous attempts and environmental restrictions

Some attempts have been made to lessen the operational problems. Most consisted of trying to get permission to heighten the dam for 10-12 m in order to gain additional volume for sedimentation and ice. It would also immerse the intake considerably which should also help with reducing the operational problems. These attempts were not successful. Some attempts were made to restrict sediment transport from the Kráká but the volume was too much for those sediment traps and the ideas abandoned. An ongoing project aims at restricting sand movement by wind using vegetation, but this is a very slow process under severe conditions in the Icelandic highlands.

The Laxá and Lake Mývatn were protected by special laws in Iceland in 1974 and put on the Ramsar list in 1977. The Icelandic laws were changed again in 2004. The area is also on the IBA (Important Bird Area) list.
The Icelandic laws allow no water level changes within the river, including the Laxá III intake pond, and no changes to discharge. Additionally, the Laxá is very productive river. Downstream of the power plants, in Aðaldalur, is one of Iceland's most famous salmon rivers. Upstream of the plants is no salmon but abundant brown trout that attracts anglers from all over the world.

2 The operational problems

2.1 Sediment transport

Fig. 2. Left: Traces of black sand on tunnel wall show how much sand was moved from the upstream end of the tunnel. Right: Sediment in the lower part of the tunnel before removal.

Water transported sediment that can pass through the waterways of the power plants is mainly sand originated from the Kráká. The volume transported yearly is of the same order of magnitude as the volume of the intake pond. Suspended sediment is about 30 thousand m^3 per year, thereof about 20 thousand m^3 would settle where velocity is under 0.5 m/s. This means that all possible locations within the pond and within the waterways, where the sand can settle due to lower velocity, are quickly filled with sediments and the additional sand transported through. Figure 2 shows examples of sand that had settled in the intake tunnel. This sand is highly abrasive and reduces the lifetime of the mechanical parts.

2.2 Trash racks and anchor ice

Due to the climate in Iceland, marine climate, the intake can not be operated with trash racks covering the whole opening. In winter, the temperature fluctuates a lot around 0°C giving the river ample opportunity to create active frazil ice that can easily accumulate as anchor ice on the trash racks.

The solution to this problem has simply been to remove two trash rack panels out of four in both openings to prevent clogging. The top and bottom trash rack panels are usually left in place.

2.3 Stones carried with ice

Stones have been transported with ice into the turbine. This material would never enter without the help of ice lowering the density of the larger stone/ice particle. These incidences have resulted in broken bolts, reduced power production temporarily and in severe cases, when the stones are too large to pass through, results in down time while the stones are being removed. These stones also reduce the lifetime of the mechanical parts.

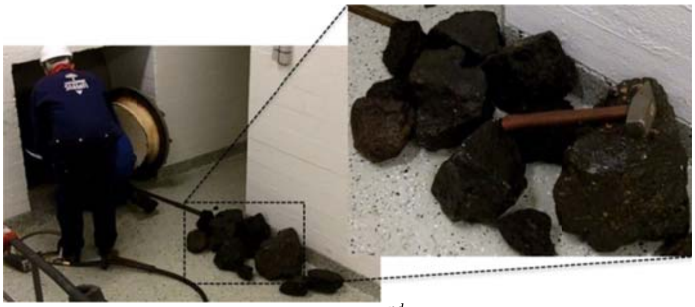

Fig. 3. Stones removed on March 22nd in 2011. Estimated size of largest stone about 40 cm.

2.4 Ice slush accumulation and added viscosity of the water

The ice production capacity of the river, upstream of the power station, can quickly reach the same volume as that of the intake pond. As an example, under severe conditions the production can be 20 thousand m^3 over only 8 hours. The ice slush produced can quickly accumulate within the upper most part of the tunnel's cross section, within the intake pond and upstream; in other words, everywhere where the velocity is low enough for accumulation. The velocity which distinguishes between settling and erosion is likely to lie in the range of 0.6-0.9 m/s where the higher values apply to newly formed ice slush (Ashton, 1986, p. 281).

As the volume available for storage of the ice is small and the velocity of the flow relatively high where it enters the pond an equilibrium state is sometimes reached where inflowing ice passes through. If the production capacity is high this can lead to higher viscosity of the flow and in some cases the viscosity has become so high that power had to be used to turn the turbine. This was done to prevent it from stopping as that could lead to a total freeze up of the turbine.

Both added viscosity and ice accumulation reduced power production capacity. In addition, the ice accumulation increases velocity in the waterways and can thus lead to erosion of the previously settled sand on the tunnel bed as the ice slush settles at higher velocities than the sand. The same phenomenon, i.e. ice accumulation induced sand erosion, is thought to be at work at Birningsstaðaflói some 5 km upstream of the power plants. If that is the case these periods would result in higher sediment load at the plants both because of erosion from the bay and from the intake tunnel.

2.5 Ice surges

The ice surges come in many sizes. The smaller ones only leave a trace of ice cubes at the upstream end of the ice cover or break into the ice cover on the intake ponds and leave the ice cubes there. The biggest ones have moved cars and caused havoc at the stations. The bigger ones often blocked the intake to the tunnel for Laxá III and it took a lot of effort to get water again to and through the intake. After changes made to the outlet branches from Lake Mývatn in 1960 these bigger ice surges have been rarer but still could cause some blockading.

3 Remediation concept and expectations

3.1 Factors left out of scope

Protection against ice surges and the transport of stones stuck in ice into the waterways were not considered. The reason is that the designer team thought the best way to tackle the ice surges would be to allow the river to leave the ice rubble behind at some dedicated upstream location. Construction upstream was not dependent on stopping the plant during construction time so it could be looked at at a later time. The transport of stones is likely to be linked to the ice surges and thus will be dealt with in combination with that.

3.2 The concept

Expected yearly sand transport into the intake pond is estimated to be similar in volume as the volume of the intake pond and ice production (ice slush) can reach this volume in a few hours or few days during cold spells. Gaining enough additional volume was not seen as a viable solution as it is prohibited to raise the water level and the space within the canyon (about 70 m wide and less than 150 m in length) is so limited that lowering the riverbed far enough to gain enough volume for ice accumulation was not seen as a viable solution.

To add to the problem, ice formations in the bay, Birningsstaðaflói, and within the intake pond and tunnel are expected to increase sediment transport. The same process should also apply to any sediment trap constructed, rendering it temporarily useless when ice formation increases the velocity over the erosion velocity of the settled sand. For this reason, it was considered necessary to tackle ice and sediment transport simultaneously and transport the material transported by the river past the power plant relatively frequently or, in the case of ice slush, continuously, as ice formations are quick to form and difficult to remove after they form. This frequent or continuous skimming of ice and sluicing of sediment was also considered beneficial in terms of mimicking the natural processes of the river.

Spillway design aimed at keeping the water level unchanged both under normal operational conditions as well as during flood events. It was decided to use as much of the old dam as possible.

3.3 The design

The old intake consisted of a simple construction at the tunnel opening with the actual intake structure, including gates, located a few meters into the tunnel in an intake cavern.

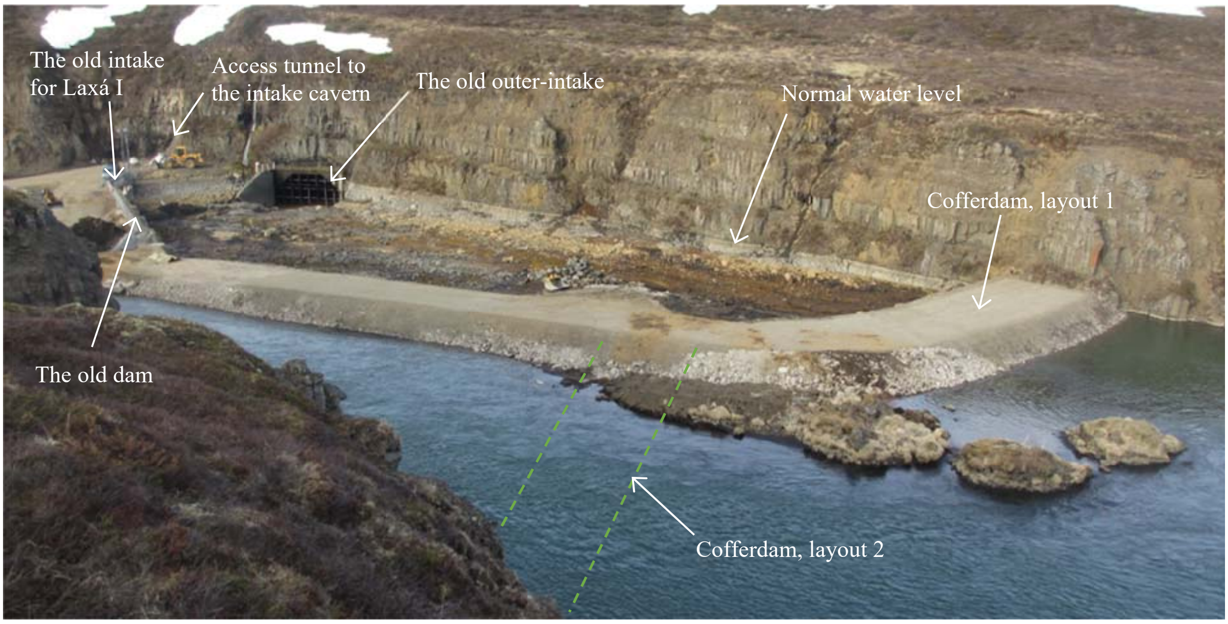

Fig. 4. The construction site in May 2016. Cofferdam, layout 1, ready and part of the intake pond dry. The old dam on the left and the upper part of the old outer-intake visible.

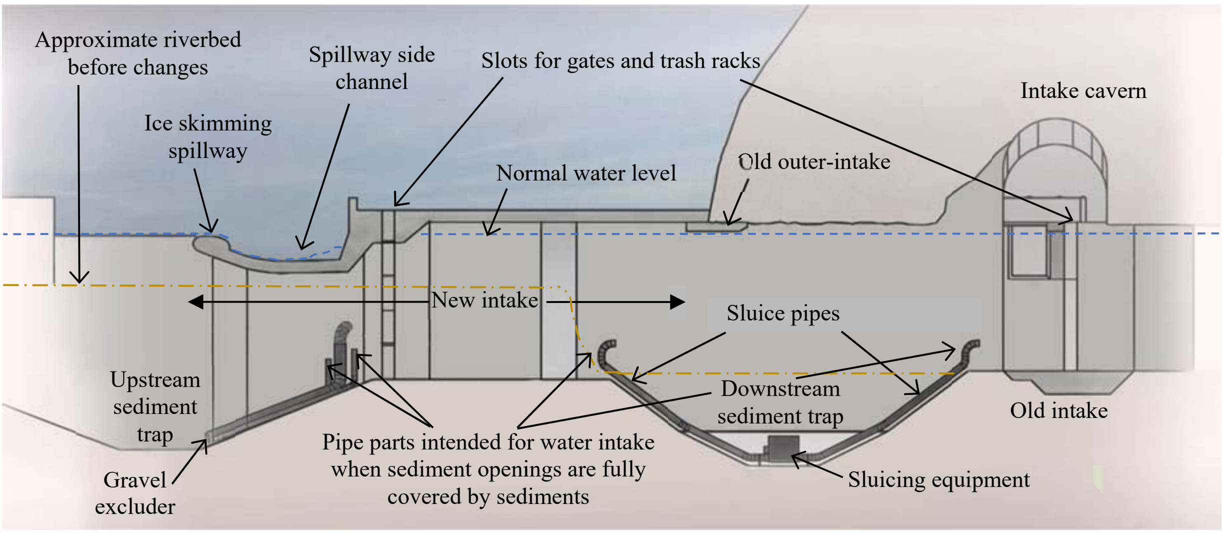

Fig. 5. Longitudinal cross section through the old and new intake.

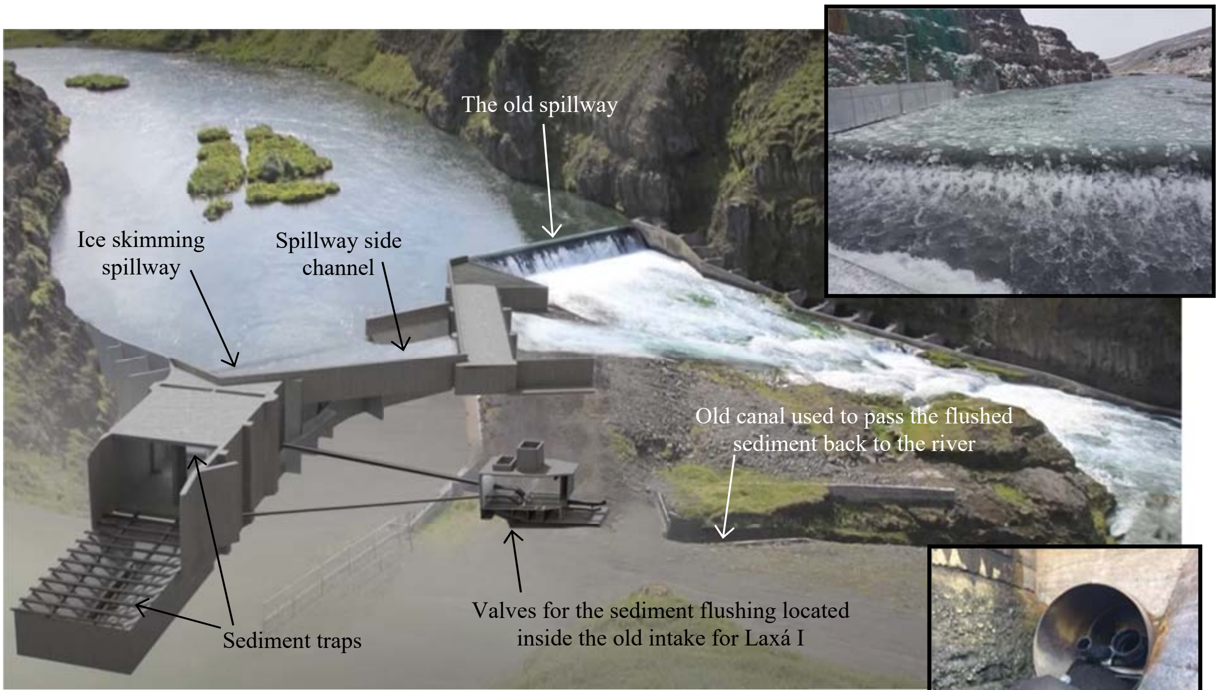

Fig. 6. A 3D drawing of the new design superimposed on top of a figure of the old. Fillings coloured with grey tones. Top right: ice flow on the ice skimming spillway (cofferdam layout 2 still present, only half the intake pond is active). Bottom right: downstream end of the sediment pipes, sand that has been sluiced through.

The new design consists of a new intake including:

- A 22,5 m long ice skimming spillway located over the intake. It conveys ice and water into a side channel designed to:
    - induce a hydraulic jump to mix ice and water and
    - have Froude number over 1 in the longitudinal direction of the channel in order to convey the mixture fast back to the river and minimize the possibility of ice accumulating in the side channel.
- Two sediment traps:

- The upstream one, located at the intake mouth, is equipped with a suction pipe from SediCon, designed to remove sediment and stones up to 50 cm in diameter. The installation consists of one Ø630 SediCon Gravel Excluder with a Stafsjø knife gate valve, DN600. Water consumption 2 m^3/s.
- The latter is located a few meters further into the intake, but upstream of the old intake trash racks. It is 20 m long x 10 m wide x 5 m deep and equipped with SediCon Sluicer pipes designed for sand and stones up to 12 cm in diameter (Ø355 SediCon Sluicer with a Stafsjø knife gate valve, DN300, water consumption 500 l/s). To prevent bigger stones from entering the trap a steel grid with 12 cm x 12 cm mesh is located above it.

Both the ice slush flushed over the ice skimming spillway and the trapped sediments are diverted back to the river downstream of the dam before entering the headrace tunnel.

The location of the ice skimming spillway above the intake was based on experience elsewhere, where the base line was that the likeliness of ice skimming working increased if the spillway was located close to the intake. Videos from the intake pond and the dam for Laxá III pointed in the same direction and showed well how only a small portion of the ice slush carried with the water passed over the old spillway while most of the ice was being carried with the main flow towards the intake.

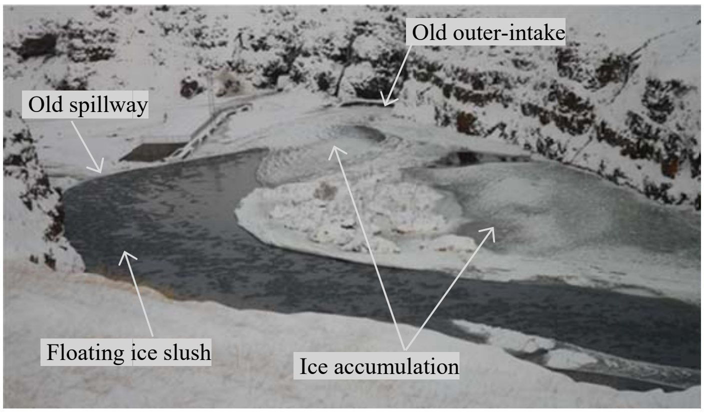

Fig. 7. Overview of the intake pond, intake and dam for Laxá III before changes. Ice slush transported with the flow, part flowing over the old spillway, but much transported with the main flow to the intake.

The choice of sediment equipment was based on the location of the openings on the sluice pipes underneath the pipes and locating the ends of the pipes above the sediment trap to insure access of water into the pipes. This made our worries about clogging vanish. Additional benefit of the system was that it uses very little water for flushing and is only based on water pressure difference.

The final design of the sediment layout and choice of equipment was made at a joint design meeting including Verkís, Landsvirkjun and SediCon.

3.4 The expectations

The expectations were as follows:

- High reduction of sand transported through the power plant and thus less abrasion and longer lifetime of the turbine.
- Significant reduction of stones transported with ice into the turbine.
- Ice free intake pond as ice slush would be constantly skimmed from the water entering the intake. The solution was thought to be likely to work but not 100% guarantied as conditions vary and ice can be tricky.

4 Gained experience

The plant was restarted in March 2017 after the remediation work was finished. Since then the intake area has not caused any operational problems for power production and the wear on mechanical parts seems normal.

4.1 Sediment handling

To start with the sediment traps were emptied every other day and worked very well. The downstream sluicer equipment, intended mainly for the sand transport, has continued to operate without a glitch. The upstream trap with the gravel excluder on the other hand has only worked part of the winter. The first winter (2017) operation stopped in November due to a valve problem. The problem was solved during a maintenance stop in May when repairs were made and a maintenance valve was added upstream of the valve. The second winter the operation of the gravel excluder was changed during cold periods and left open, still it became blocked during one of the cold spells in December 2018. The team managed to get it unblocked and operational for a few weeks but then it became blocked again in February 2019 and could not be unblocked until spring due to ice hindering access. Why this happens is difficult to say but it is most likely linked to small ice surges that can cause some sediment fills to fall into the trap, still a speculation. Ice accumulation could also be blocking the smaller water intake pipes that are located well above the sediment trap.

Two scheduled maintenance stops have given opportunities to investigate further. The first one was in May 2018. On that occasion the waterways were partly emptied giving an opportunity to inspect a small part of the tunnel for sediment traces. Surprisingly it was completely sand free. Inspection of the turbine showed no traces of sediment induced abrasion. During the second one, in May 2019, the tunnel was not emptied. Inspection of the turbine indicated that some sand and/or cobbles are likely to have passed through, but much less than before the changes.

4.2 Ice handling

The ice skimming spillway worked well before the removal of the second cofferdam when the intake pond was much smaller and narrower, and the old spillway was being rebuilt and thus not operational. During operation in winter time when the cofferdam had been removed, it has only worked for a short time before becoming blocked with ice.

Fig. 8. The ice skimming spillway and lowest part of intake pond covered with ice formation and snow in February 2019. Small figure to right: summer conditions.

The reason is most likely one of or a mixture of two of these:

- The velocity within the intake pond is most likely too low, allowing ice to slow down and accumulate upstream of the ice skimming spillway where it has time to thicken, get stronger and grow upstream before it is pushed onto the spillway where it stops and continues to thicken and grow.
- Water level on the ice skimming spillway too low for skimming resulting in accumulation from the spillway and upstream.
- Loss of water over the old spillway.

This will be researched further.

These circumstances have not caused operational problems as the intake has not become blocked. The discharge in the Laxá is very stable because of its spring-origin which makes it easier for the flow to keep the opening relatively stable and unblocked even though the ice diminishes the cross section and even though the discharge can temporarily become slightly lower due to ice accumulation within the river (i.e. Birningsstaðaflói) upstream of the plants. The new design has helped as the opening is much larger and deeper than before and the flow lines through the lower end of the intake pond, to and through the intake, are more streamlined than before.

4.3 Next steps

The performance of the new structures and solutions will be evaluated and investigated further during the next years and improvements made in order to improve fully functioning time of all elements of the design.

References

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The Authors

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