Studio Anne Holtrop

ETH Zürich

HS21

MATERIAL GESTURE:

CHANGE

Towards Hydroscopic Design

TRAVEL GUIDE

- Jungfraujoch
- Konkordiaplatz
- Great Aletsch Glacier
- Massa River
- Gibidum Dam & Reservoir
- Massa Gorge
- Hydroelectric Power Plant
- Rhône River

CONTENTS

Our site follows the water trail from the Jungfraujoch glacier saddle down to the Rhône River, finishing at the Illgraben Debris-Flow Measuring System.

JUNGFRAUJOCH

The Jungfraujoch is a glacier saddle that sits in between the Jungfrau and the Monch mountain peaks, at an altitude of 3,463 metres. The flat southern side is made up of the Jungfraufirn, one of the branches leading into the Great Aletsch Glacier, and has a subcontinental climate with annual mean precipitation of 758 mm. The Jungfraujoch railway station and sphinx observatory were built on the east side of the saddle and the railway station is the highest in Europe. The Jungfrau-Aletsch site provides an outstanding example of the geological formation of the High Alps resulting from uplift and compression which began 20 to 40 million years ago. The region covers an altitude range from 809 m to 4,274 m and displays 400-million-year-old crystalline rocks thrust over younger carbonate rocks due to the northward drift of the African tectonic plate.

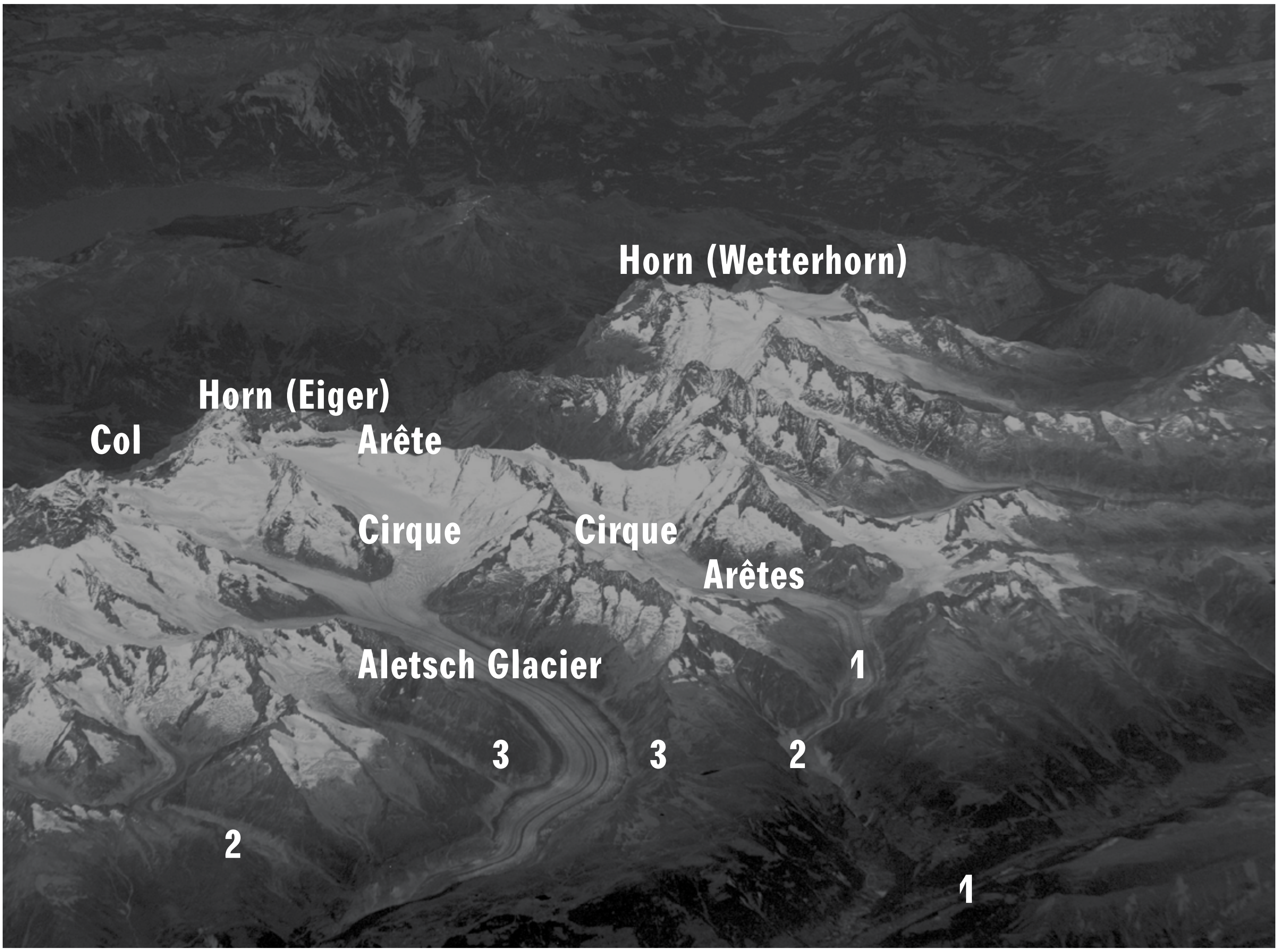
MONCHSJOCH HUT

A crevasse feature near the Monchsjoch Hut.

FIRN

An example of firn layering visible in the wall of a large crevasse on

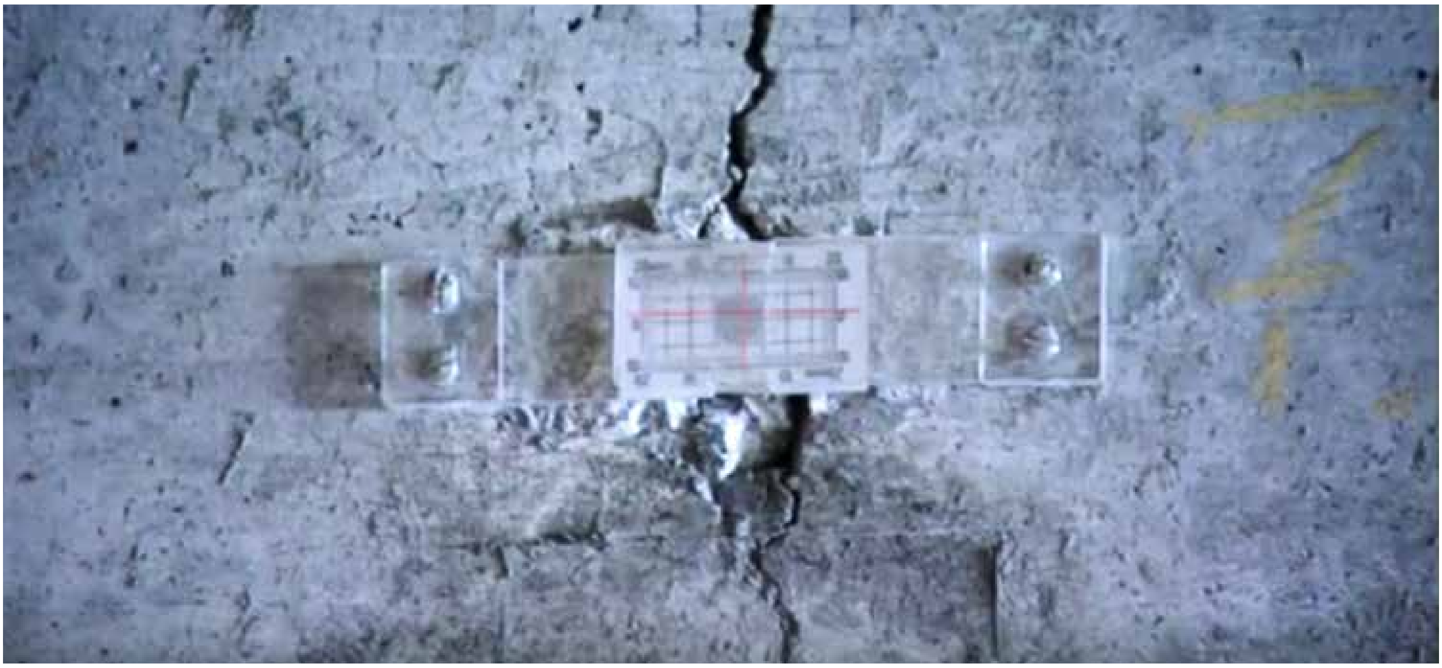
Weissmiesgletscher, Switzerland.



JUNGFRAU-ALETSCH GEOGRAPHICAL FEATURES

A view of the Swiss Alps in the area of the Jungfrau-aletsch.

1 U-shaped glacial valleys
2 hanging valleys
3 truncated spurs



STILLS FROM VIDEO 'SECURING THE JUNGFRAU RAILWAY'

(Top) Keusen using a micrometer. (Bottom) A measuring device positioned

over a crack seen in the concrete reinforcement.

THE MONCHSJOCH HUT

The Monchsjohc Hut is a refuge for climbers before their ascents to Jungfrau, Mönch and other peaks of the region. The hut is the highest-altitude serviced hut in Switzerland, an impressive example of mountain engineering and architecture.
A tank capable of holding 3000 litres of water was installed at the Monchsjohc Hut that collects meltwater for tourism use.

FIRN

Firn is partially compacted granular snow that is at the intermediate stage between snow and glacial ice. Firn is found under the snow that accumulates at the head of a glacier. It is formed under the pressure of overlying snow by the processes of compaction, recrystallisation, localised melting, and the crushing of individual snowflakes. This process is thought to take a period of about one year. Annual layers of firn may often be detected by thin films of dust or ash that accumulate on the surface during each Summer. Further compaction of firn, usually at a depth of 45 to 60 m results in glacial ice, distinguished by its impermeability to air and water. The density of firn is generally accepted as 0.4 to 0.84 grams per cubic cm, and its grain size ranges from 0.5 to 5mm. Britannica, The Editors of Encyclopaedia. "Firn". Encyclopedia Britannica, 19 Nov. 2014, www.britannica.com/science/firn)

JUNGFRAU-ALETSCH GEOGRAPHICAL FEATURES

Arete: The narrow ridge of rock between two U-shaped valleys.
Col: The lowest point along mountain ridges that constitute passes between glacial valleys. Also referred to as Saddle, Wind Gap or Notch.
Horn: Steep peaks that have been glacially and freeze-thaw eroded on three or more sides. A horn occurs when glaciers erode three or more aretes.
Cirque: Bowl-shaped basins that form at the head of a glacial valley
Truncated Spur: The ends of aretes that have been eroded into steep V-shaped cliffs in the corresponding main valley.
Hanging Valley: Valleys of tributary glaciers that hang above the main valley. Hanging valleys are found high up on the sides of larger U-shaped valleys.
U-Shaped Valley: Valleys with a U shape in cross-section, with steep, straight sides and a flat or rounded bottom. Formed by glaciation.

SECURING THE JUNGFRAU RAILWAY

Narrator: Permafrost is the invisible cement that binds mountain

peaks over 2,500 meters together. But today permafrost is a victim of climate change and mountains are beginning to crumble. The Jungfrau-Eiger Massif in Switzerland, all the building structures here are built on permafrost, the problem is that when permafrost melts the subsurface begins to move, as does everything built on it.
Hans-Rudolf Keusen is one of Switerland's leading experts when it comes to rock falls and mudslides and he is responsible for making sure that the Jungfrau Railway, a major tourist attraction, is secure. The cog railway travels high up into the Junfraujoch. It stops at an altitude of around 3,500 meters. On the edge of the north face of the Eiger is a small train station, here, windows have been blasted into the mountain face. These windows are Keusen's first security check station as he makes his way to the Jungfraujoch. The problem is that if the mountain becomes too unstable, the Jungfrau Railway will be at risk. He regularly climbs out of the windows and measures the width and depth of the cracks in the rock with a geological compass. Such cracks have become more and more common as the north face of the Eiger loses its permanent ice covering.
Hans-Rudolf Keusen: "For some time now, as a result of climate change, the ice fields have disappeared and water has been able to permeate the rock through these vertical fissures. This water can then cause the rock to burst from the interior. And it is, of course, of the utmost importance to perform checks on the Eiger face where these window are located."
Narrator: Keusen also monitors the railway's tunnel system. The support pillars in particular must rest on securely frozen earth. Every year when summer arrives and the ice on the rock melts water can infiltrate the bedrock, the pillars warp and lose structural strength. Metal measuring gauges have been fixed into the walls.
The geologist regularly checks to see if they have shifted using a micrometer. The pillars have already been reinforced with thick concrete. Not just in Switzerland, but everywhere in the countries of the Alps railway tunnels and cable car pylons are rooted into the permafrost. Both in and on the mountain the melting away of permafrost has repercussions.
Keusen: "We are basically inside the mountain right now. It is subjected to pressure from the water masses. And the cable car pylons above are affected by the slow creeping movements caused by the permafrost melt, making them a risk factor that must be monitored."
Narrator: Thanks to constant checks tourists on the Jungfrau-Eiger Massif are safe from harm.

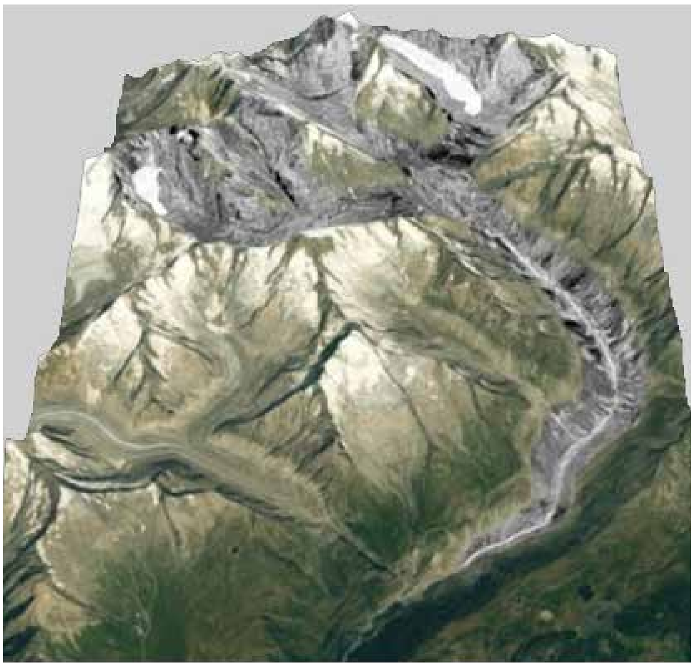
Buildings of the future will, however, have to be engineered in a different manner completely if they are to be of long-term use.
'Securing The Jungfrau Railway As The Permafrost Thaws', 3 mins. britannica.com/video/179626/railway-Jungfrau-permafrost-thaws

JUNGFRAUJOCH SOUNDSCAPE
Philip Samartzis is a sound artist and associate professor at the RMIT University in Melbourne. He spent three weeks recording sounds at the Jungfraujoch research station, mapping sounds of climate change and the site; of moaning winds formed by the cold (the Bise) and warm (the Fohn) winds mixing at this altitude, rocks breaking away from the mountain and ice movements at the Aletsch Glacier below. He also installed hydrophones (underwater microphones) to capture glacier melt sounds. Accumulating over 150 hours of recordings he then made them into a 45-minute sound impression of natural and human-made sounds he recorded in the region. Sound has become a crucial tool to monitor unexpected movements in mountains due to climate change. A recent rockslide at the Matterhorn mountain has brought scientists to place a network of seismic and acoustic sensors to listen carefully to the mountains' internal frequencies.
Another intervention of this kind is the recording of forests. Marcus Maeder, who works at the University of Applied Sciences and Arts, has compiled recordings of the Pfynwald Forest in Valais. His recordings illustrate the quieting of the forest due to the drought and heatwave of 2018.

KONKORDIAPLATZ

Konkordiaplatz, or Concordia Place, is a plateau situated south of the Jungfraujoch. It is a location of convergence, where four smaller glaciers – the Aletschfirn, the Jungfraufirn, the Ewigschneefäld, and the Grüneggfirn – meet to form the Great Aletsch Glacier. The area is completely uninhabited apart from the Konkordia Hut which lies above the glacier, on the western slope of Gross Wannenhorn.

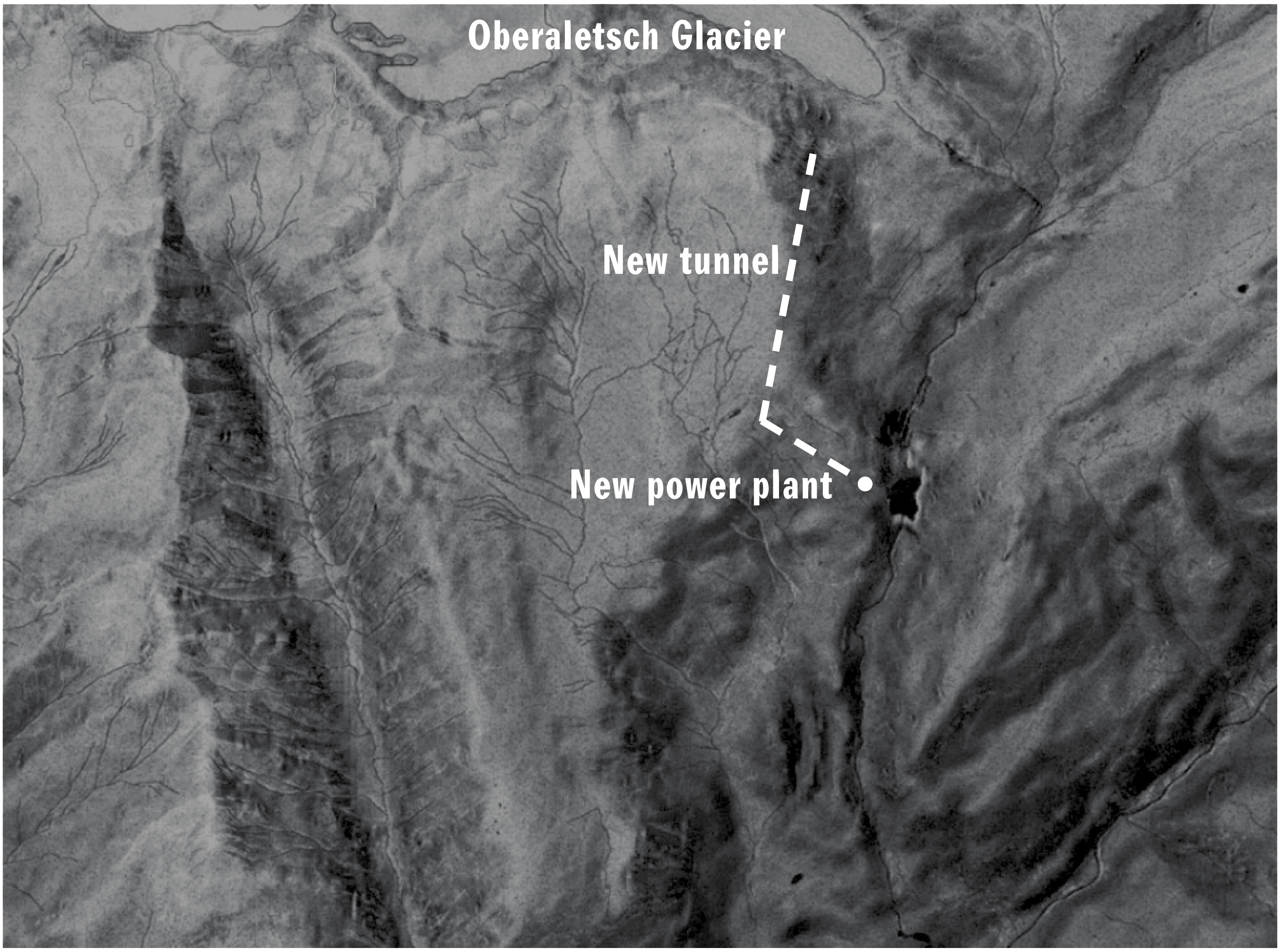
max. 2°C warming



4-8°C warming

FUTURE LAKES

Simulated extent of the Great Aletsch Glacier retreat by year 2100 with two climate scenarios. Study conducted by Guillaume Jouvet and Matthias Huss of the Laboratory of Hydraulics, Hydrology and Glaciology, 2019, (ETHz)



PROPOSAL FOR A NEW HYDROPOWER PLANT

Proposal for new hydropower plant at Gibidum Dam by 2050 at post-glacial reservoir site below Oberaletsch. Water from the Oberaletsch would generate electricity at the new plant.

KONKORDIA HUT (2850 m ASL)

VIEWPOINT to observe Konkordia Hut, ogive and medial moraine features

GLACIAL CREVASSES, OGIVES AND MORAINES

GLACIAL CREVASSES

FUTURE LAKES

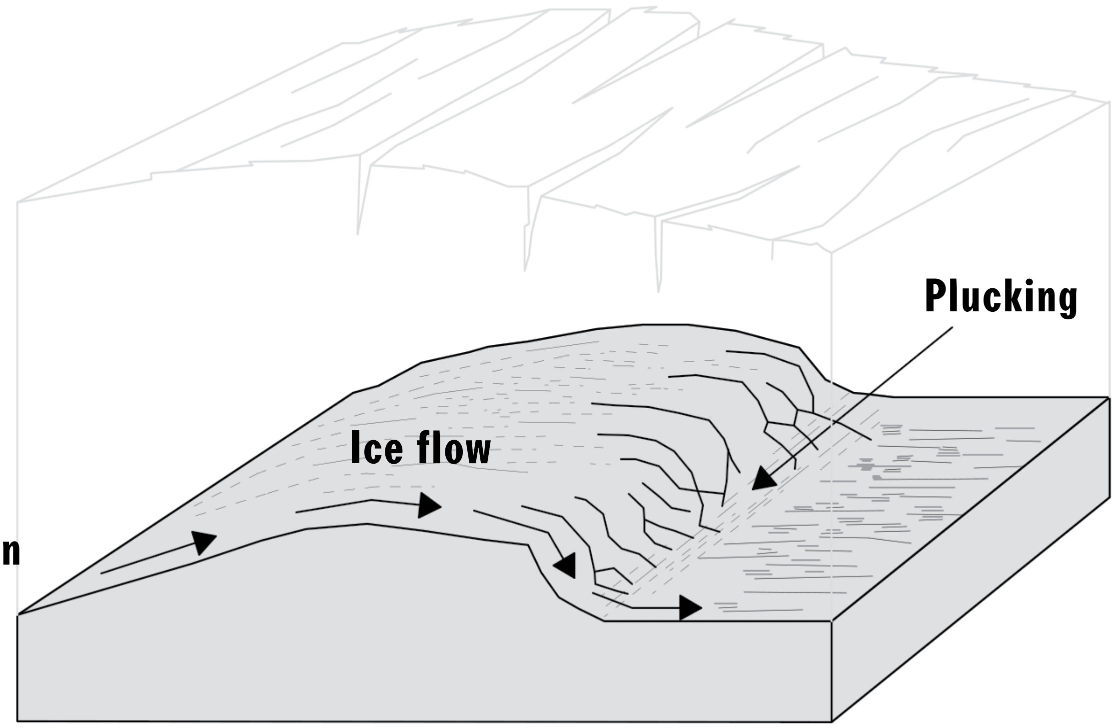
In 2020, hydropower energy counted for 56.4 % of domestic electricity production in Switzerland. Since the decision to close the Swiss nuclear power stations, which make up 35.2 % of national energy, the Swiss Energy Strategy 2050 targets in its Energy Act that hydropower should produce at least 37.4 TWh a year by 2035. This places pressure on advancements in hydropower energy production. Glacial melting offers new perspectives for hydropower in the periglacial environment as suitable sites for new reservoirs become ice-free due to climate change. This potential has been studied by the Laboratory of Hydraulics, Hydrology and Glaciology (ETHz) with the Swiss Competence Center for Energy Research. Together the teams were able to identify 500–600 depressions currently under glaciers, which might be filled with water and become new lakes after the glacier recedes. This includes a new lake at the Aletsch Glacier, the largest depression noted at Konkordiaplatz with a maximum depth of 300 m and a volume of 250 hm^3, which can be compared with the volume of Lac d’Emosson, one of the largest reservoirs in Switzerland. A further potential site has been recognised at the Oberaletsch Glacier, under its leading edge. By 2050, this site is expected to be a lake, therefore, engineers have proposed building a new power plant at the existing Gibidum Dam and reservoir and tunnelling under the mountain up to the site.

GLACIAL CREVASSES, OGIVES AND MORAINES

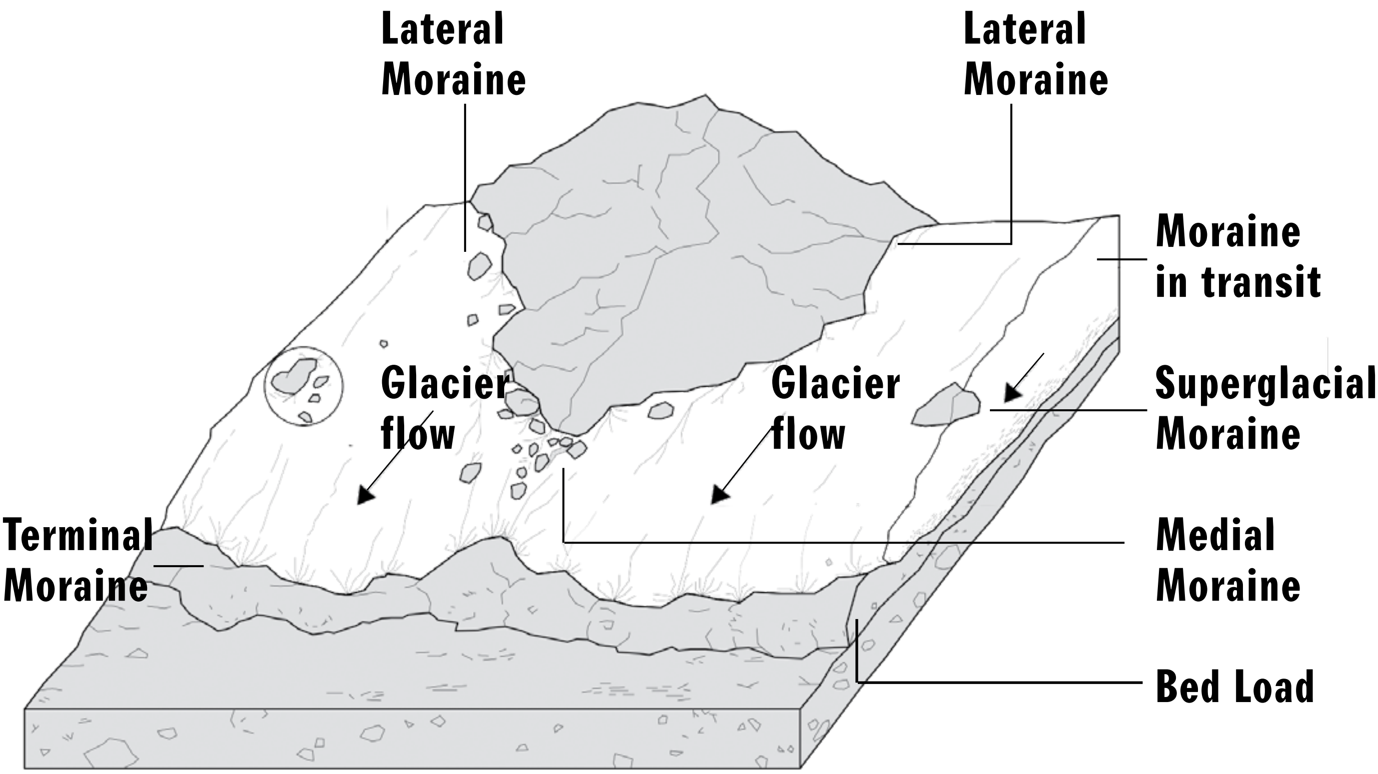
Due to the different speeds at which the glacier moves, tension builds within the brittle, upper part of the glacial ice. The top of the glacier fractures, forming cracks called crevasses.
Ogives are bands that form on some glaciers just below icefalls. The bands alternate in both height and color, and result from seasonal patterns. Darker bands form through increased melt and refreezing in the summer, when sediment collects on the glacier surface. Lighter bands form in cooler months, when snow accumulates and traps tiny air bubbles. Because the ice flows faster down the center of the glacier, the ogives are shaped into arcs that point towards the end of the glacier.
https://nsidc.org
A moraine is material left behind by a moving glacier. This material is usually soil and rock. Just as rivers carry along all sorts of debris and silt that eventually builds up to form deltas, glaciers transport all sorts of dirt and boulders that build up to form moraines.
www.nationalgeographic.org

GREAT ALETSCH GLACIER

The Great Aletsch Glacier is the largest glacier in Europe, and the longest glacier in the Alps, at 20 kilometres in length. The weight is roughly 10 billion tonnes. Due to climate change, the glacier is currently retreating at an average rate of 50 metres a year and melting significantly at its edges.



MODES OF GLACIER EROSION



FORMATION OF GLACIER MORAINES

A rock fragmented via Freeze-thaw weathering

A valley floor post glacial plucking

Glacial striations formed via abrasion

A glacier dirt cone

A glacier table

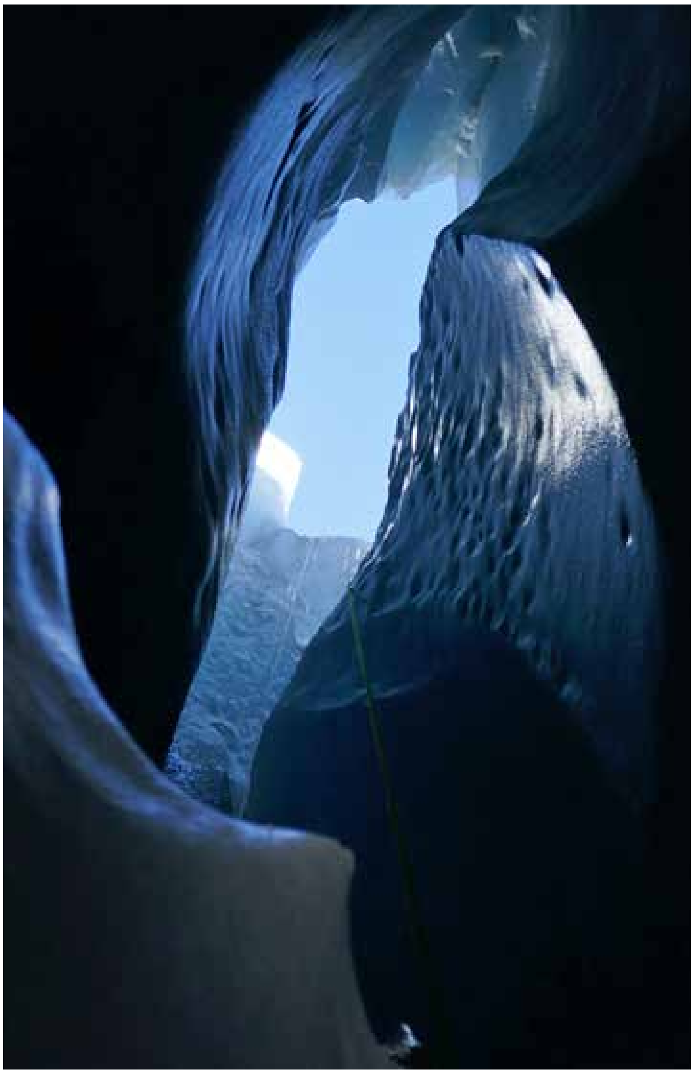
Blue veins of rotated crevasse traces

Post glacier moraine

THE ALETSCH ICE CAVES

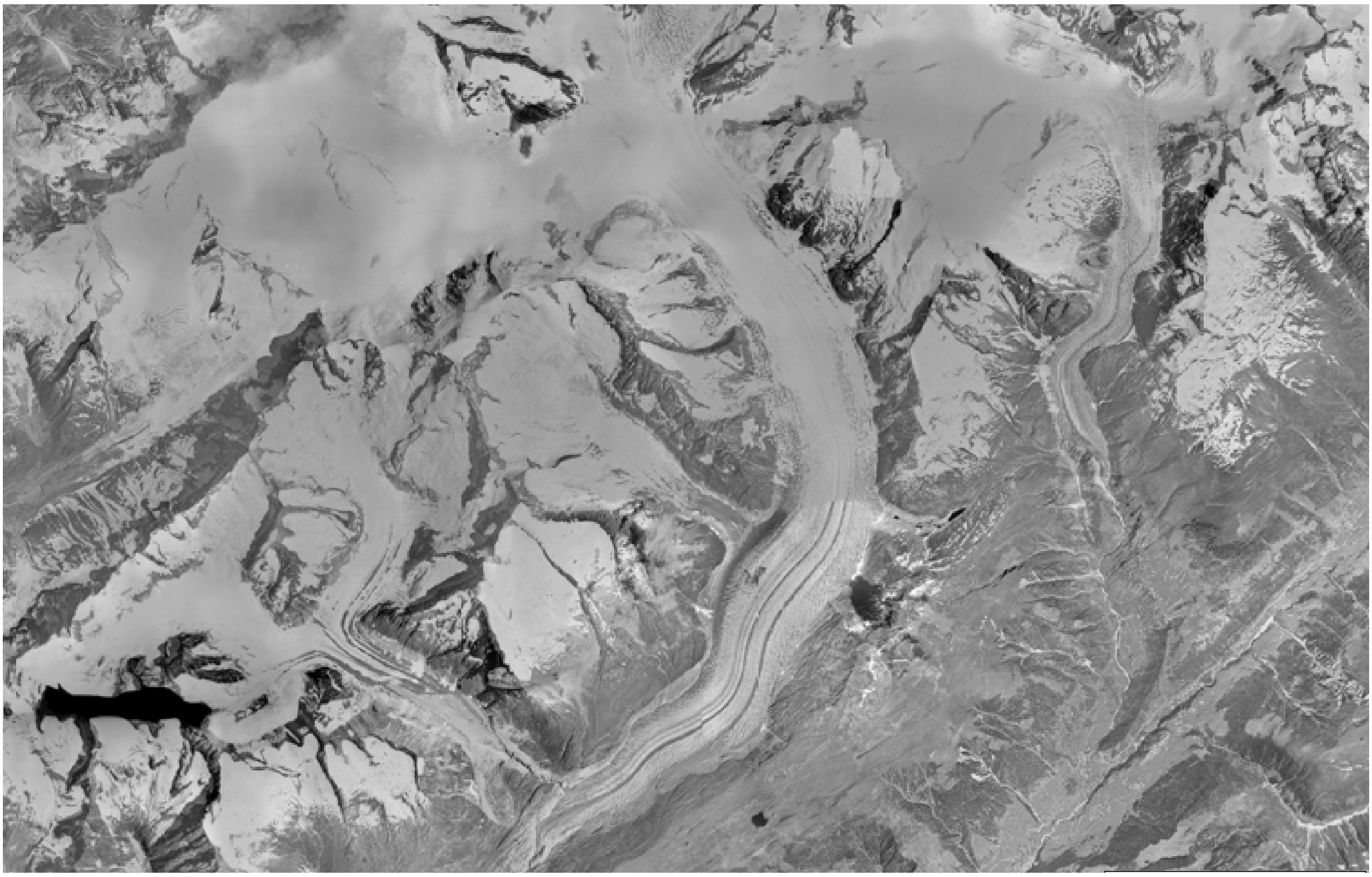
(Top) Scalloped surface and (bottom) rock sedimentaion via glacial abrasion

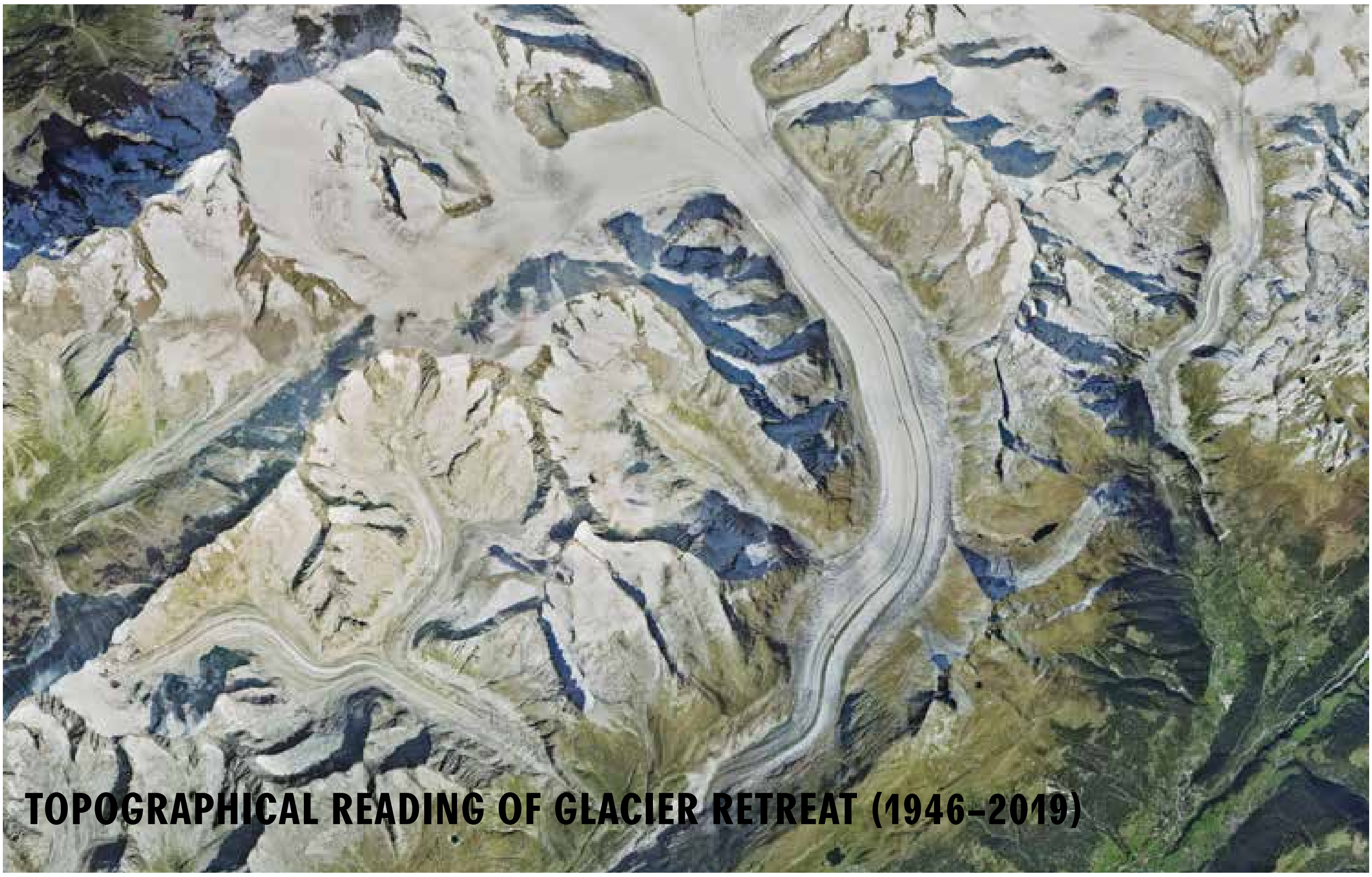
THE ALETSCH ICE RIVERS



ALETSCH GLACIER MOULIN

Exterior and interior views of a Moulin on the Aletsch Glacier.





TOPOGRAPHICAL READING OF GLACIER RETREAT (1946–2019)

Maps avaliable at www.geo.admin.ch

MODES OF GLACIER EROSION

Compression melting refers to the glaciers' force of weight that builds pressure, producing heat at the bottom of the glacier and melting a layer of ice. The glacier begins to slowly glide over this melted water, transporting with it huge amounts of rock, from small pebbles to huge boulders via "plucking". The attached rocks mimic sandpaper, pushing and scraping the valley floor and walls, a process called "abrasion" or "bedrock sculpting", leaving behind striations in the bedrock surface. This movement works to shape the valley from a V-shape to a U-shape as the force of the ice at its edges is significantly lower.

Freeze-thaw weathering refers to meltwater or rain that flows into cracks in the bedrock. At night, this water freezes and expands thus causing the cracks to get larger, eventually fragmenting the rock.

Plucking refers to meltwater from a glacier that freezes around lumps of cracked and broken rock, often loosened by freeze-thaw weathering. When the glacier moves downhill, rock is plucked from the back wall. When a large amount of plucking has occurred, the rate of abrasion increases as more rock is embedded in the base of the glacier.

THE ALETSCH ICE CAVES

An ice cave located at Fiesch was formed via meltwater streams that carved out a tunnel at the base of the Aletsch Glacier and by the wind that aids to hollow out the tunnel. The outcome is scalloped and translucent walls that transmit a bright blue light.

THE ALETSCH ICE RIVERS

Meltwater runs across the surface of the glacier forming ice rivers, which normally end by flowing into a moulin, which takes the water underneath the glacier. The colour of the streams can vary depending on the 'glacial sediment' that is picked up via abrasion and plucking.

ALPINE PILGRIMAGE

In 1674, the Catholic towns of Fiesch and Fieschertal began a pilgrimage and prayer in order to slow the growth of the glaciers after the towns endured a series of disasters. One such disaster happened when pieces of the Aletsch Glacier fell into Lake Marjelen, which caused immediate and devastating flooding in the villages below. During the 'Little Ice Age', the Aletsch and Fiescher glaciers grew, reaching their maximum lengths around the year 1850, and since the 1860s, have been retreating. Since this time, the Aletsch Glacier has lost nearly 3 miles in length and 200 metres in depth. The fear of flooding has instead turned into a concern of forest fires, drinking water and energy production. Therefore, in 2009, the local parish council asked the Vatican to approve a change in the wording of the prayer, from pro-glacier retreat to anti-glacier retreat. The transformed pilgrimage continues today each year on July 31st, starting from the village of Fiesch.

MONITORING ROCK DAMAGE

Landslides and rockfall triggered by retreating glaciers are expected outcomes of climate change and pose a threat to alpine villages. The twentieth-century retreat of the Aletsch Glacier tongue has triggered a widespread but slow landslide movement. The precise processes within shrinking glaciers that result in rock damage and rock slope faults are difficult to observe as they happen under the glacier.
In 2017, the Swiss National Science Foundation funded the installation of custom-designed Shape Array monitoring systems, in order to survey this glacial change and its effects on the surrounding rock formations. The system consists of three inclinometer chains installed 50 metres deep in vertical boreholes. These chains measure the horizontal strain and temperature within the rock slope that is adjacent to the glacier. Each chain includes a series of sensors that measure tilt relative to gravity. This data works to analyse the level of stress the rock is subjected to due to glacial retreat, giving an understanding of the risks of rockfall and landslides.

CHAPTER IV.

GLACIER PHENOMENA.

Thus Nature works as if to mock at Art,
And in defiance of her rival powers;
By these fortuitous and random strokes
Performing such inimitable feats
As she with all her rules can never reach.—COWPER.

IN describing the formation and course of a glacier, we omitted, for the sake of clearness, all mention of the *moraines*, which greatly alter the external aspect of glaciers, though they have no important effect upon their formation. The term moraine is often used loosely to signify all stones and dirt strewn on the surface of a glacier, but it has properly a more limited meaning, which cannot better be explained than in the words of Professor Tyndall:*—

"The surface of the glacier does not long retain the shining whiteness of the snow from which it is derived. It is flanked by mountains which are washed by rain, dislocated by frost, riven by lightnings, traversed by avalanches, and swept by storms. The lighter débris is scattered by the winds far and wide over the glacier, sullying the purity of its surface. Loose shingle rattles at intervals down the sides of the mountains, and falls upon the ice where it touches the

* "Glaciers of the Alps," p. 263.

rocks. Large rocks are continually let loose, which come jumping from ledge to ledge, the cohesion of some being proof against the shocks which they experience; while others, when they hit the rocks, burst like bomb-shells, and shower their fragments upon the ice. Thus the glacier is incessantly loaded along its borders with the ruins of the mountains which limit it; as the glacier moves downward, it carries with it the load deposited upon it. Long ridges of débris thus flank the glacier, and these ridges are called *lateral moraines*. Where two tributary glaciers join to form a trunk-glacier, their adjacent lateral moraines are laid side by side at the place of confluence, thus constituting a ridge which runs along the middle of the trunk-glacier, and which is called a *medial moraine*. The rocks and débris carried down by the glacier are finally deposited at its lower extremity, forming there a *terminal moraine*."

Every medial moraine having once been lateral, until the junction of some new affluent made it medial, and supplied a new lateral moraine to the united glacier on the outer side of its own stream, there is obviously no difference in origin between the two kinds. There is however considerable dissimilarity in appearance, the medial moraines being prominent to all eyes, and the lateral ones being easily confounded with the solid ground of the valley side. The lateral moraines are also continually receiving increase from the source to which all alike owe their rise; débris of all sizes, from huge rocks down to the finest grit, are showered down from the bounding mountains on the edge of a glacier, covering it sometimes so thickly that few would discern the ice beneath, except at places where crevasses have cut through the mass. Conspicuous instances of lateral moraines are not easily given in photographs, since they tend to confuse themselves with the hill-side up to which they slope; but a little study of the picture at p. 78, will disclose a large one on the left bank of the Unter Grindelwald glacier, and there is also one visible in the first illustration to Chap. VIII., on the left bank of the Ober Aletsch glacier.

Medial moraines on the contrary are extremely conspicuous in every comprehensive view of a glacier possessing them; they form long and strongly marked lines down its length, making the surface of a straight glacier look like a strip of music-paper. Such moraines are well seen in the two pictures last mentioned, and less conspicuously in the illustration opposite p. 109, where the starting of a medial, by the junction of two lateral moraines, is also shewn. It is very rarely indeed that a large glacier is found possessing no medial moraines, that is to say descending from one single source, and not formed by the aggregation of two ice-streams; the Rhone glacier, however, as may be seen at p. 23, is a noted exception.

The size of the medial moraines will of course depend on the nature of the mountains which bound the branch glaciers to which they were originally lateral. If the inclination of the mountains is not very great, and their sides are in consequence thickly covered with snow, comparatively little débris will be discharged from them; but if they are steep and rocky, a considerable amount of disintegration will necessarily take place, and give rise to large accumulations of moraine. So also the geological structure of the rocks, by determining the amount to which they will yield to the influence of the weather, is of great importance to the size of the moraine. If the amount of rocks and stones forming a medial moraine be large, it rises in a ridge above the level of the surrounding ice. Most of the long black lines which seem from a distance to be mere discolourations of the surface of a glacier, are really huge ridges many feet high. At first sight these seem to be simply the accumulation of débris, but on more careful inspection it is seen that the whole mass is ice, superficially covered by the stones. The reason is, that the moraine protects the ice beneath it from the direct influence of the sun and air, which waste away the surface on each side. The stones are of course themselves warmed at the same time, and transmit the heat to the ice below; but if the stones are large, the amount thus conducted is much less than the quantity of heat working on the undefended ice. Moreover the heat which is conducted through the moraine, being necessarily obscure,* is prevented, by a remarkable and well-established property of ice, from penetrating into its substance. Thus the moraine is gradually raised above the surrounding level, and it will generally be found that the height of the ridge increases as it descends the glacier. In the accompanying picture is given a good near view of a moraine of no great dimensions on the Ober Aletsch glacier, beyond which, at a distance of more than two miles and a half, rises the ridge of the Beichgrat.

Medial moraines are often found to disappear, engulfed in the ice, where the glacier is much rent by crevasses; and they will at times again emerge from their imprisonment below an ice-fall, and once more form continuous ridges down the glacier. How much of this re-appearance is due to the wasting of the ice down to the level to which the moraine was swallowed up, and how much to the stones being really squeezed out again by the pressure, it is of course impossible to determine.

The rate of motion of a glacier has a tendency to diminish as it approaches its termination, and when this is the case, the moraine matter, instead of continuing to move in comparatively narrow

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* *Obscure* heat is heat proceeding from a non-luminous source, such as a lump of metal not red-hot.

ridges, is more and more spread abroad over the surface of the glacier, until it in some instances, such as the Unteraar, covers the whole end of the glacier so completely, that it becomes hard to discover from a small distance what the dark and confused mass of stones and rubbish really is. This is properly called a terminal moraine, since the strict signification of the term moraine is stones and dirt carried on the ice of a glacier; but the name is more frequently applied to the curved line of stones deposited by a glacier at its termination, and lying free of the ice.

Most glaciers of the Alps have at some period been more extensive than at present, and have left traces of their former selves in the shape both of lateral moraines along the mountain sides parallel to the existing ones, and of terminal moraines forming a succession of concentric arcs similar in shape to the end of the glacier. By these old moraines, as well as by other indications, much is disclosed of the ancient condition of the ice-streams; indeed we may sometimes find the same thing happening under our eyes. The Rhone glacier is known to have shrunk steadily for many years, and the evidence of it is sufficiently visible, though from the unusual clearness of the glacier not very conspicuously. Six or seven old terminal moraines can be traced in front of the present termination of the Rhone glacier, through which the stream has cut its way. One of these is very clearly seen in the illustration at p. 23, and one or two more may be discovered in it by careful inspection.

The same causes which elevate the medial moraines in long ridges above the level of the ice operate also to produce other glacier phenomena, exhibiting on a smaller scale, but in a manner still more unmistakeable, the working of the natural laws already mentioned. The objects most closely analogous to moraines are what are termed *dirt-cones*, of one of which, noticed on the Unter Grindelwald glacier, a picture is given below. From the surface of the ice there rises what appears to be a conical heap of sand or dirt, but is in reality a mound of ice, coated more or less thickly with dirt. In the illustration a patch of the ice is visible, where the sandy covering had, by

A DIRT CONE.

some accidental blow, been cleared away; this cone is about four feet high, but they may be found of all sizes, from a few inches up to eight or nine feet, and of shapes somewhat divergent from the typical form.

High up "among the hidden bases of the hills," a quantity of gritty fragments are dislodged from some rocky slope, and fall in a heap on the glacier. It may happen that they are speedily dispersed by the wind, and spread widely over the surface, contributing their mite towards toning down the shining whiteness of the upper névé into the blackish hue the glacier assumes in lower regions. Sometimes however such a patch of dirt falls on a sheltered spot, or is covered by snow before the wind has had time to dissipate it; then it travels downwards unmolested, and emerges at length in the open region below the snow-line. Should an ice-fall occur in the course of the glacier, our dirt-heap will have but a very faint chance of passing down it undisturbed; in all probability it will be entirely dispersed or swallowed up in the ice. Hence it is that dirt-cones are seldom found except on glaciers whose flow is smooth and equable; there are probably more on the Aar glacier alone than in the whole range of Mont Blanc.

Supposing however that our patch of grit has braved all the dangers which beset its path, and has safely landed on a tolerably smooth and level reach of the open glacier, it soon becomes elevated above the surface of the surrounding ice. The sun's heat falls with equal potency on the whole; but while the general surface is melted, the ice under the dirt-heap is protected, and remains intact. If the dirt happens to cover the area of a tolerably symmetrical circle, thickest near the centre, a perfect cone will be formed, since the layer thinnest round the outside will only serve to protect the ice partially, while the centre will protect it entirely, and will gradually be raised until the grit is spread uniformly over the whole surface of the cone. It has then done its work; the ice must begin to melt, and the water trickling off it will gradually wash away the dirt, and thus accelerate the process of melting.

Whatever be the shape of the patch of dirt when the formation of the cone begins, the thickest layer will necessarily rise highest, or more accurately will retain its height while the surface melts around it, and the thinner parts will slope gradually to it in proportion to their thickness. Thus where heaps of grit happen to have fallen in close proximity to each other, miniature chains of hills will be created out of them, varying infinitely in form like their mighty rivals, but all tending more or less towards the conical type. Dirt-cones will of course usually be found in close proximity to a moraine, since they have a common source in the débris falling from the mountain sides; and in fact a moraine, when it rises, as it usually does, in a ridge above the level of the ice, is merely a dirt-cone on a very large scale and extended to a great length instead of being isolated. Occasionally also the layer of dirt which forms the nucleus of a dirt-cone, is washed by the rain off an existing moraine down to the ice beside it; and probably most of the cones found on glaciers below a steep fall are originated in this manner.

It will be found on investigation that the ice under the moraines and dirt-cones, when a portion of it is uncovered, appears clear and almost black, like a mass of very dark glass, while the surface of the glacier in their immediate vicinity is white and opaque. The reason for this difference may be easily stated; the unprotected ice is disintegrated by the rays of the sun, and its interstices being filled with air and water, it thence derives a white hue. The ice under the moraines, on the contrary, is protected from the direct influence of the sun, and therefore remains thoroughly compact and transparent; while the coating of stones and dirt prevents any light from shining into the mass from other quarters than the one spot uncovered by the observer.

The same general principle may be discerned in the formation of *glacier-tables*, which are blocks of stone raised on pedestals of ice.

A fragment of rock falls on the glacier apart from its congeners, which form a moraine in the usual way. If it fall on the open glacier the growth of a glacier-table begins immediately; if it fall in the region of everlasting snow the process is deferred until in course of time it reaches the lower elevation, where the sun can act freely on the glacier. The stone protects the ice immediately under it, while the surrounding surface is wasted away; and thus gradually it is left on the top of a column of ice, as in the annexed illustration. This table was found on the Aar glacier, a locality specially favourable to

A GLACIER TABLE.

their formation, since the coarse granite, which constitutes a large proportion of the mountains whence the branches of the Aar glacier take their rise, seems to cleave very frequently into slabs, such as fully carry out the idea of a table when elevated on their icy pedestals. The figure beside it in the picture, which is that of a man of average stature, will give a sufficient idea of the dimensions of this table; but it is not a third of the size of one discovered on the previous day, which unfortunately slipped off its pedestal before we could photograph it.

If the sun's rays fell vertically upon the slab of stone, there would be scarcely any limit to the height to which it might be raised; the pedestal would be exposed only to the wasting influence of the air around it, when warmer than the freezing-point, and would but very slowly indeed become too frail to support the superincumbent weight. But since the sun's rays fall obliquely on the table, two effects are produced, which both tend to the same result. The southern side of the block of stone receives more heat than the northern, and consequently transmits more to the ice beneath; and further, as soon as the stone is raised some little height above the surrounding surface, it ceases entirely to shade the southern side of the pedestal. Hence the stone gradually dips more and more towards the south, and finally slips off its pedestal, which being no longer protected speedily disappears, while the formation of another table begins under the stone.

The production of all the glacier phenomena which we have been hitherto considering depends on the condition that the sun's heat should not be able to penetrate the layer of stone or dirt which covers the ice. Supposing however that the stone be a small one, or the dirt thinly scattered, a result follows which is precisely the converse of those before described. Stones or grit, especially if they be dark in colour, absorb the heat with much greater rapidity than ice, so that if they are small enough to conduct the heat to their under-surface more quickly than the heat penetrates the exposed ice, they will gradually sink into the ice. A certain size of stone of course will neither sink in nor be raised above the surface as a table, but will remain on the same level with the ice around it; and thus it is that we sometimes find thin lines of moraine distinctly visible in a glacier, yet not forming an elevated ridge. Several such moraines may be observed in the illustration to Chapter IX., lying along the unusually smooth and level surface of the Ober Aletsch glacier.

The holes formed by stones or thin patches of dirt, sinking into the glacier, will often grow to a depth of many feet, and are always filled with water, which appears of a lovely blue colour, due of course to the ice in which it is contained and not to itself. The water in these holes is the purest and coldest imaginable, and is very fully appreciated by the mountaineer, when he reaches the lower level after a day spent in climbing among the heights.

Many of the water-holes found on a glacier are however formed in a totally different manner, and only become filled with water after having served another purpose. Mention has frequently been made already of the melting of the ice on the surface of a glacier by the direct influence of the sun, and the question will very probably have occurred to the reader, as to what becomes of the water thus formed. While the mass is still névé, and has not yet been consolidated into glacier, we have seen that the water sinks through the upper layers, and aids in solidifying the lower ones. When however the substance of the glacier has become tolerably hard ice, water will no longer penetrate downwards, but runs over the surface in whatever direction it can most readily make its escape. Thus channels are formed in the surface of the glacier, along which run streams of water, growing in volume as they descend, and widening and deepening their bed, like rivers of a larger growth. A picture of a glacier rivulet will be found in the concluding chapter, where the subject of the carving of the surface of glaciers by this means is again referred to.

It is obvious that if the glacier be much broken by crevasses, there will be no space for the formation of superficial streams of any magnitude. It will frequently happen, however, that, even where the flow of the glacier is equable and its surface continuous, small local strains, such as a protuberance in the bank of the glacier, or some slight inequality in its bed, will produce cracks which penetrate very deeply, though there is nothing to make them widen into large crevasses. Imagine such a crack intersecting the course of a surface stream; some of the water will rush down it, and gradually wear away the ice, until soon a funnel is formed large enough to receive the whole volume of water, which pours into it in a cataract. These funnels are called *moulins*, and they are to be found wherever there is an unbroken surface of glacier. The instance, photographed on the next page, is taken from the Unter Grindelwald glacier, and is of about the average size, the diameter of the funnel being rather more than a yard.

The edges of a moulin are speedily wasted by the sun and air, so as to form a somewhat bell-shaped mouth to the hole, which makes it occasionally difficult to look down; and the rush of the falling water renders every effort accurately to measure the depth unavailing. There is little doubt that some moulins penetrate the whole thickness of the glacier, and that the waters descending them form no inconsiderable part of the stream which issues from under every glacier; others, and probably the majority, do not reach the bottom, the water finding its way into some opening in the heart of the ice, and tunnelling onwards for some little distance until it meets with another vertical shaft. A singular instance of water returning to the surface after a sub-glacial course is described in Chapter VII.

AN ACTIVE MOULIN.

It was once supposed that the moulins did not move with the mass of the glacier, but Professor Tyndall has clearly proved that they move in precisely the same manner as the ice around them. This erroneous impression originated in the undoubted fact that they are constantly found in the same locality, but the explanation is easily given. The formation of moulins is due, as we have already seen, to the breaking of the ice, where it is generally continuous, under the influence of some local strain: and as the shaft moves downwards, the channel of the stream flowing into it moves also. "But as the motion continues other portions of the glacier come into the same state of strain as that which produced the first crack; a second one is formed across the stream, the old shaft is forsaken and a new one is hollowed out, in which for a season the cataract plays the thunderer. I have in some cases counted the forsaken shafts of six old moulins in advance of an active one."*

The extinct moulin, of which a picture is given on page 68, was found on the Unter Grindelwald glacier in the immediate neighbourhood of the active one pourtrayed above, though the two were not created by the same stream. The moulin now doing the work of the forsaken one shown below was not a hundred yards distant from it, the glacier between the two unbroken by crevasses and very gently inclined, and the deserted channel of the stream clearly marked—thus exemplifying in every particular the theory above stated. The old shaft, which necessarily communicated more or less directly with the bed of the glacier, had had no time to be squeezed out of shape, or to have its sub-glacial adits choked up. In a few more years this will probably have happened, and the hole will be full of water; in a few more it will reach the brow of the steep descent out of the Eismeer, a crevasse will rend it asunder, and subsequently the pressure which results from another change of inclination will obliterate all trace of it.

MASSA RIVER & GORGE

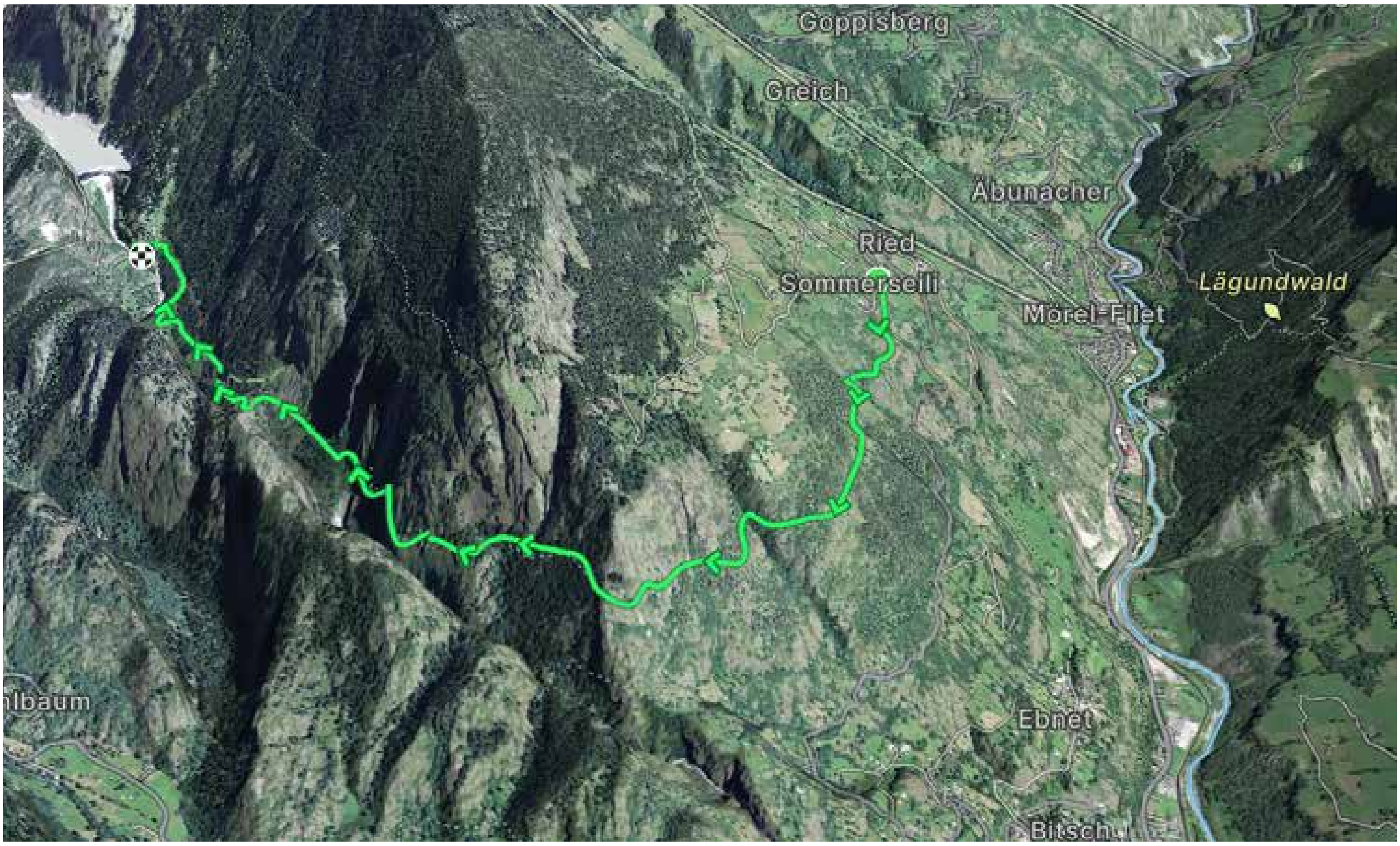
The Massa River is predominantly created from the running meltwaters of the Great Aletsch Glacier. From the tongue of the glacier, it runs down to the Morel Hydropower Plant before collecting in the Stausee Gibidum Reservoir. From there, it passes through the Massa Gorge before meeting the Rhône River.

The Massa Gorge was carved by the movements of the Great Aletsch Glacier over millennia. It is 6.5 km long and continues to be polished and shaped by the meltwater of the Aletsch Glacier.

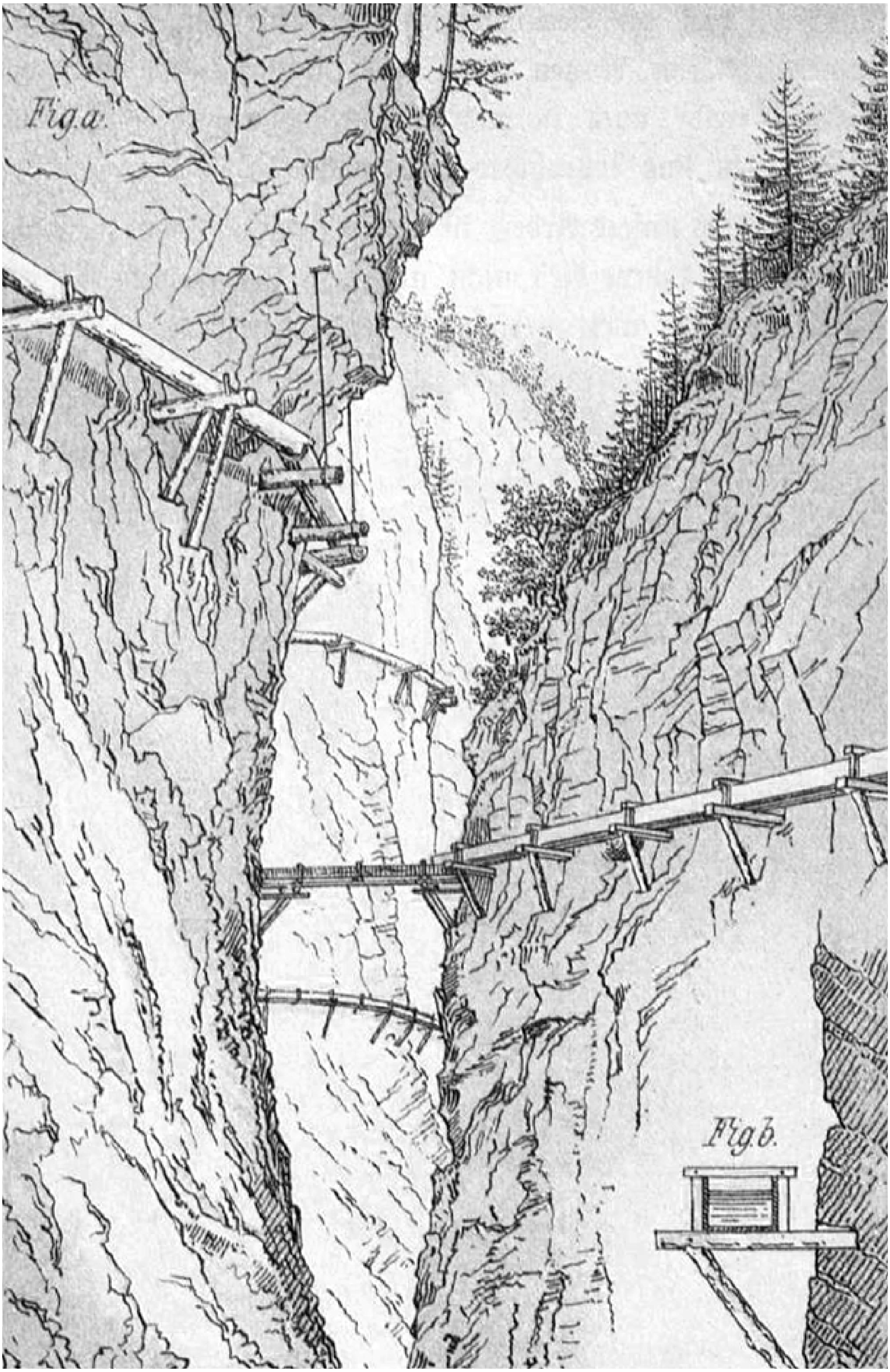
MOREL HYDROPOWER PLANT

(FORMER) BISSE DE RIEDERI (water channels)

BELALP-RIEDERALP SUSPENSION BRIDGE

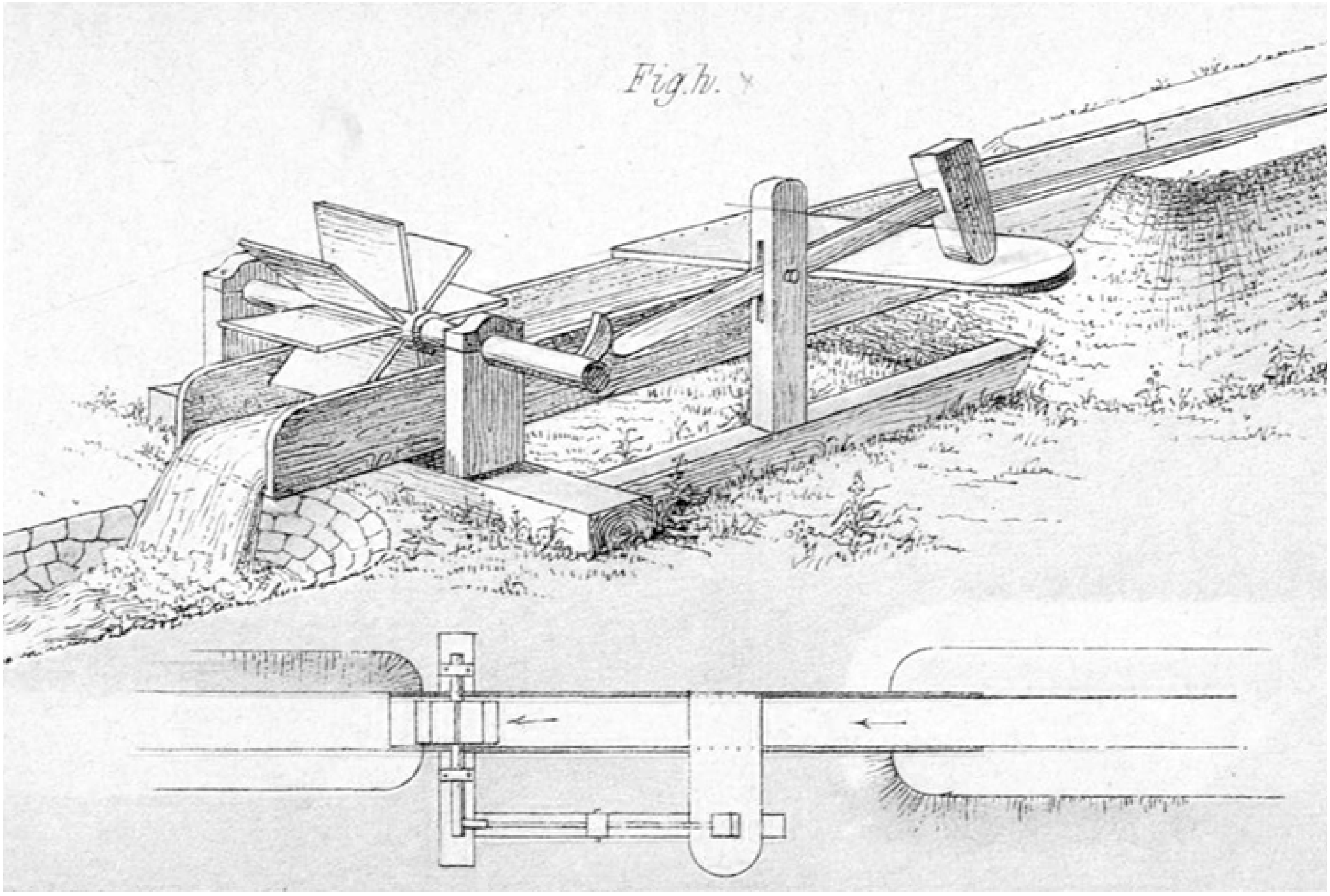


BISSE DE RIEDERI – MASSAWEG TRAIL (RIED-MÖREL TO BLATTEN)



TRADITIONAL WOODEN WATER CHANNEL DESIGNS

TRADITIONAL STONE WATER CHANNEL DESIGNS



TRADITIONAL WATER HAMMER

Traditional Water Channel Designs. Illustrations from the book: Blotnitzki, Leopold. Ueber die Bewässerungs-kanäle in den Walliser-Alpen, Bern, 1871.

Available at the ETH Library.

MASSA GORGE


Calcite, Gypsum


Quartz, Hematite


Iron Rose, Molybdenite

MOREL HYDROPOWER PLANT

The water shortage in the alpine region of Ried-Mörel, combined with the boom in industry after the Second World War, led to the building of the Morel power plant in the 1940s. Situated on the Massa River above the Stausee Gibidum Reservoir, it is a small run-of-river power station with a 2.7 km gravity tunnel that leads to a hydropower plant in Morel called Laufkraftwerk Morel Aletsch. The plant has an average energy production of around 138 GWh per year.

BISSE DE RIEDERI

The Valais region lies within a ring of high alpine mountains and thus is partially in a rain shadow, so areas of the canton can be defined as semi-arid. The traditional response was to construct irrigation systems to compensate for the periodic water deficit during the summer months. The Bisse de Riederi is an ex-irrigation channel first mentioned in documents dating from the year 1385. This has been further confirmed by a recent discovery of an old bisse structure preserved under the Aletsch Glacier, uncovered due to glacier melt. The meltwater at the Massa River was partially siphoned off and channelled via gravitational flow through dug earth channels or wooden structures installed around rock walls. This water was mainly used for cereal and hay production, as well as for washing and drinking water. The Bisse de Riederi is mostly wooden and remained active until the 1940s, since which time a hiking trail called the Massaweg has been created that follows the former bisse. From Blatten, it takes you across the Massa River, following the water trail towards the Rhône Valley, finishing at Ried-Morel. Traditionally, these channels were made with local wood and sealed with moss and sediments which form naturally with the flow of water. Sediment-rich water has recently been recognised as aiding a recent rewilding effort at other active bisse sites. For farmers in the past, sediment saturation was a problem when it came to watering crops and was removed before use by collecting the water in a pit, thus allowing the sediments to settle, before siphoning off the top layer for irrigation. At the turn of the 20th century, many bisses were replaced with galvanized metal, masonry and concrete, and in some cases PVC. There are many bisses in the Rhône Valley that are still active today, all of which you can find at www.les-bisses-du-valais.ch. Two that are close to our site are Bisses de Stigwasser, Wyssa & Oberschta and Bisses de Niwarch & Gorperi.

BELALP-RIEDERALP SUSPENSION BRIDGE

Belalp-riederalp suspension bridge is 124 meters long and is positioned 80 meters above the river.

TRADITIONAL WATER CHANNEL DESIGNS

The channels were prone to frequent damage from slope movements and rockfalls. In some cases, to confirm the flow of moving water a ‘Water Hammer’ system was designed where small water wheels were installed that drove hammers to hit the wood, creating a sound that would convey its working ability to the guard in charge. The sound of water flow was part of the working life of the bisse guards and farmers. Most irrigation was done at night, meaning the farmers had to be very sensitive to the sound of water flow as vision was limited, in order to not risk flooding.

RARE CRYSTAL AND MINERAL SITE

In 1965, during the construction of the hydroelectric power plant, a large cleft with huge rock crystals was discovered. The largest pieces were destroyed due to the use of explosives. Those that were saved reached lengths of up to one metre. The crystals included byssolite, halite, calcite and various fluids. In the 1990s, a second cleft opened revealing huge quartz, calcite and chlorite crystals. In the upper part of the gorge, veins with copper, lead and zinc ores are often found. A weak uranium mineralisation with finely dispersed pitchblende, argentopyrite, herzenbergite and uranium secondaries has also been reported.

GIBIDUM DAM & RESERVOIR, HYDROELECTRIC POWER PLANT

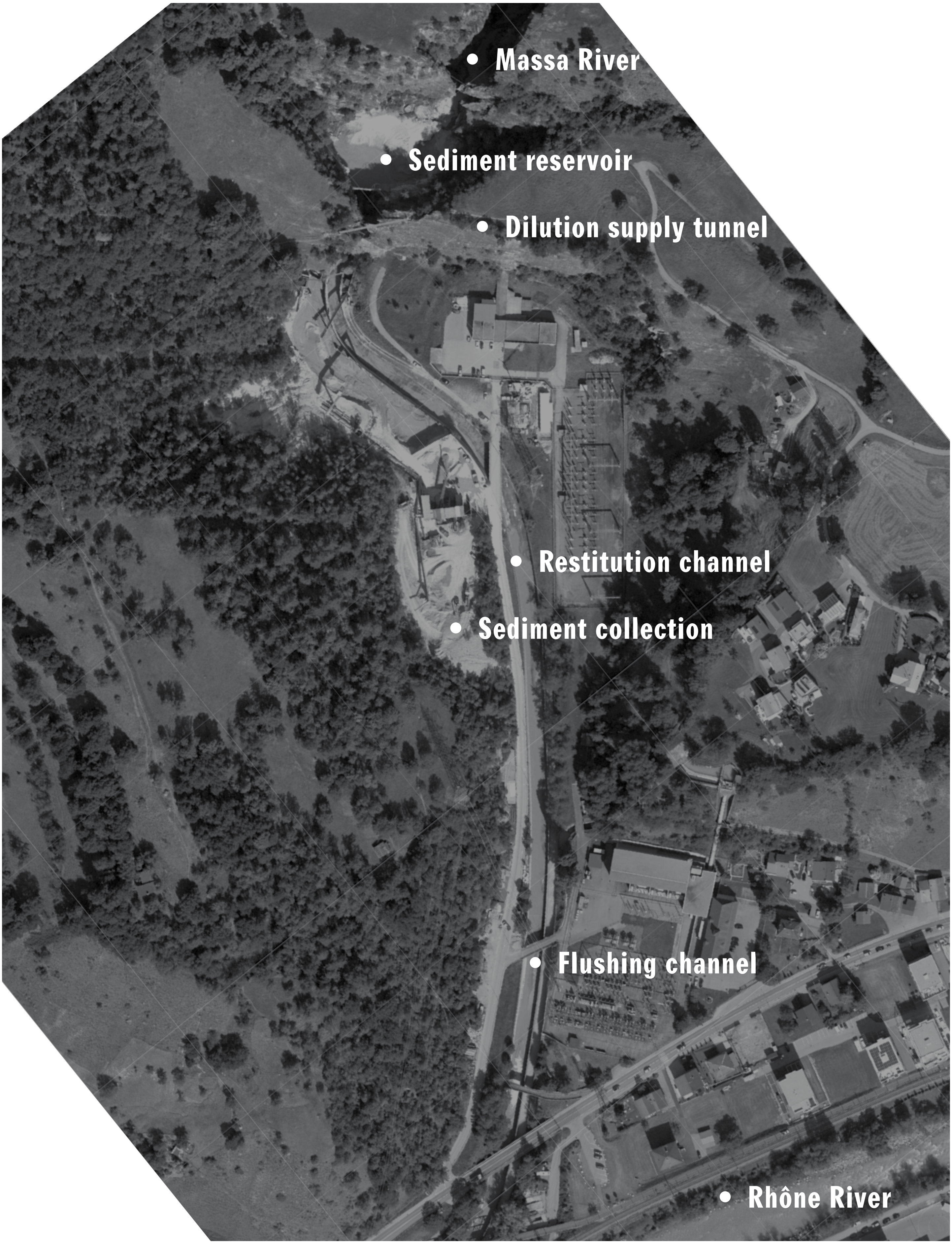
Stausee Gibidum is a water reservoir first filled in 1969, after the construction of the Gibidum Dam was completed. The dam reaches a height of 122 metres and has a crest length of 327 metres. At maximum capacity, the reservoir can store 8.8 million cubic metres of water.

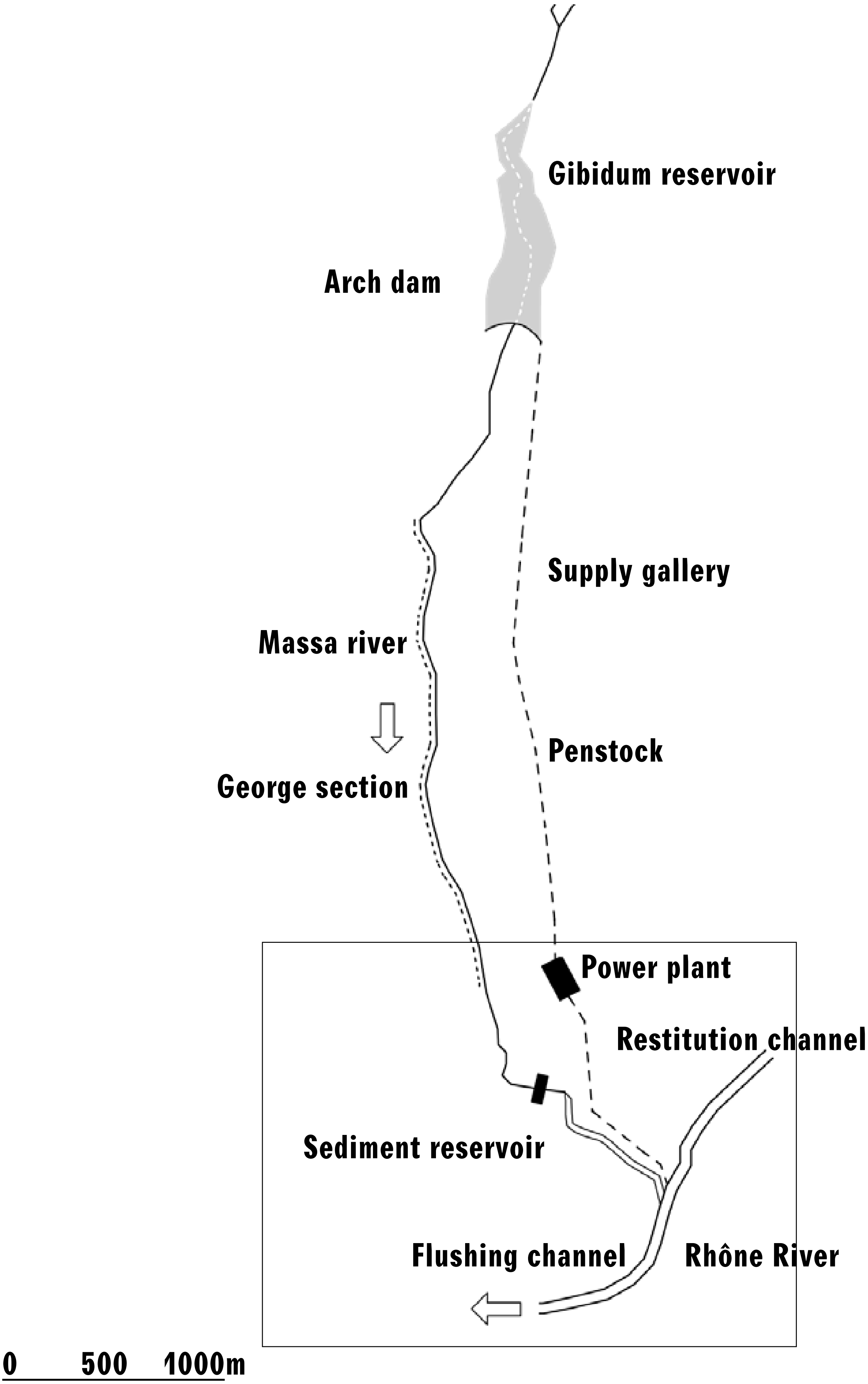
(Left) Surface waves due to an anti-dunes regime during sedimentation in the flushing channel. (Right) High sediment load leading to the channel overtopping in 1999. (Below) Stausee Gibidum after the flushing process.

ELECTRA-MASSA HYDROELECTRIC STORAGE POWER PLANT

Anti-corrosion protection coating on the inside and outside of the penstock



MAP OVER CHANNEL, TUNNEL AND POWERPLANT CONNECTIONS


Gibidum reservoir
Arch dam
Supply gallery
Massa river
Penstock
George section
Power plant
Restitution channel
Sediment reservoir
Flushing channel
Rhône River
0 500 1000m

ANNUAL FLUSHING OF STAUSEE GIBIDUM

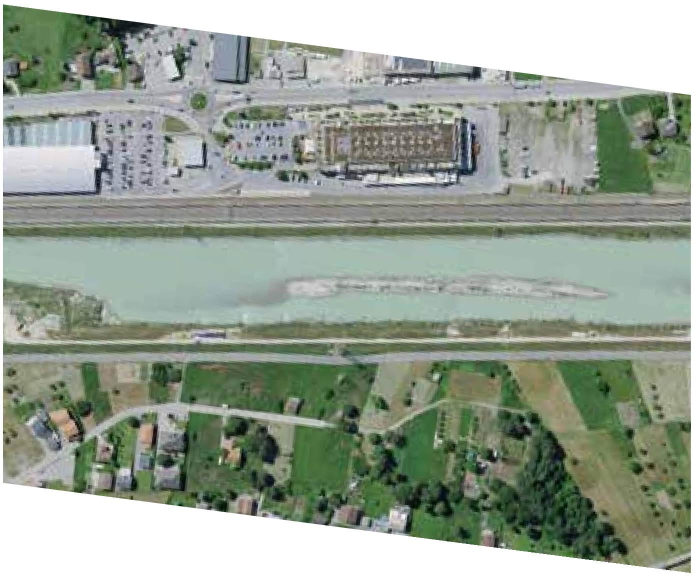
Unlike many other Swiss reservoirs, the quantity of glacier meltwater at Stausee Gibidum is very high, as around 65 % of its catchment area is glaciated, meaning the water is very rich in sediments. The dam acts as a huge sand and silt trap; the finer sediments settle down near the base of the dam while coarse material accumulates in the delta, which develops during the summer. This problem requires a unique solution; that the entire reservoir be flushed annually, during which energy production is paused for 4–7 days. As a consequence of the flushing process, the 700 m long channel at the base of the Massa River has often suffered a silting process, leading to high surface waves due to an anti-dunes regime during sedimentation (see anti-dunes diagram on pg 88). In 1999, this resulted in the water overtopping the channel walls and flooding the local area. In order to improve the understanding of sediment input and output in the flushing channel, physical and numerical modelling was performed in 1994 and again in 2002 at the Laboratory of Hydraulic Constructions of the École Polytechnique Fédérale de Lausanne (EPFL). One outcome of this research was to introduce additional clear water via a dilution supply tunnel built at the upper limit of the channel, with the aim to reduce the sediment concentration at the outflow (see diagram on pg 76).

ELECTRA-MASSA HYDROELECTRIC STORAGE POWER PLANT

The Electra-Massa hydroelectric storage power plant is located in the town of Bitsch, positioned where the Massa River meets the Rhône River. When water inflow is high, the turbines process 55 thousand litres of water per second, and in such cases, bear a sediment load of up to 40 tonnes per hour. The station includes three Pelton turbines that produce an average annual energy production of 564 GWh. Due to high levels of sedimentation, there is a heightened problem of erosion. In October 2020, the reservoir was drained in order to complete renovation works, renewing the anti-corrosion protection coating on the interior and exterior of the penstock – the pipe connecting the reservoir to the power plant.

RHÔNE RIVER

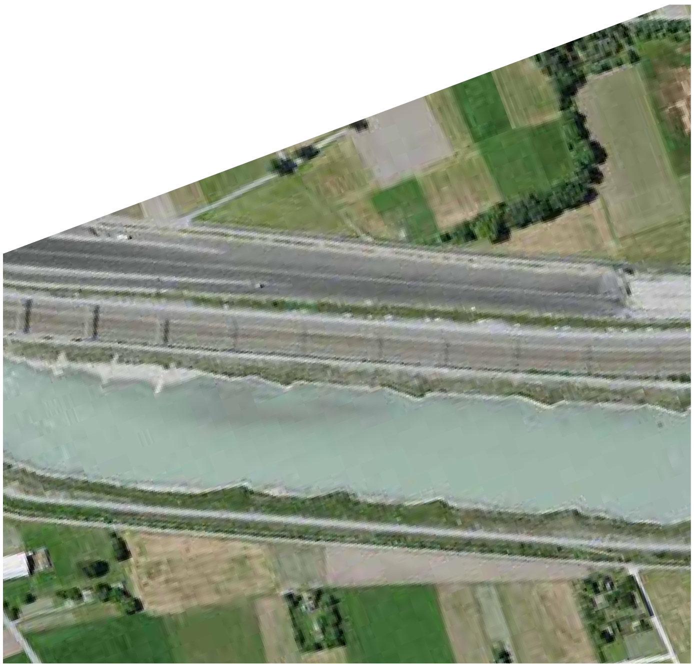
The Rhône River is one of the most significant waterways of Europe and is the only major river flowing directly to the Mediterranean Sea that is predominantly Alpine in character. It carries a high amount of sediment, giving it a milky colour. The section of the Rhône River that we are studying, from Bitsch to Leuk, has mostly been channelled, diked, narrowed and the surrounding plains have been drained.



RHÔNE RIVER SECTIONS

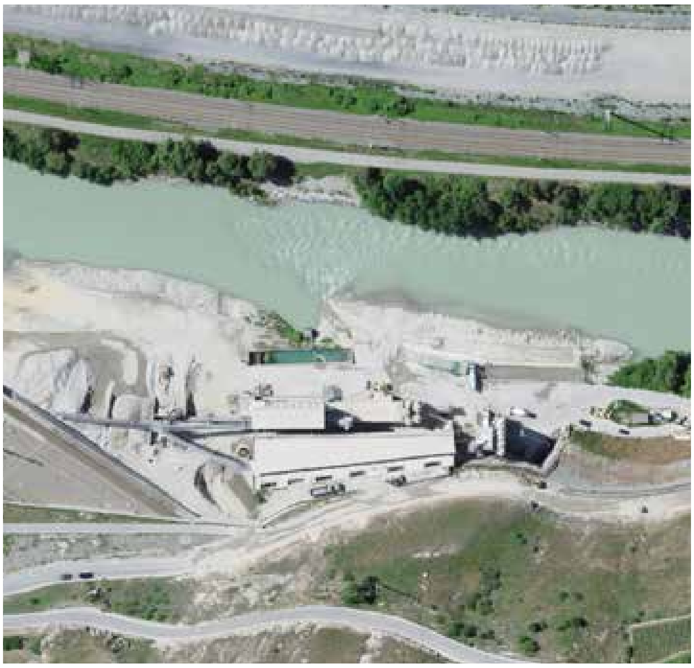
Brig (left): The water from the Massa River joins the Rhône where the river is channeled.

Brigerbad (right): Note the use of spur dikes along the river edge building an island of sediment deposit.



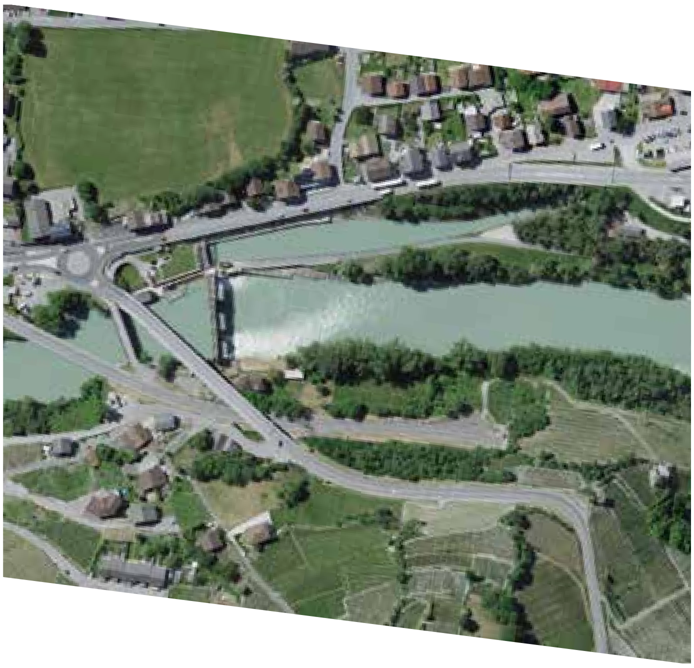
Baltschieder (left): Note the fish farm situated in the circular pool on the bottom right; the use of spur dikes along the river edge; the water from the Vispa river merging with the Rhône; the Vispa containing far fewer sediments.

Baltschieder (right): Note the channeled banks with small spur dikes.



Raron (left): Note the collection of sediment deposits.

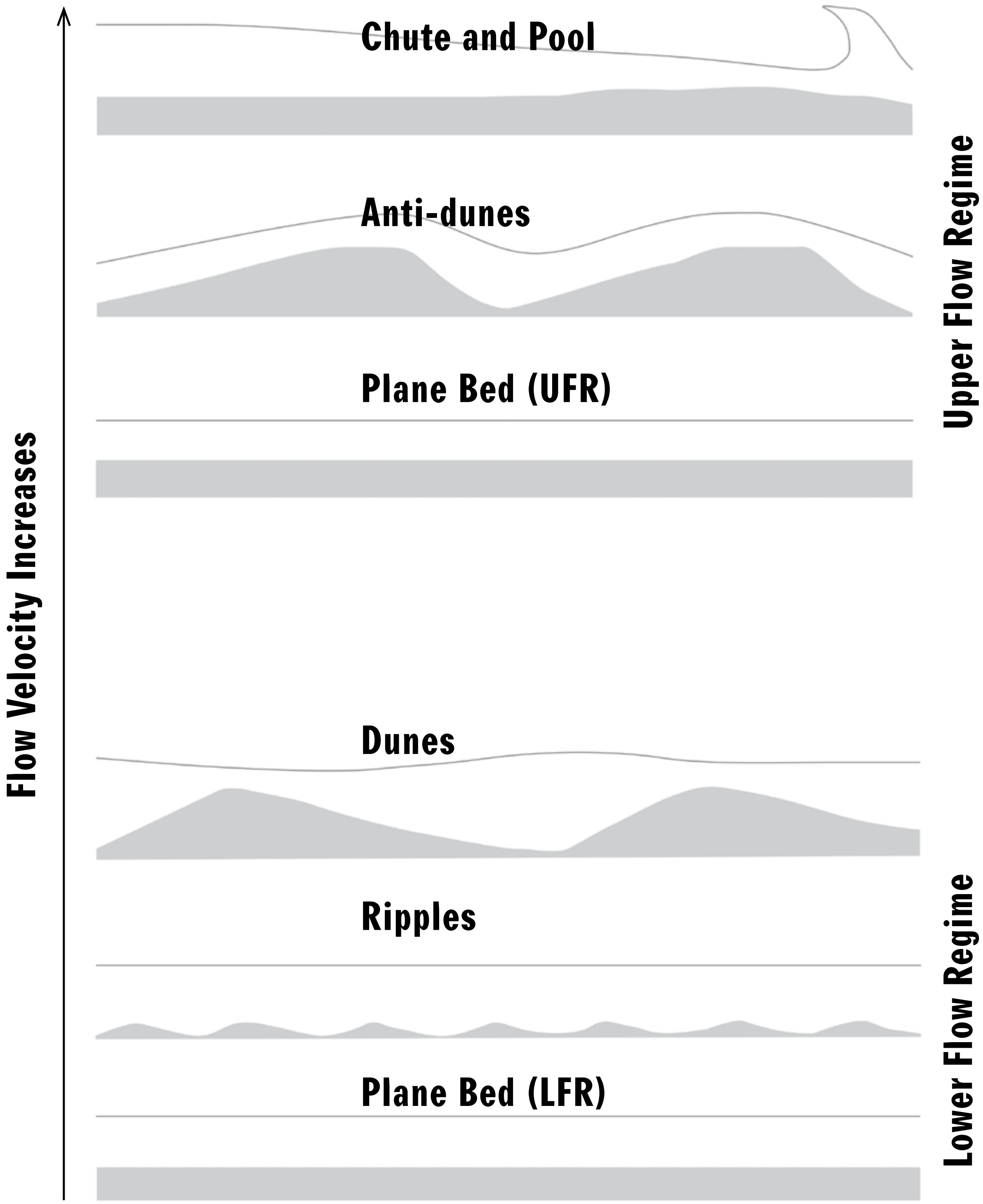
Raron (right): Note the water collection pools.



Leuk (left): Note the hydropower operation at the bridge.

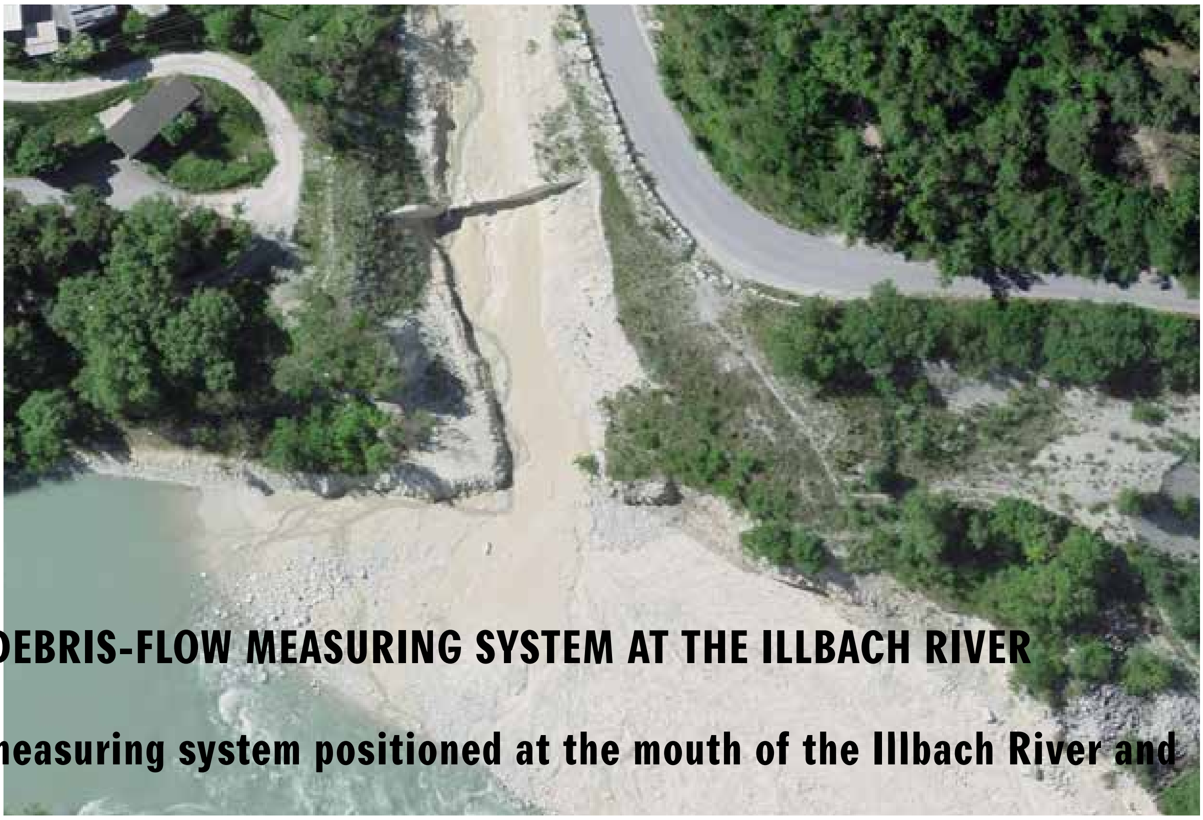
Leuk (right): Note the gravel, sand, and concrete works situated to the side of the river. At this point the river is unchanneled, leading to the natural widening of the riverbed.

Satellite maps can be found at map.geo.admin.ch.



SEDIMENT TRANSPORT IN RIVER FLOW

The diagram shows the most common bedform transitions and surface water configurations for lower and upper flow regime sedimentation.



THE DEBRIS-FLOW MEASURING SYSTEM AT THE ILLBACH RIVER

The measuring system positioned at the mouth of the Illbach River and

the large amount of sediment transported into the Rhône River.

MUD FLOW AT THE ILLBACH RIVER

YouTube 1:11 mins, 2016

SEDIMENT TRANSPORT IN RIVER FLOW

Sediment can either be suspended: floating in the water column; or bedded: settled on the bottom of a body of water. Bedload is the sediment transported by a river in the form of particles too heavy to be in suspension, such as sand, gravel, or coarser particles that roll or bounce along the riverbed. If the water flow is strong enough to pick up sediment particles, such as sand, they will become part of the suspended load. The wash load is a subset of the suspended load, comprised of the finest suspended sediment (typically clay and silt, less than 0.00195 mm in diameter). These particles remain in permanent suspension as they are small enough to stay afloat. The diagram on the right shows the most common bedform transitions and surface water configurations for lower and upper flow regime sedimentation. Lower flow regimes are dominated by bedforms that differ from the surface of the water, and upper flow regimes are dominated by bedforms that correspond with the same line as the surface of the water. Diminished water quality occurs with unusually high sediment transport rates, as is the case at our specific site on the Rhône River, which has a high concentration of glacial silt. Turbidity can cause water temperatures to rise as sediments absorb more solar heat than water. Rising water temperatures will cause dissolved oxygen levels to drop, as warm water cannot hold as much oxygen as cold water. Suspended sediment can block sunlight from reaching submerged plants, decreasing photosynthesis rates and lowering dissolved oxygen levels further.

DEBRIS-FLOW MEASURING SYSTEM

The Illgraben catchment is one of the most active debris-flow sites in the Alps, which poses a great risk to the more populated areas downstream at Leuk. This problem has led to the installation of an alarm system that can provide an early warning of critical debris flow. The measuring system installed in 2019, developed by the Swiss Federal Research Institute WSL and the WSL Institute for Snow and Avalanche Research SLF, replaced an earlier system that was destroyed in 2016 by large boulders. The new measuring system is currently the largest in the world and consists of a force plate supported on a steel frame, and six load cells. It is installed in a concrete check dam so that when debris flow comes down the channel, it is directed to flow over the plate in a uniform manner before entering the Rhône River. The system is currently able to provide an alert signal 5–15 minutes prior to the arrival of debris flow or flash floods.

GLOSSARY OF RIVER TERMINOLOGY

Aggradation (Aggrade): A progressive buildup or raising of the channel bed and floodplain due to sediment deposition. The geologic process by which streambeds are raised in elevation and flood plains are formed. Aggradation indicates that stream discharge and / or bed-load characteristics are changing. Opposite of degradation.

Alluvial Fans: An alluvial fan is an accumulation of sediments shaped like a section of a shallow cone, with its apex at a point source of sediments, such as a narrow canyon emerging from an escarpment.

Avulsion: A change in channel course that occurs when a stream suddenly breaks through its banks.

Backwater: (1) A small, generally shallow body of water attached to the main channel, with little or no current of its own, or (2) A condition in subcritical flow where the water surface elevation is raised by downstream flow impediments.

Backwater Pool: A pool that formed as a result of an obstruction like a large tree, weir, dam, or boulder.

Bedrock: The solid rock beneath the soil and superficial rock. A general term for solid rock that lies beneath soil, loose sediments, or other unconsolidated material.

Bed Slope: The inclination of the channel bottom, measured as the elevation drop per unit length of channel.

Caving: The collapse of a stream bank by undercutting due to wearing away of the toe or an erodible soil layer above the toe.

Channel: An area that contains continuously or periodically flowing water that is confined by banks and a streambed.

Channelisation: The process of changing (usually straightening) the natural path of a waterway.

Critical Shear Stress: The minimum amount of shear stress exerted by stream currents required to initiate soil particle motion. Because gravity also contributes to streambank particle movement but not on streambeds, critical shear stress along streambanks is less than for streambeds.

Cut Bank: The outside bank of a bend, often eroding opposite a point bar.

Drainage Area: The total surface area upstream of a point on a stream that drains toward that point. Not to be confused with watershed. The drainage area may include one or more watersheds.

Drainage Basin: The total area of land from which water drains into a specific river.

Dredging: Removing material (usually sediments) from wetlands or waterways, usually to make them deeper and wider.

Debris Flow: A rapidly moving mass of rock fragments, soil, and mud, with more than half of the particles being larger than sand size.

Debris Torrent: Rapid movement of a large quantity of materials (wood and sediment) down a stream channel during storms or floods. This generally occurs in smaller streams and results in scouring of the streambed.

Deltas: A river delta is a landform created by deposition of sediment that is carried by a river as the flow leaves its mouth and enters slower-moving or stagnant water.

Embankment: An artificial deposit of material that is raised above the natural surface of the land and used to contain, divert, or store water, support roads and railways, or for other similar purposes.

Floodplain: Land built of sediment that is regularly covered with water as a result of the flooding of an adjacent river.

Fluvial Deposits: Sediments deposited by the flowing water of a river.

Incised River: A river that erodes its channel by a process of degradation to a lower base level than existed previously or is consistent with the current hydrology.

Levee: An embankment constructed to prevent a river from overflowing (flooding). A levee bank can also occur naturally. River may be immediately flanked by a buildup of sediment that forms natural levees. These provide some defense against flooding, but are occaisionally breached in areas producing floodplain splays—coarse fan-shaped deposit of sediment created during high flow events.

Mean Annual Discharge: Daily mean discharge averaged over a period of years. Mean annual discharge generally fills a channel to about one-third of its bank-full depth.

Meander: The winding of a stream channel, usually in an erodible alluvial valley. A series of sine-generated curves characterized by curved flow and alternating banks and shoals.

Runoff: Water that flows over the ground and reaches a stream as a result of rainfall or snowmelt.

Sediments: Sediment refers to soil-based, mineral matter (e.g. clay, silt and sand), decomposing organic substances and inorganic biogenic material, and during a high flow event rocks are also considered as sediment. Most mineral sediment comes from erosion and weathering, while organic sediment is typically detritus and decomposing material such as algae.

Sedimentation Tanks: Wastewater tanks in which floating wastes are skimmed off and settled solids are removed for disposal.

Watershed: An area of land whose total surface drainage flows to

a single point in a stream.
Weir: A weir or low head dam is a barrier across the width of a river that alters the flow characteristics of water and usually results in a change in the height of the river level. They are also used to control the flow of water for outlets of lakes, ponds, and reservoirs.
www.friendsofthereedyriver.org

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Debris Flow
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