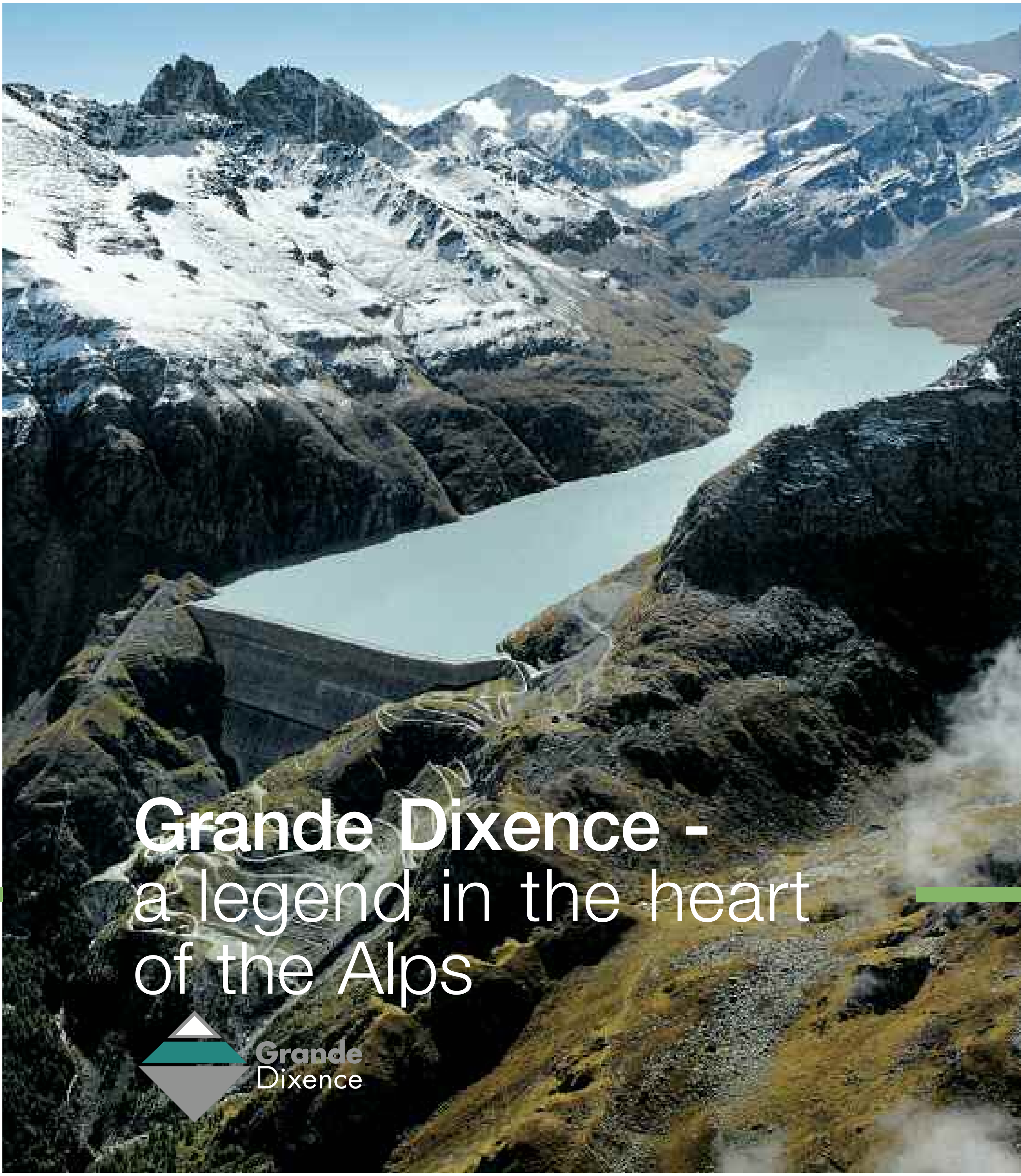
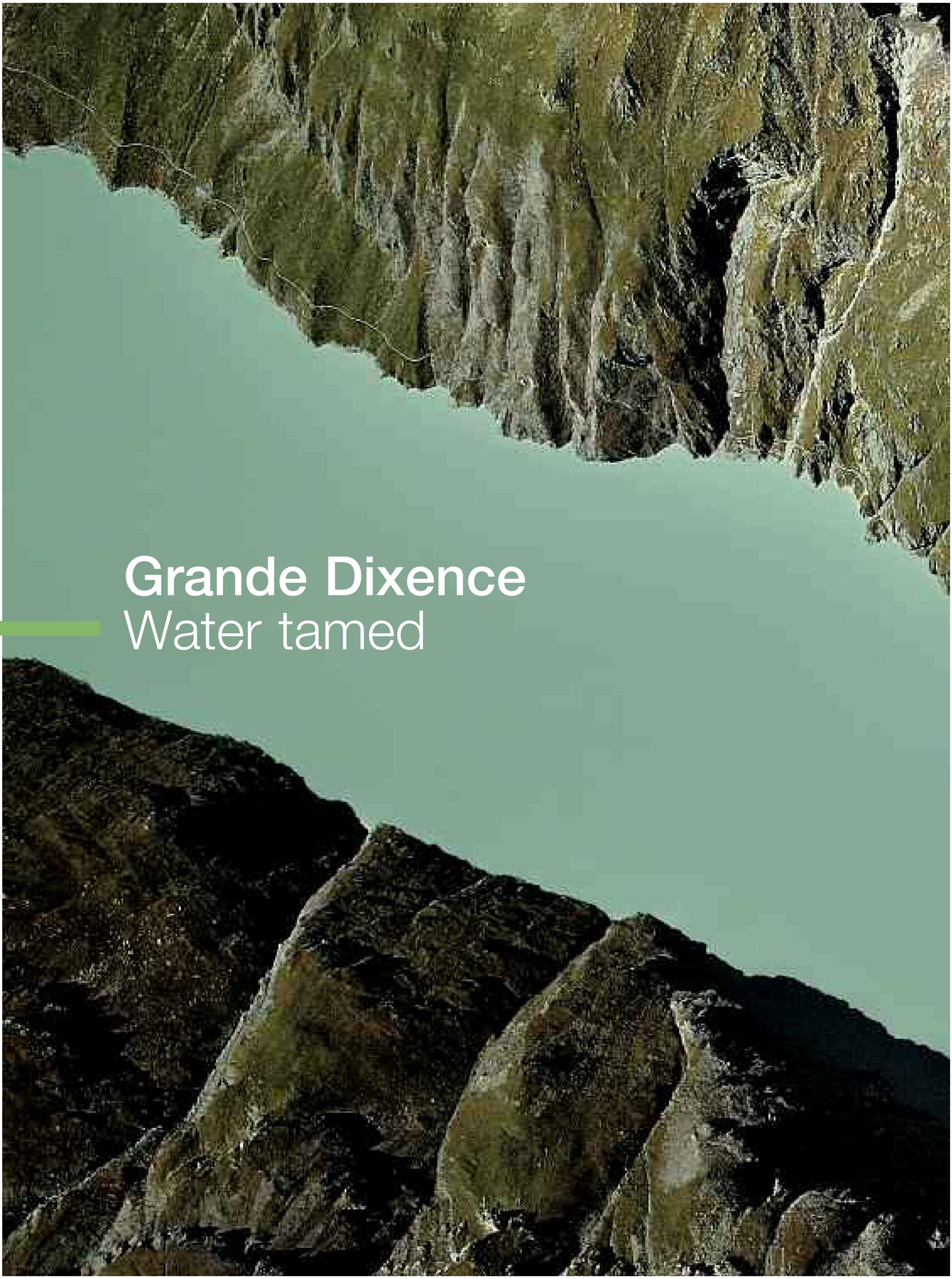


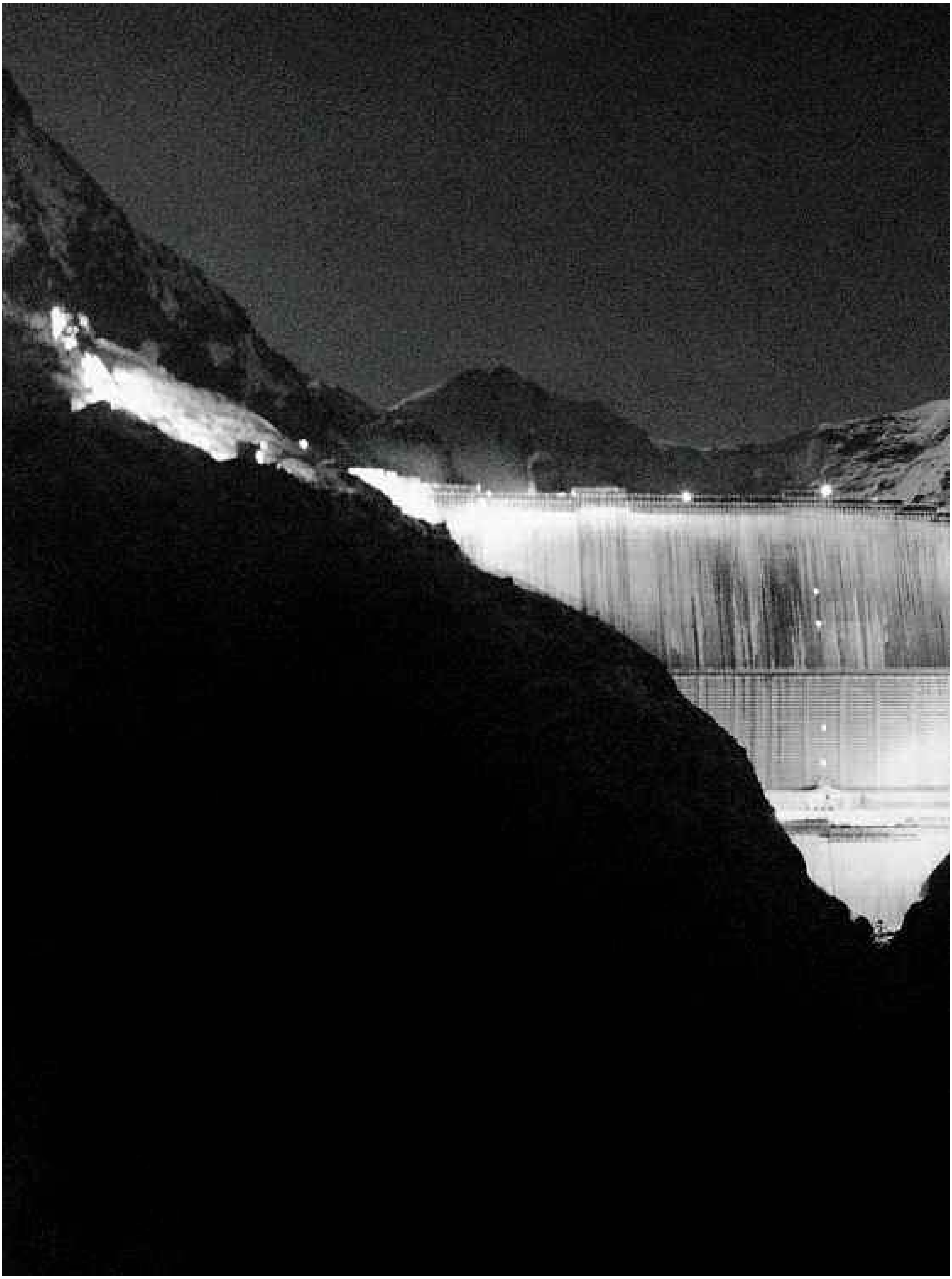
Grande Dixence -
a legend in the heart of the Alps

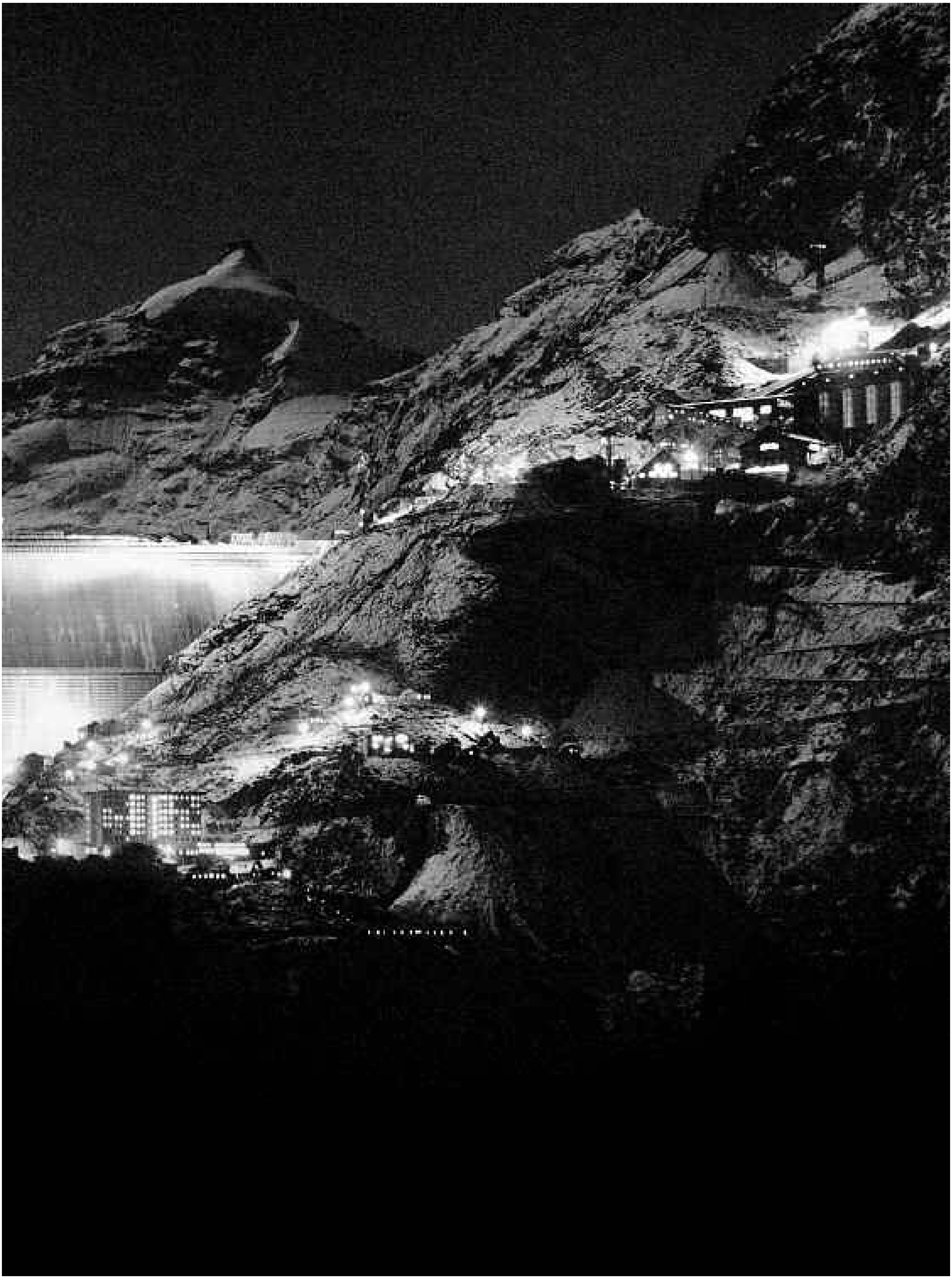
Grande Dixence

Summary



Grande Dixence
Water tamed





Construction **from then until now**

Epic construction **of the dams**

Water tells a tale

Water…The primeval element without which there can be no life.
Water…Silent, tranquil, asleep in Lake Dix.
Water…Wild and turbulent, raging through the turbines.
Water…An inexhaustible source of energy.

Valais Canton possesses the most beautiful, the most inestimable of riches: white gold! With its 900 km^2 of eternal snows, it is Switzerland's water tower. A precious reservoir of life and energy in the heart of Europe. Thanks to its altitude and Alpine foothills, more than two thirds of the rainfall is kept in solid form over the winter. When spring and summer come, snow and ice become liquid.

People have always attempted to domesticate the bubbling, vital flow. They have battled against water and its outbursts. But above all, they have fought for water and the blessings it brings. Valais Canton has witnessed these struggles throughout its history: the painstaking work of raising dykes along the river Rhône in order to bring it under control; the extraordinary network of 200 "bisses" or canals that collect essential water for pasture and rye crops from the valley head; the ingenious system for irrigating the vines.

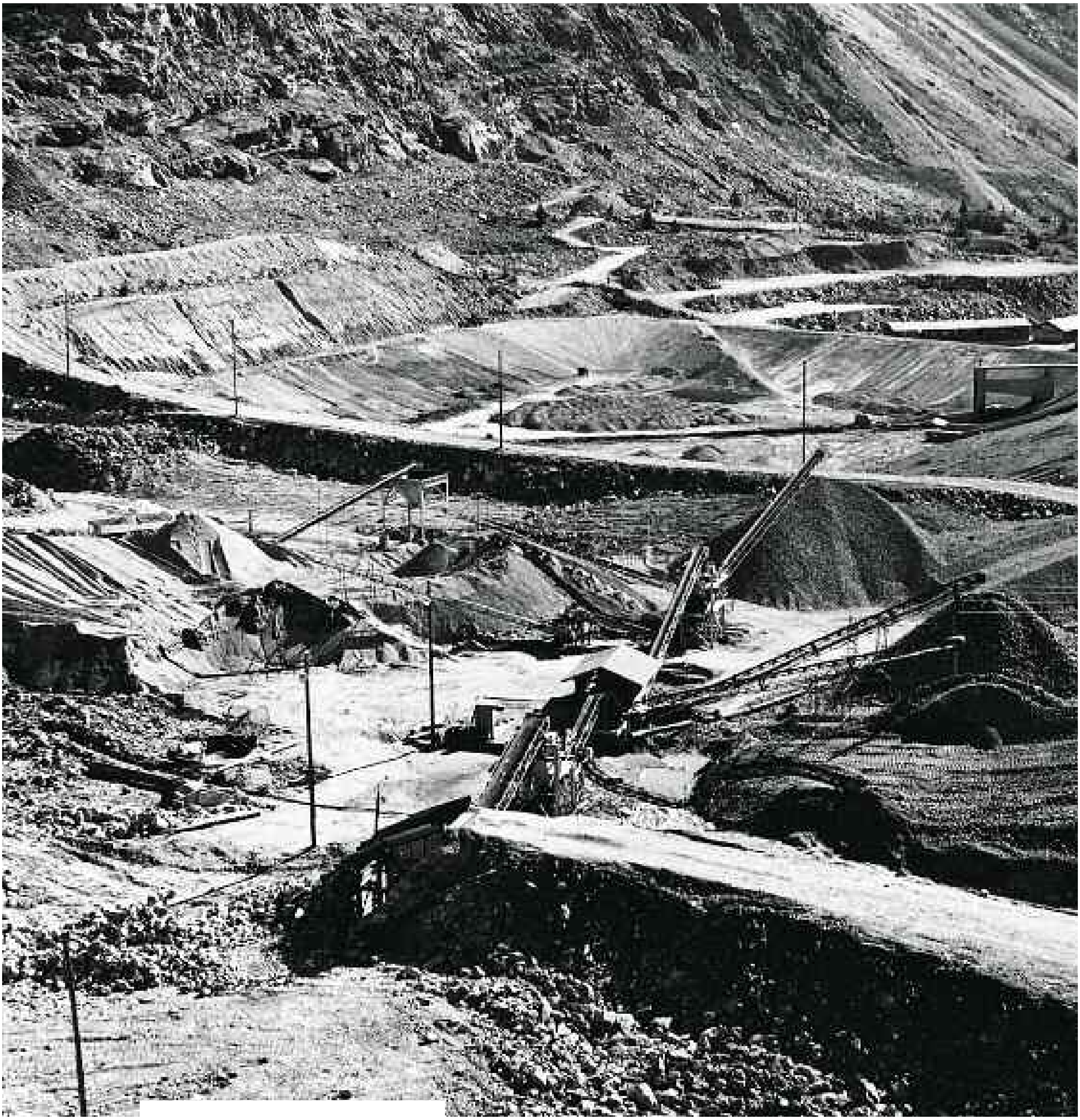
Closer to us in time, the last century saw the epic construction of the dams, the titanic struggle deep in the mountains to catch and store the most incredible form of energy: hydroelectricity. Today, thanks to the dams, Valais Canton generates 10 billion kWh of this clean, renewable and environmentally-friendly energy.

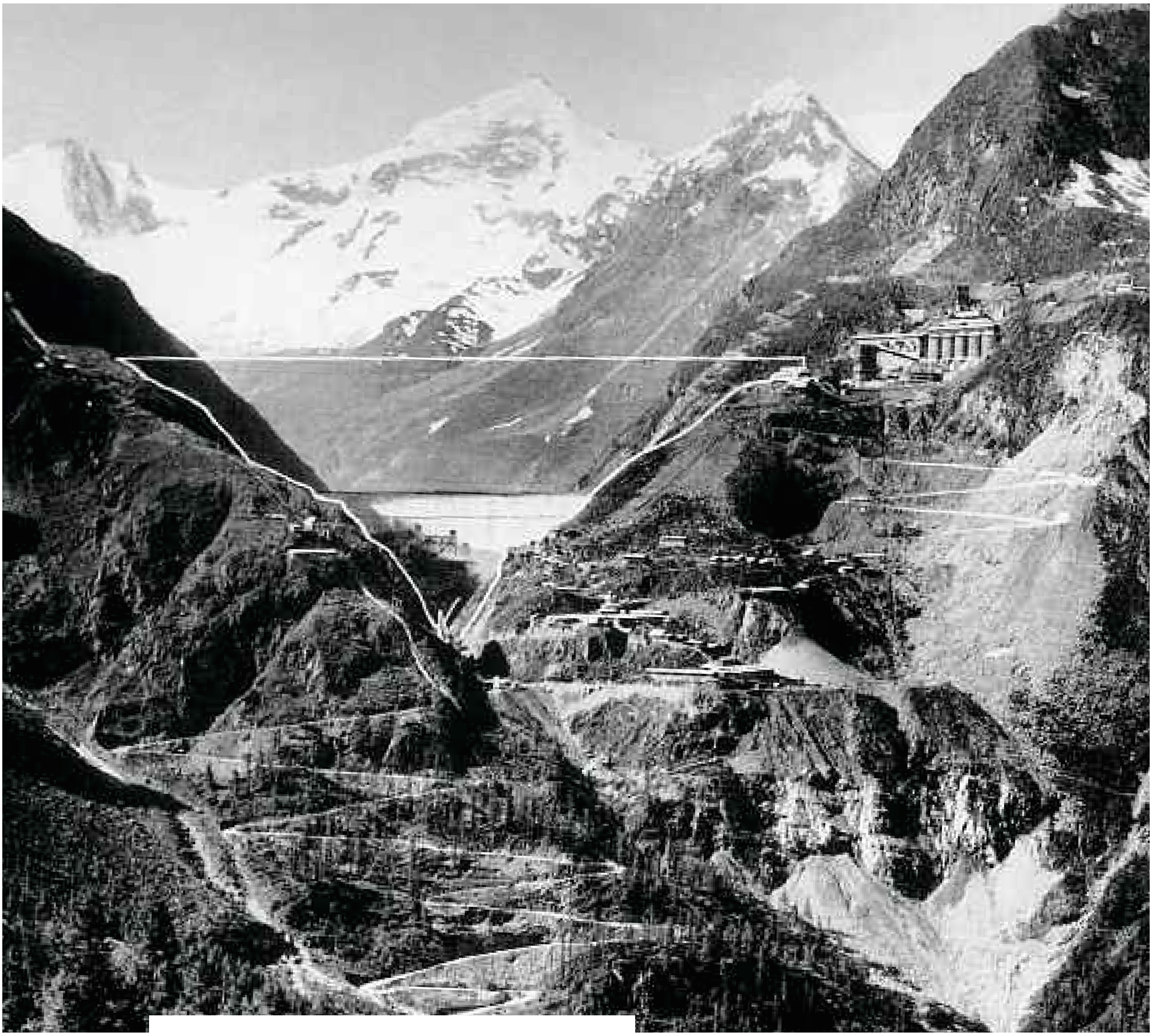
One of the outstanding episodes in the conquest of this "white coal" was without a doubt the building of the Grande Dixence complex. This scheme, worthy of the Pharaohs of ancient Egypt, is the jewel in the crown created by human ingenuity and courage to harness the potential of a unique glacial basin covering 350 km^2.

Immediately after the Second World War, Switzerland needed energy to develop its industries. In 1945, the Swiss Federal Water Department took stock of the country's hydropower potential. When the experts analysed the possibilities of the Rhône basin, they concluded that there were still some valleys that could profitably be developed.

1951: Construction works start at Grande Dixence to collect water from the Viège (Matter Valley) and the Borgne (Hérens Valley) rivers. The first Dixence dam, built barely 15 years before, is to be submerged in the new lake, engulfed by a construction site on an absolutely record scale.

1965: The Grande Dixence scheme is operational. It has taken around 15 years of unremitting work and 3000 men labouring tirelessly in shifts to realise this dream of modern times… an inverted pyramid, an inexhaustible source of energy.

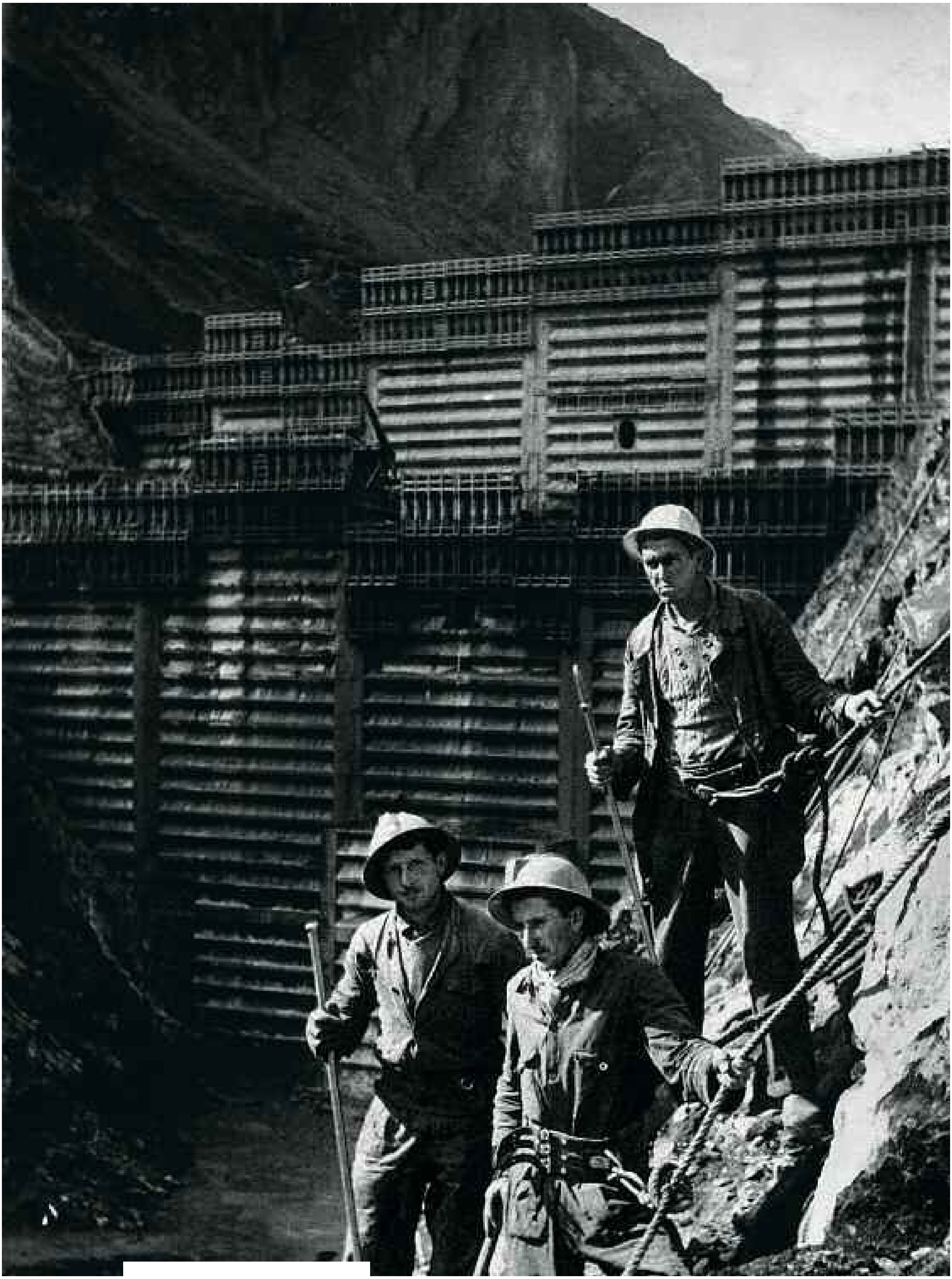




Dix Valley soon became accepted as the site with the greatest potential for development. This high mountain valley had all the geological and topographical conditions that made it ideal for conversion to a giant reservoir. No built-up area would be affected, the only agricultural land was high altitude pasture and, above all, the predicted storage capacity was enormous: 400 million m^3.

Geologists, hydrologists, surveyors and engineers tackled the solving of two major problems. First, how to enlarge the existing lake with the Dixence complex built some 15 years before. Second, how to create collecting works capable of gathering water from the neighbouring Matter, Ferpècle and Arolla valleys.

These two achievements engaged more than 3000 men in a struggle that lasted through to the beginning of the 1960s. A bold avant-garde project that today contributes to the well-being of the whole community.



3000 men to **tame the power of the glaciers**

A superlative construction project

The Grande Dixence scheme, the building project of the last century, to which every superlative applies, is a tremendous source of power. In its own way, it is also a monument to the glory of human ingenuity. This concrete temple enthroned in a mineral universe would never have been possible without the vision, intelligence, determination and courage of human beings.

Geologists, hydrologists, surveyors, engineers, guides, skilled and unskilled labourers… more than 3000 individuals fighting to tame the power of the glaciers. In cold or stormy weather, in the snow or under a blazing sun, they joined together to complete the biggest gravity dam in the world.

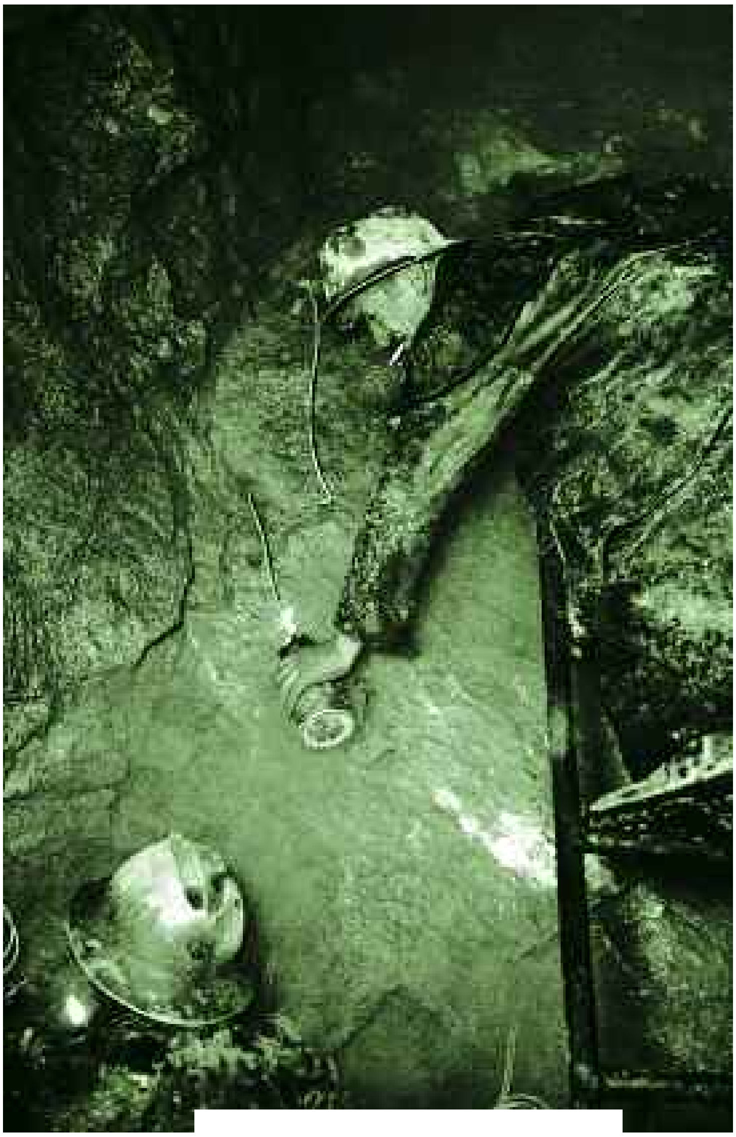
To say that working high in the mountains is difficult is an understatement. The cold and storms at an altitude of 2400 m have to be experienced fully to understand how the lungs burn, how the joints tear. The snow and the blazing sun must have been met head-on truly to feel how the skin freezes and withers, how the lips burst. How the body collapses with the pain and fatigue, the spirit cursing the water seeping everywhere…

From the beginning, those in charge of the project knew that they would have to cope with difficult living conditions. The question was how to manage such a large pool of labour on a high-altitude building site. At its peak, in October 1954, 1600 men - from Valais Canton, from the rest of Switzerland and from Italy - were working together on the Grande Dixence site.

The pace of work was intense: 11 hours of labour by day and 10 hours at night. But everything possible was done to reduce the hardships on site, and make the general environment as pleasant as possible. The accommodation was completely different from the temporary huts of construction sites at the time. During the winter of 1953-1954, an imposing building was constructed from prefabricated blocks. The workers nicknamed it the Ritz! The Ritz hotel and restaurant still welcomes visitors and ramblers today at the foot of the dam.

A social service, entertainment, a weekly film show, a library, and games rooms were provided for the workforce. But the men did not simply wait for everything to be offered to them on a plate. They got organized, established a brass band, a gymnastic society, choirs, football teams. Every winter, they organized a ski race: the Miners' Trophy.
Thanks to these excellent arrangements, the accident rate was extremely low for a site on such a scale. Unfortunately, despite every precaution, it was not possible to avoid tragedy completely. The most serious accidental injuries were caused by the collapse of the Cheilon tunnel calotte and by an avalanche on 16 February 1961 that killed three guides on guard duty.

The dam was completed on 22 September 1961… 3 years ahead of time. Some 500 million Swiss francs were paid out in wages over 11 years.



Le Chargeur gallery, vibration of concrete, 1955

Logistics
of a campaign army

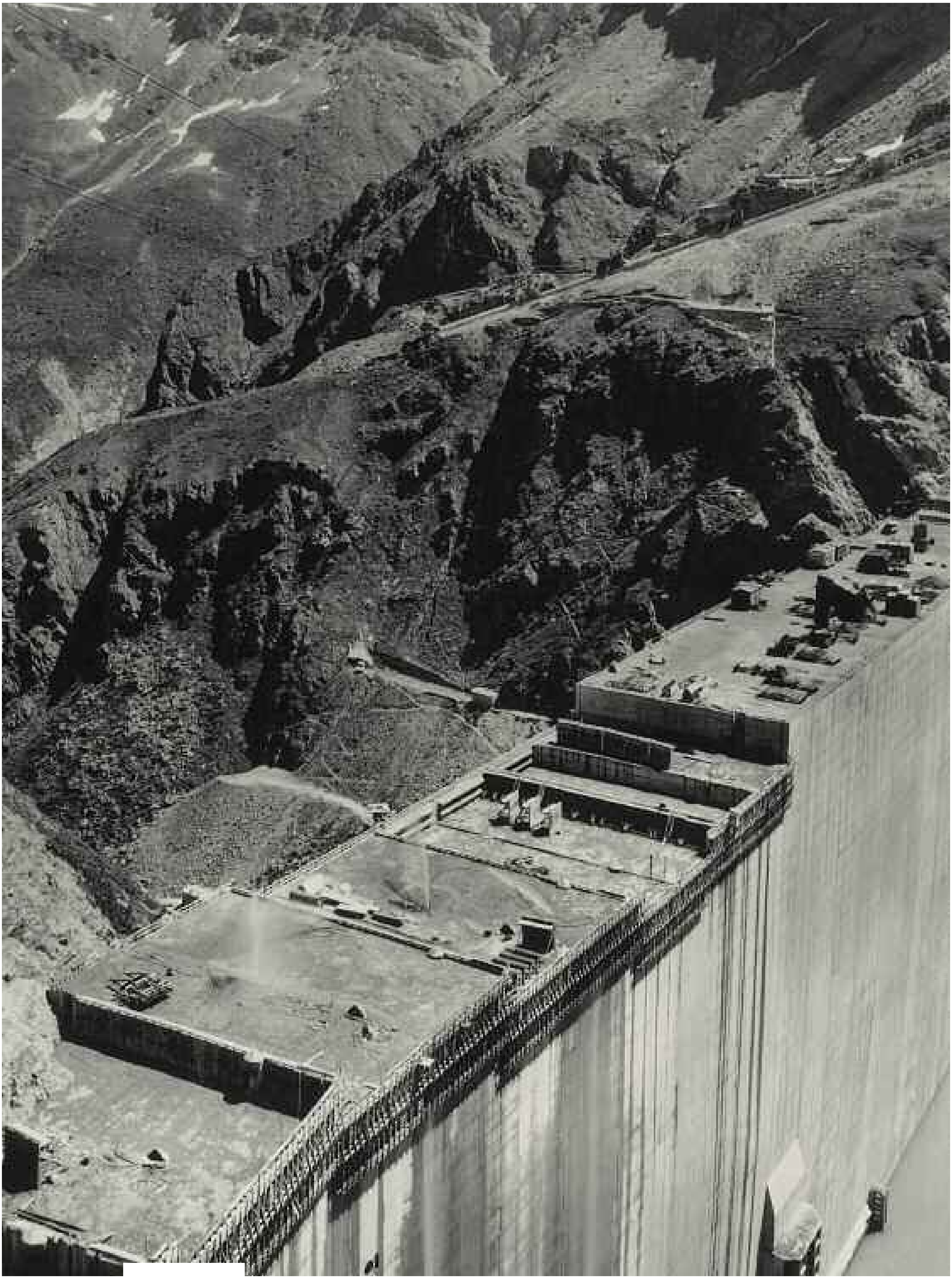
A mountain of concrete

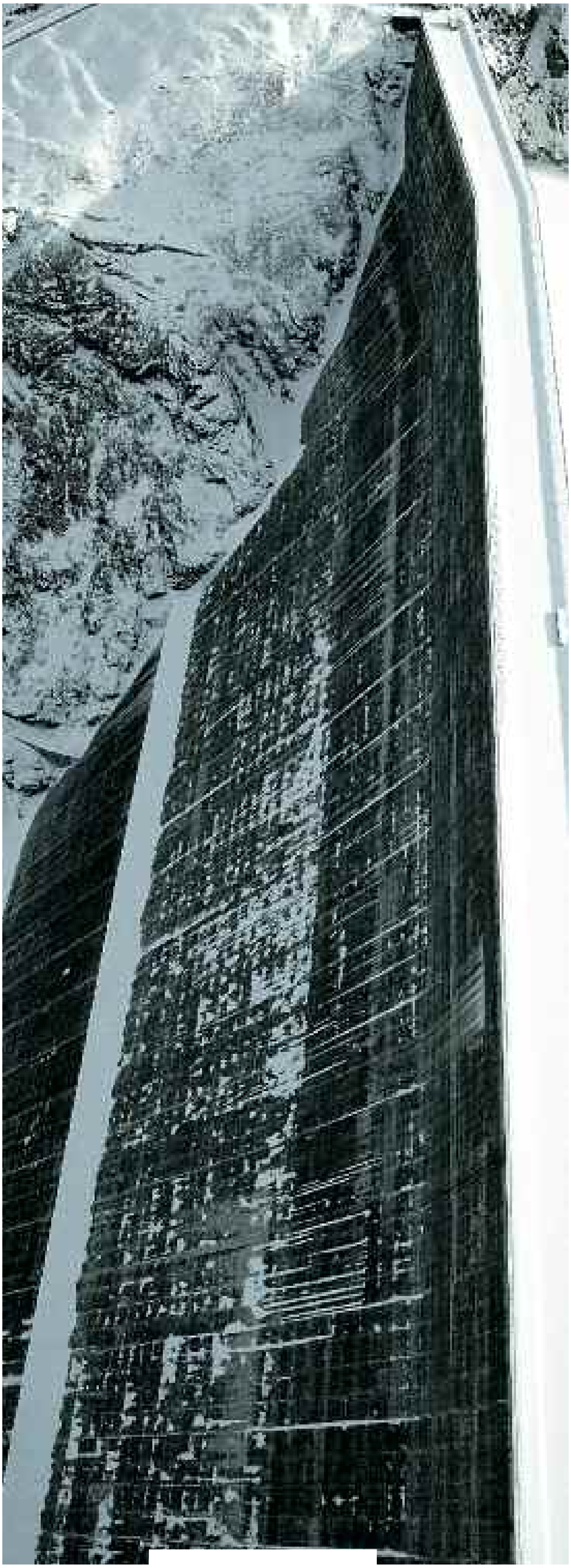
Casting a mountain of concrete in the depths of the Dix Valley took the courage and skill of thousands of men. But over and above the work effort, a network to supply the construction materials had to be thought of, designed and constructed. Without the logistics of a campaign army, there would be no regular deliveries of gravel, cement, concrete…

The success of the Grande Dixence construction project was due in large measure to that uninterrupted supply of materials, which enabled the pace of the work to be maintained night and day. The vital raw material for the dam was quarried from the Prafleuri moraine, at above 2600 m altitude. The rock was crushed into gravel on the spot. Endlessly long underground conveyor belts then carried the gravel to the Blava concrete plant.

The dam alone required 1.3 million tonnes of cement - a figure impossible to visualise. To give an idea, no fewer than 9 cement works in Switzerland were kept working flat out for years to achieve this output. Special wagons were ordered to carry everything by rail. Cableways, purpose designed, then transported the cement in 400 kg canisters. And all at a pretty pace: 200 tonnes an hour!

Ropeways spanned the void between the sides of Dix Valley and carried the buckets to whichever part of the dam was currently being built. These ropeways were very strong and able to carry up to 20 tonnes. But above all, whatever the weather conditions, at night, in fog, snow or rain, they enabled the concrete to be deposited with remarkable accuracy. Although the sloping sides of the valley are more than 700 metres apart, the tolerance margin was only... 50 cm!





Types
of dam

Gravity dam

Grande Dixence is a typical gravity dam. It is essentially a triangular body with an extremely broad base which gets narrower towards the top. Its own weight (15 million tonnes in the case of Grande Dixence) is enough to resist the water pressure.

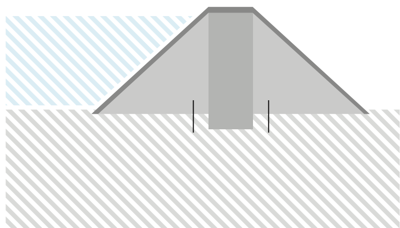
There is also a variation of this design: the gravity-arch dam. This type of storage dam gets its stability both from its own weight and from the transferral of the water pressure to the valley sides (e.g. Schlundbach dam in Lucerne Canton).

Arch dam

In contrast to the gravity dam, which is often a massively heavy construction, the concrete arch dam is particularly elegant. But the decision to build this type of dam depends on many factors: the shape of the valley, the lie of the land, the materials locally available …

The arch dam’s main characteristic is clean lines giving an impression of lightness. Rather than fighting the weight of the water head on, the arch transfers both the vertical and horizontal stresses to the valley sides. The Z’Mutt dam, at the foot of the Matterhorn is a perfect example.

Embankment dam



The principle of the embankment dam is straightforward - a certain amount of material is gathered together in order to hold back the water. Generally, at the centre of the dam there is a completely watertight core. It is reinforced both upstream and downstream by backfilling and piles of rock.

In contrast to the other types of concrete dam, the embankment dam has a cross-section that is much wider than it is high (e.g. Mattmark dam in Valais Canton).

An underground **arterial system**

The tunnelling of the mountain

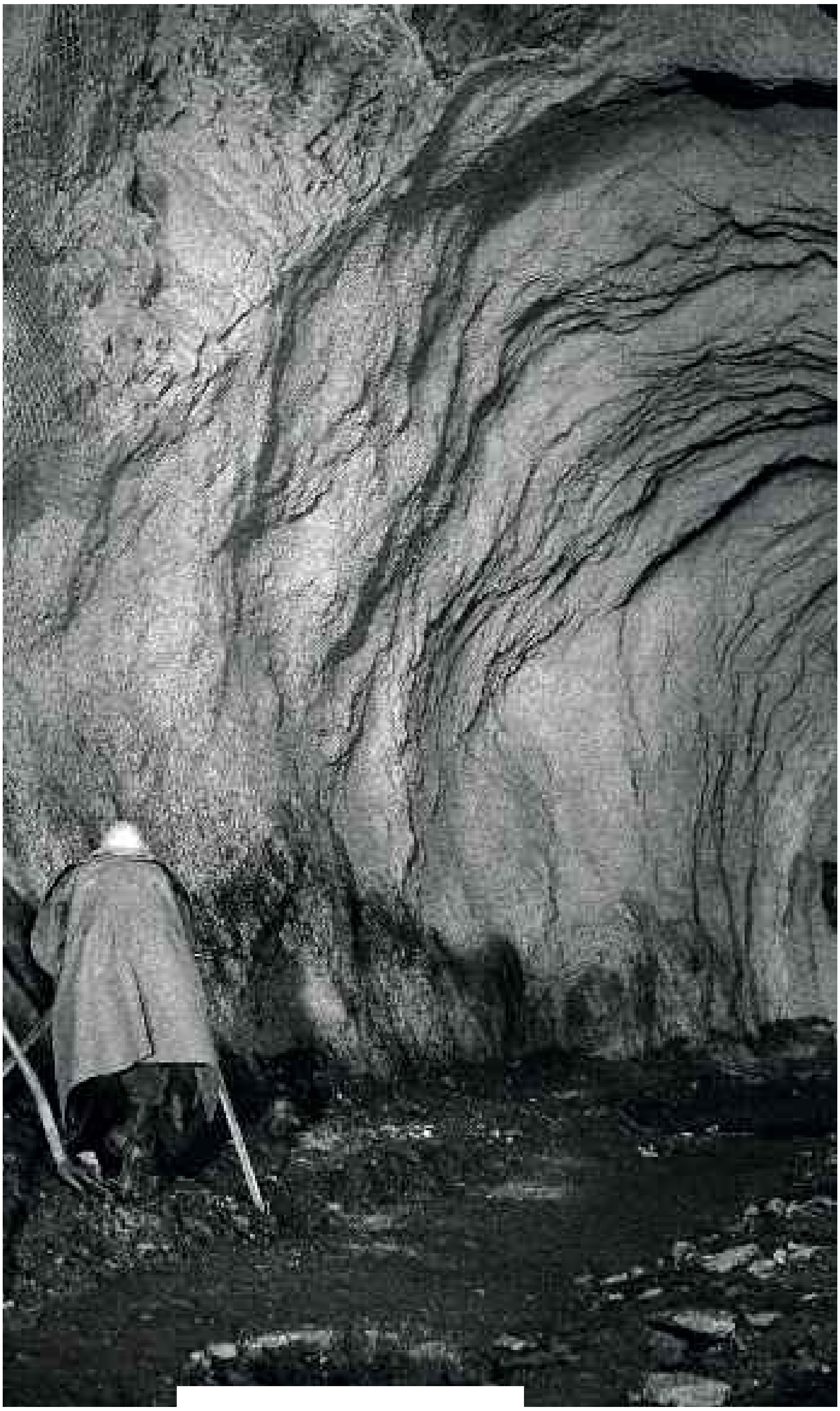
The building of the Grande Dixence dam is itself a pharaonic achievement. But impressive as the sight of that gigantic wall is, it is only the tip of the iceberg. What was unique about the project was not the challenge of building a wall capable of retaining an artificial lake, however vast. The particular feature of Grande Dixence, the spark of genius produced by its design engineers, is that it is able to collect water from 35 glaciers in Valais Canton, from the Zermatt to the Hérens valleys. And this great feat has been made invisible, hidden away, safe from the weather. Deep in the entrails of the mountain, at the very heart of these peaks and valleys.

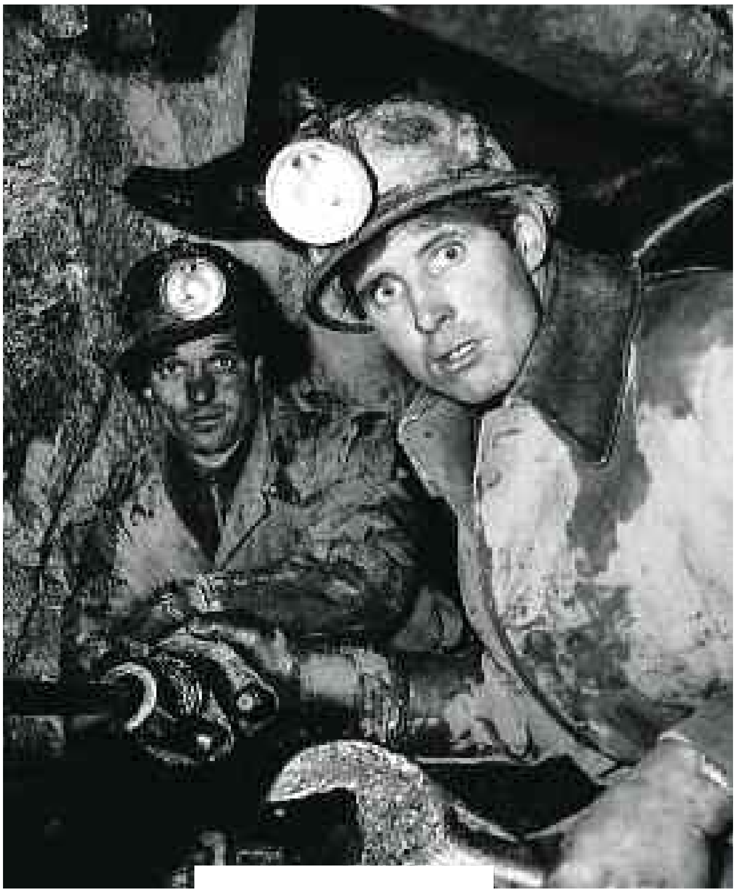
In order to bring all this water to Dix Valley, men had to survey the rock in every detail. They probed it, sounded its seismic activity and examined its geology before drilling and tunnelling into it. There were enormous constraints associated with the creation of these vital collecting works that are just like the arterial system of the human body. And one key figure was always at the forefront of everyone's mind: 2‰! An obsession with this number made the engineering teams, the physicists, the surveyors and the geographers, who worked in turn on the route to be taken by the future main water conduit, suffer most dreadfully.

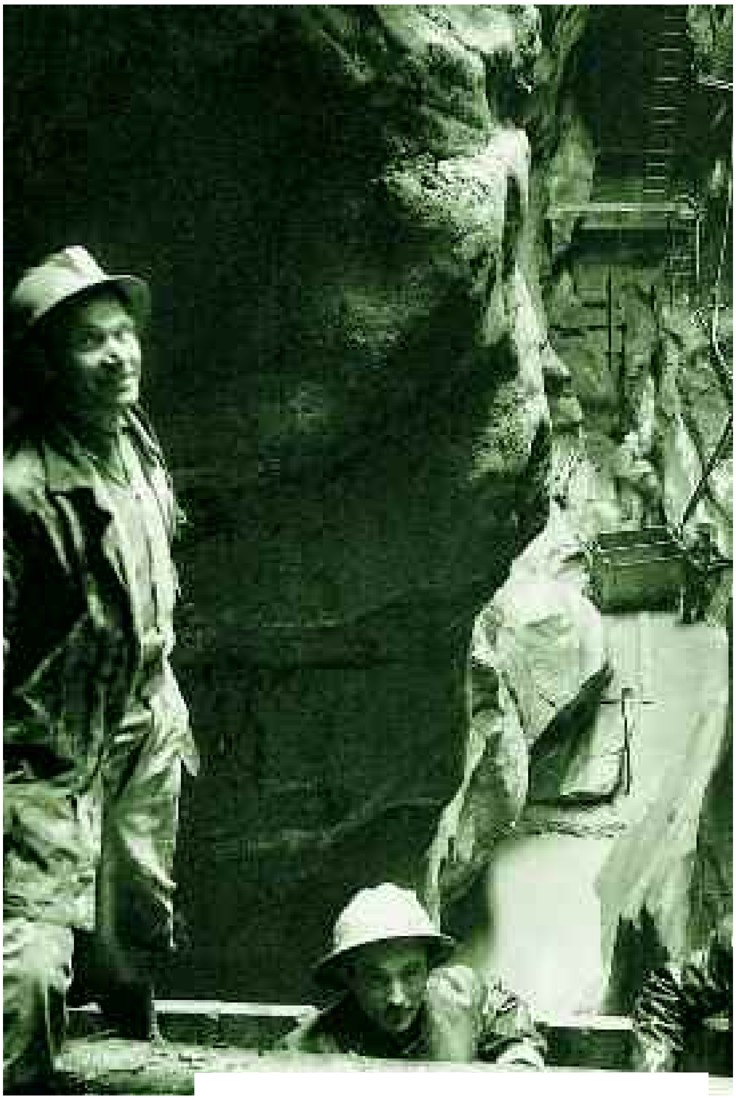
2‰ was the gradient that had to be achieved throughout. It was the constraint that simply had to be respected in plotting the route to be taken by the water collecting works.

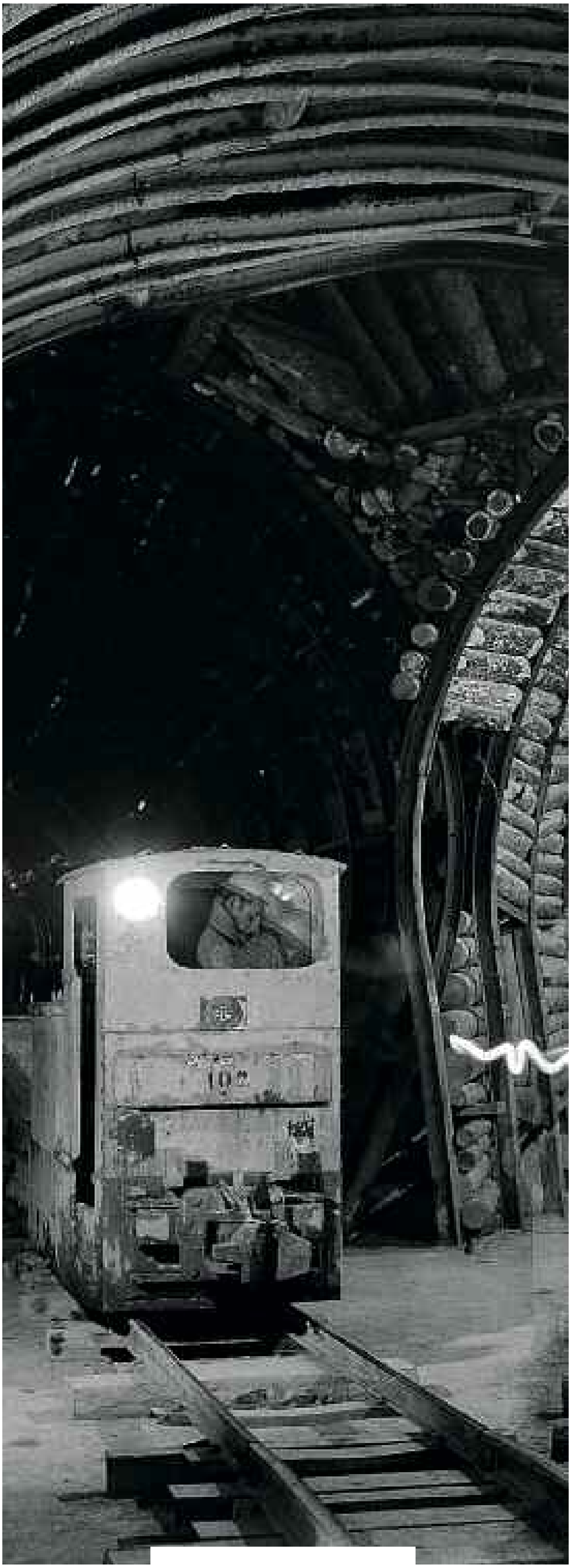
At the arrival point, the challenge had been met beyond every expectation. Around 100 kilometres of tunnelling criss-cross the mountain. 75 water intakes feed the tunnels. 4 pumping stations are needed to route some of the water. The need for pumping stations may come as a surprise. But a particular feature of the Grande Dixence complex is that certain major glaciers - Ferpècle, Arolla, Z'Mutt and Gorner for example - are at a lower level than the main water conduit which is at a spot height of 2400 metres. The water must therefore be pumped up to the required altitude in the collector that forms a real underground river, parallel to the Rhône.

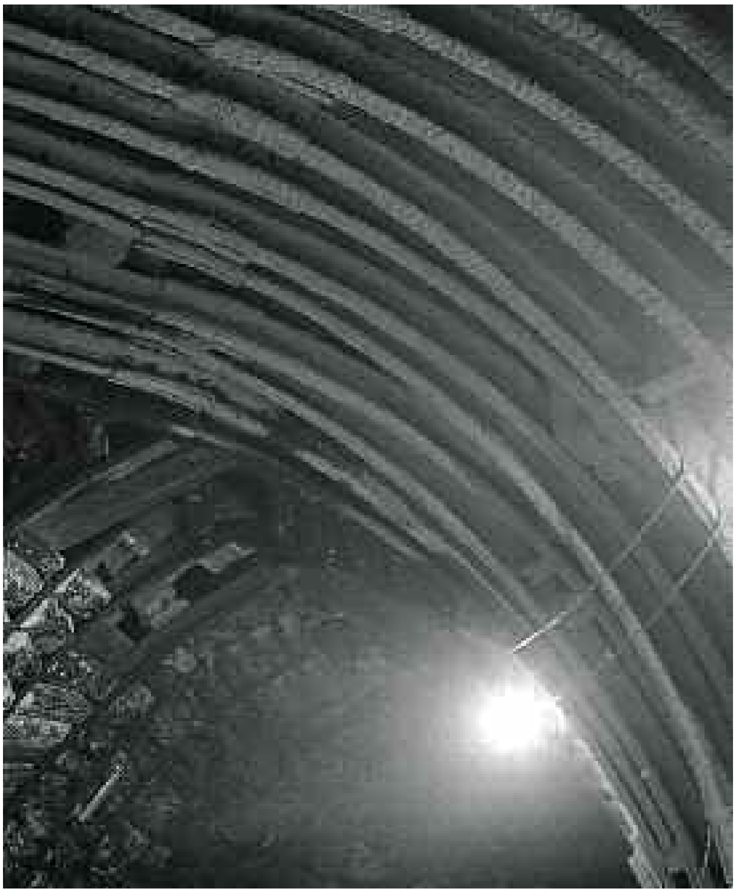
The laborious civil engineering works lasted 15 years. At the 23 high-altitude building sites studding the valleys, every centimetre of tunnel had to be hacked out of the rock. And with this kind of work, it is impossible to move faster than technology allows. The dimensions of the front leading the attack cannot be changed. There is no point in increasing teams or doubling up machinery.







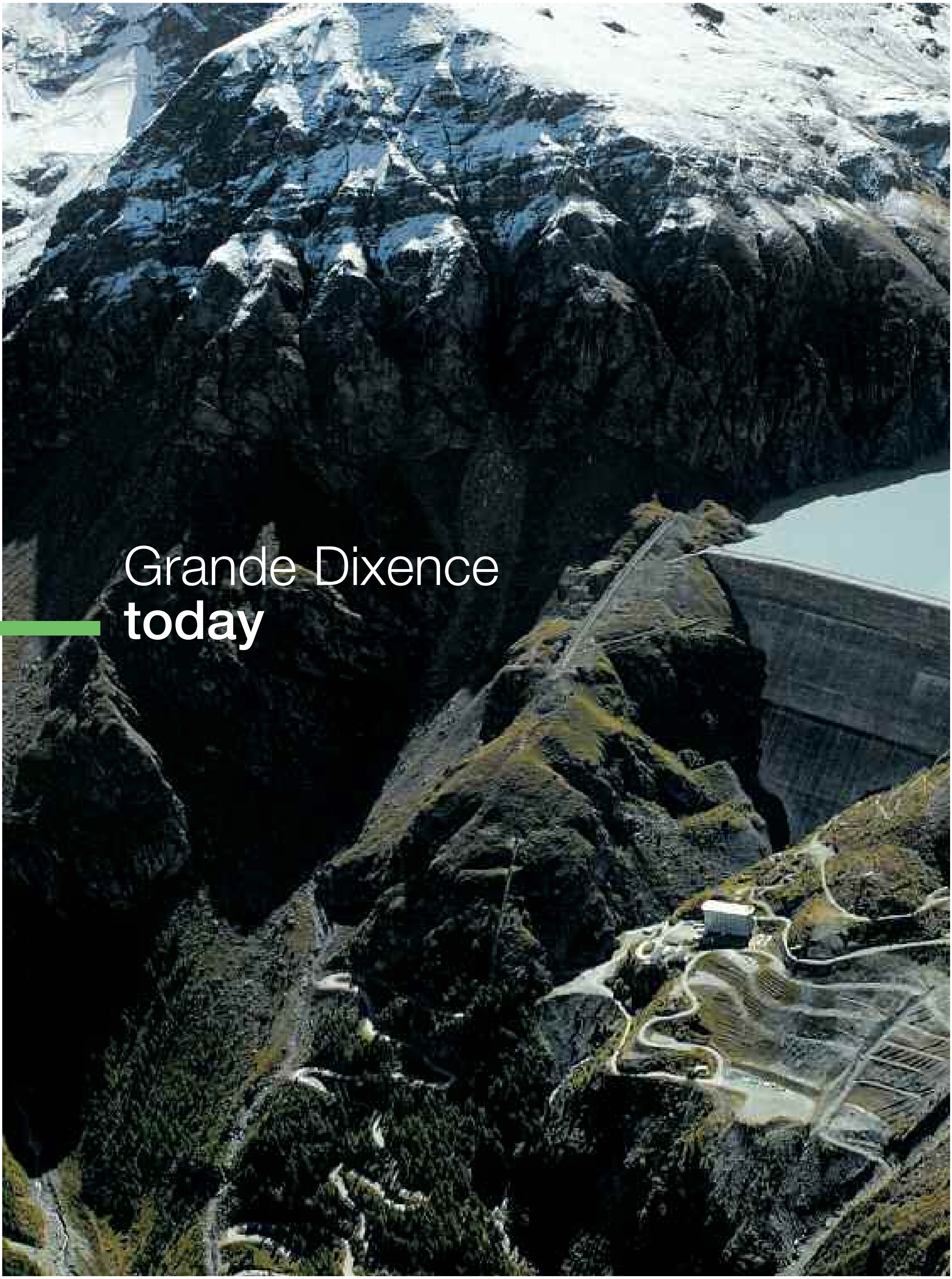




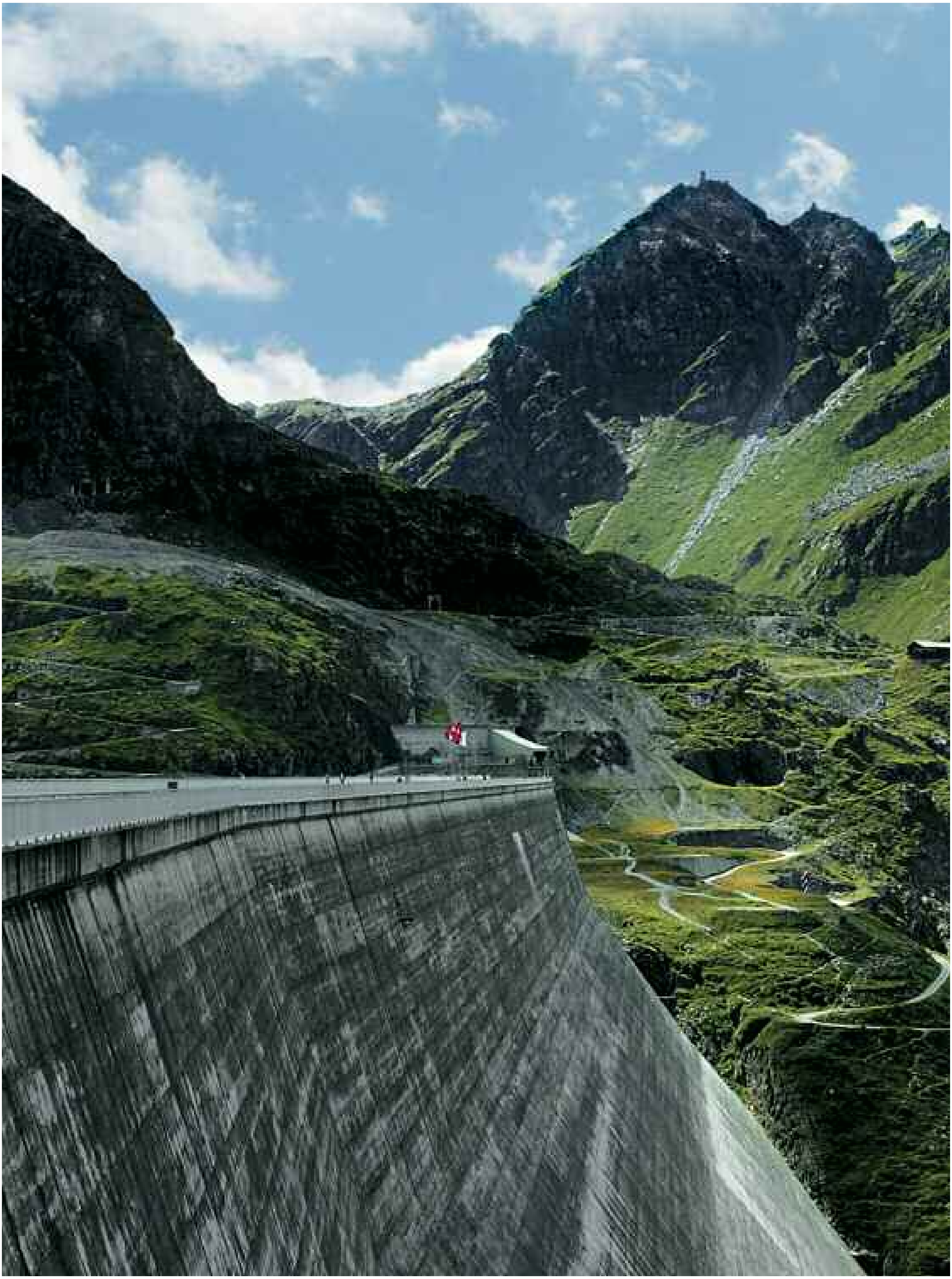
Working conditions on the dam were harsh. And so were conditions at the sites where the collecting works were being constructed. Living conditions inevitably suffered from the rigours of high altitude, the risks of avalanche and rockfalls and the discomfort of tunnel working. In the heroic mythology of great construction projects, the driving of the Bricola, P4 (Arolla collector) and Stafel tunnels occupy prime positions.

In the valleys of Valais Canton, old folk still talk about Mellichen and the Alphubel, inhospitable places where food had to be brought in by helicopter in the winter and where two hundred and fifty men were attacking the mountain simultaneously on ten fronts. They also remember the Stafel siphon where the supporting beams split as though they were matches. A tunnel where it was impossible to move forward more than 50 centimetres without being forced to shore up the roof…

Of course, the bonuses, a feature always associated with mining work, were a motivation for the men who formed the rock assault force. But to be a good miner, it was still a question of showing yourself to be a hard worker, capable of boldness and tenacity. The mountain people of the Valais, who formed the majority of these elite troops, prided themselves on having these qualities. The drilling teams often comprised people from the same region, and even the same valley. They were a particularly sought after labour force that later went on to drive the Swiss motorway tunnels.



Grande Dixence **today**



The highest wall **in the world!**

A record-breaking dam

Half a century has passed since human endeavour built the Grande Dixence dam. And fifty years later, the wall nestling between the flanks of the Dix Valley remains unique. At 285 metres, it is still the highest wall in the world!

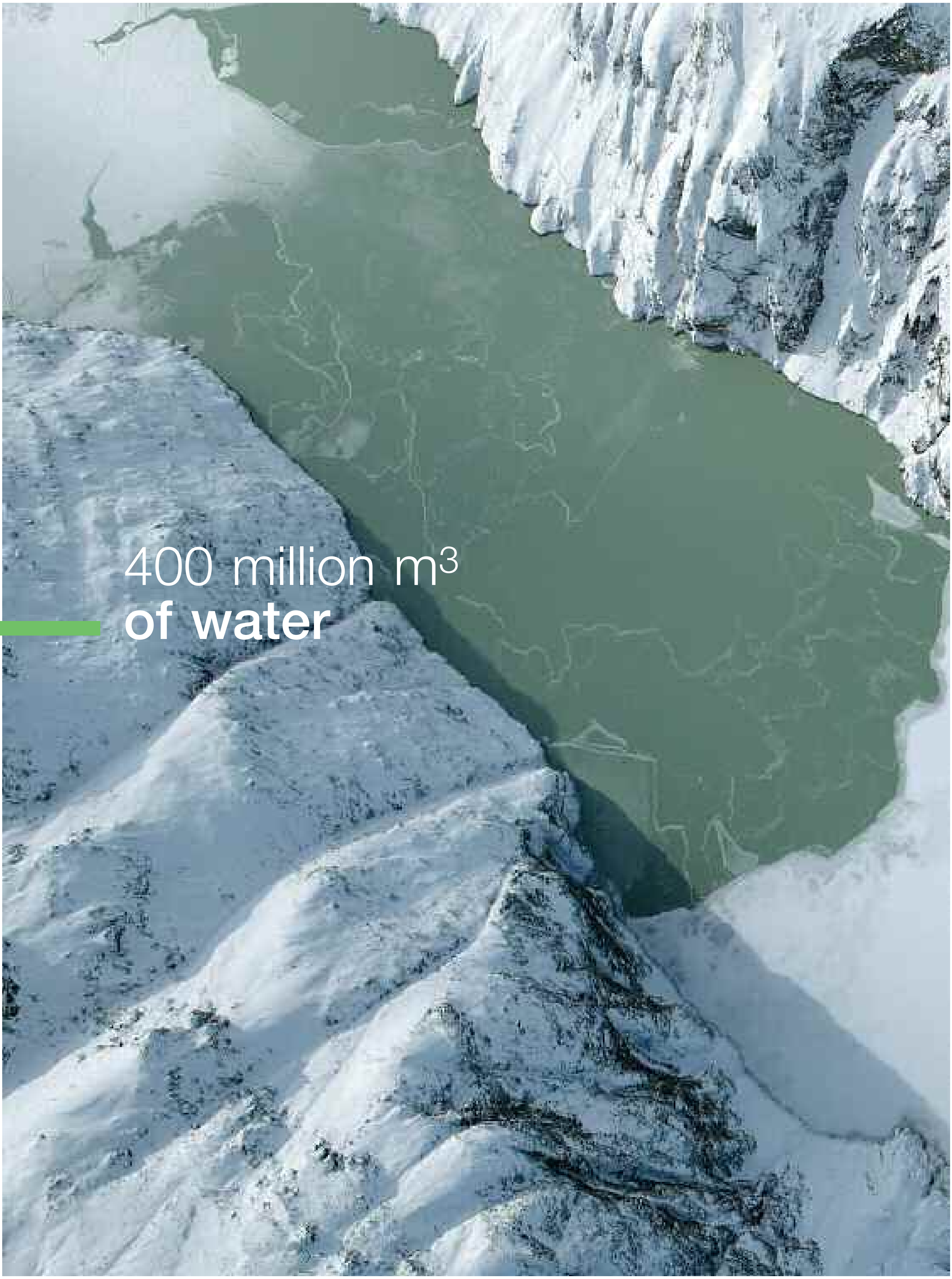
In order to be able to contain the more than 400 million m^3 of water stored each year (a volume equal to 8000 years of the Valais grape harvest for example), the Grande Dixence gravity dam has beaten many records. No fewer than 6 million m^3 of concrete were poured between the mountains: a wall 1.5 metre high and 10 cm wide could be built around the equator with that volume of concrete. At its base, the dam is two hundred metres thick (equal to the length of two football pitches). At the top - in technical terms the crest of the dam - it narrows to a ribbon of only… 15 metres.

To make the soil foundation watertight, the grout curtain surrounding the dam goes down 200 metres into the gneiss and granite of the surrounding mountain mass. It extends 100 m into each valley bank. The wall itself is made up of 16 m x 16 m concrete blocks jointed together in a way that ensures maximum cohesion, strength and impermeability.

Visitors entering the Grande Dixence cavern on foot are always surprised by the bottomless shafts that allow the structure to be monitored. Stretched by 150 kilo counterweights, seven pendulums plunge silently across the full depth of the wall. They measure deformation in the retaining wall continuously. This system allows the movements of the dam to be checked to an accuracy of 5 hundredths of a millimeter.

Because the concrete monster breathes! This 15-million-tonne gravity dam, this colossus that is heavier than the Great Pyramid of Cheops is sensitive to change. Depending on whether its stomach - its lake - is full or empty, the crest moves 11 centimetres downstream or back to its initial position.

Apparently peaceful, Lake Dix is surging energy domesticated by man. 3.65 km^2 in area (for comparison, the area of Lake Joux, in Vaud canton, is 9.5 km^2), it is 5.3 km long and has a maximum depth of 227 metres. This energy reserve enables enough electricity to be supplied throughout the year to meet the needs of a region of around 400,000 households.


400 million m^3
of water

A real challenge: **spot height 2400**

Water collecting works

The Grande Dixence dam is a gigantic stopper and Lake Dix, an artificial lake, is an energy storage unit. These feats of human ingenuity were placed strategically at the heart of a 357 km^2 catchment area, half of which is covered by 35 glaciers. But a way still had to be found of catching and collecting all the liquid gold slipping between the rocks.

An immense system of collecting works and underground canals was designed and driven through the mountain. Again, the numbers make the head spin. In order to collect the water that flows between the Mischabel and Mont-Blanc de Cheilon mountains, approximately 100 kilometres of tunnel had to be dug, including a 24-kilometre main water conduit at 2400 metres altitude. No fewer than 75 water intakes stud the 35 glaciers and supply Grande Dixence with its precious raw material.

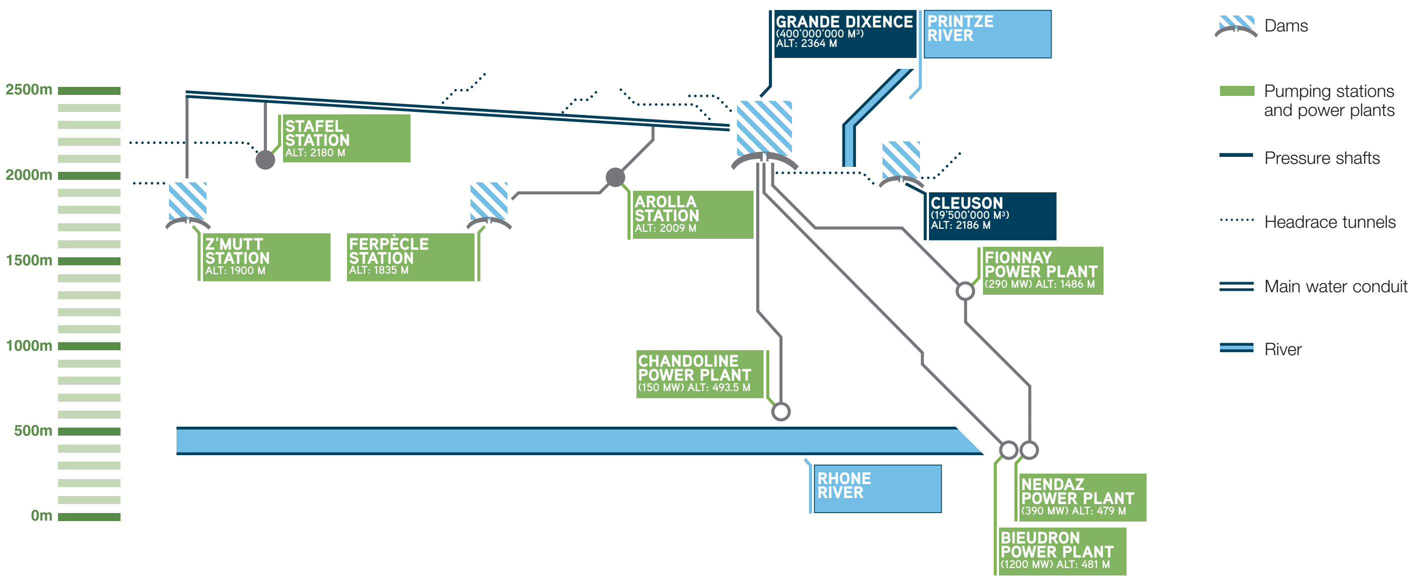
Logically, one would think the water would be brought to dam level simply by gravity, flowing gently along the mountainside to the retaining point. But that means a catching point above the Grande Dixence dam. In fact, this is not always the case. Scarcely 40% of the water filling Lake Dix reaches it by following the natural gradient. So how could water be collected at 2400 metres, the altitude at which the main water conduit feeds into the reservoir? How could this challenge be met successfully when the largest glaciers in the area have a melting zone below that essential spot height?

The high altitude of the dam forced the design engineers to demonstrate their ingenuity. In order to drive back the waters of the Gorner at the foot of Mont-Rose, from Stafel at the foot of the Matterhorn, from Ferpècle at the foot of Dent-Blanche, and from Arolla at the foot of Mont Collon, there was only one option: pumping. 4 stations with a total capacity of 186 MW (equivalent to the power of about 35 locomotives) were built from scratch.

Altogether, these pumping stations deliver a total volume of 300 million m^3 of water to the main water conduit, at the same time consuming 380 million kWh of energy, mainly at times of low energy demand.

Thanks to this clever arrangement, the energy potential of this Swiss Alpine region has been fully realized. By gathering as much water as possible in Lake Dix, either by natural flow or by pumping from neighbouring valleys, the water of an entire region can be exploited in the form of peak energy, its prime asset being its flexibility.


VIEGE
RIVER
STAFEL
STATION
ALT: 2180 M
Z'MUTT
STATION
ALT: 1900 M
AROLLA
STATION
ALT: 2009 M
FIONNAY
POWER PLANT
(290 MW) ALT: 1486 M
GRANDE DIXENCE
(400'000'000 M³)
ALT: 2364 M
FERPÈCLE
STATION
ALT: 1835 M
PRINTZE
RIVER
BORGNE
RIVER
CLEUSON
(19'500'000 M³)
ALT: 2186 M
RHONE RIVER
BIEUDRON
POWER PLANT
(1200 MW) ALT: 481 M
CHANDOLINE
POWER PLANT
(150 MW) ALT: 493.5 M
NENDAZ
POWER PLANT
(390 MW) ALT: 479 M


2500m
2000m
1500m
1000m
500m
0m
GRANDE DIXENCE
(400'000'000 M³)
ALT: 2364 M
PRINTZE
RIVER
STAFEL
STATION
ALT: 2180 M
AROLLA
STATION
ALT: 2009 M
CLEUSON
(19'500'000 M³)
ALT: 2186 M
Z'MUTT
STATION
ALT: 1900 M
FERPÈCLE
STATION
ALT: 1835 M
FIONNAY
POWER PLANT
(290 MW) ALT: 1486 M
CHANDOLINE
POWER PLANT
(150 MW) ALT: 493.5 M
RHONE
RIVER
NENDAZ
POWER PLANT
(390 MW) ALT: 479 M
BIEUDRON
POWER PLANT
(1200 MW) ALT: 481 M
Dams
Pumping stations
and power plants
Pressure shafts
Headrace tunnels
Main water conduit
River

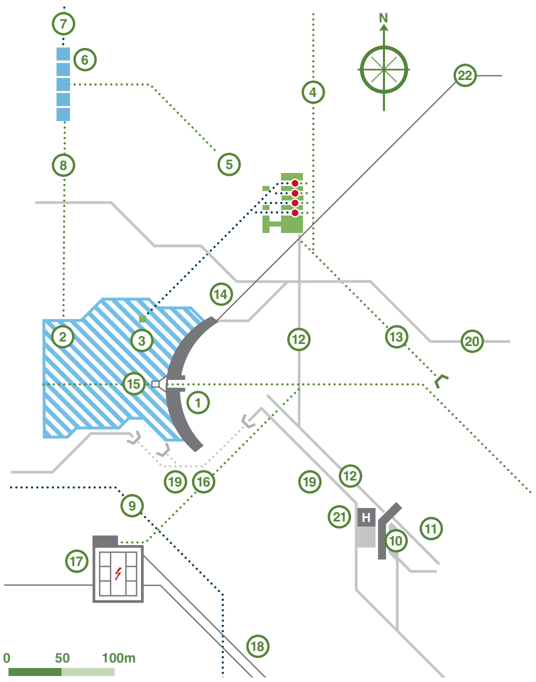
Z'Mutt
pumping station

Beauty spot

At the bottom of the Mattertal valley, clinging to the last Alpine pastures, a few elegant 'mayens' are evidence of the hamlet of Z'Mutt. In this beautiful and peaceful spot, the Grande Dixence engineers were determined to show respect for nature and harmony. As far as possible, the concrete invasion was kept within limits. The only major visible section is the dam that blocks the gorge. Yet, despite its height of 74 metres, the slim and elegant arch dam blends discreetly into the landscape. Apart from the service building, all other facilities (sand and gravel traps and pumping station) are below ground.

Here in this wild enchanting place, water is gathered from the Bis and Schali glaciers that overhang the Viège and from the Gorner. Some experience was needed before the Gorner was brought under control. Every summer in fact, the sudden emptying of a glacial pocket threatens to submerge everything.

4 pumps with a total capacity of 88 MW are used at Z'Mutt to deliver 140 million m³ of water each season. They are driven through a penstock, an inclined steel-lined shaft that brings the water from 1900 metres altitude to the Trift tunnel at 2400 metres altitude or the level of the main water conduit.



1 Arch dam, height 74 m
2 Afterbay reservoir, useful volume 700,000 m³
3 Water intake and headrace tunnel, ø 2.30 m
4 Discharge shaft to main water conduit, ø 1.80 to 1.90 m
5 Schali-Bis steel-lined shaft, ø 1,35 m
6 Bodmen underground afterbay reservoir, useful volume 2500 m³
7 Schali-Bis headrace tunnel, discharge rate 8.5 m³/sec.
8 Bodmen spillway tunnel
9 Gornera headrace tunnel, discharge rate 25 m³/sec.
Service and control building
Operating cableway
Access gallery to power plant
Drainage tunnel
Dam access tunnel
Emptying of afterbay reservoir and return to Z'Mutt stream
Cable gallery
Switchyard
130 kV line
Roads and road tunnel
Z'Mutt-Schönbühl path
Heliport
To 12 MW plant in Mutt (EWZ)

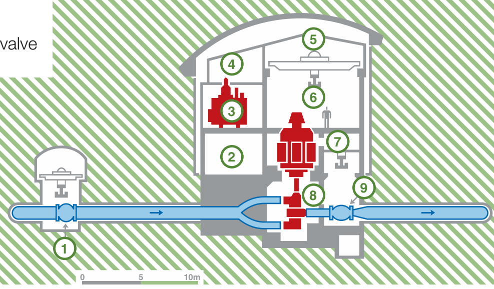
Cross-section of station

2 units each comprising:
1 pump delivering 5.5 m³/sec., head 470 m, and
1 synchromotor, 30 MW

2 units each comprising:
1 pump delivering 3.2 m³/sec., head 65 m, and 1 synchromotor, 14 MW

Total pumping station discharge rate: 17.4 m³/sec.

1 Low pressure control valve
2 Internal services
3 Transformer
4 Cable gallery
5 Overhead travelling crane
6 Machine hall
7 Motor
8 Pump
9 High pressure control valve



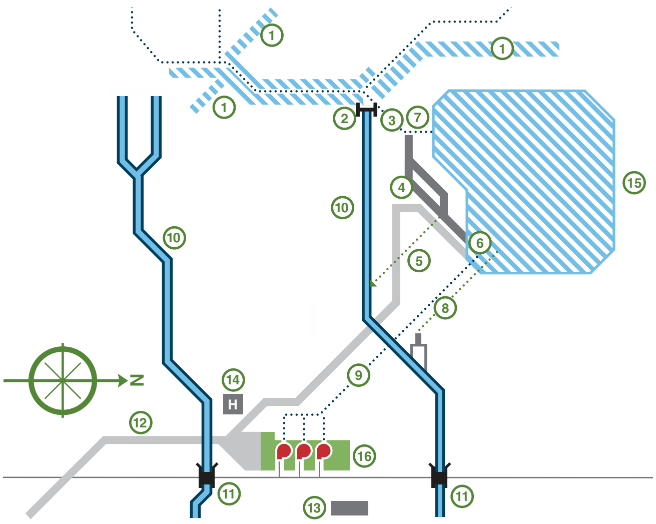
Stafel
pumping station

At the foot of the Matterhorn

With its cold mineral colours, this is a unique landscape, breathtaking in its beauty and solitude. Standing solidly at the foot of the renowned north face of the Matterhorn, Stafel is a terminal moraine of the Z'Mutt glacier.

The only features betraying the presence of humans are two large sand traps and an afterbay reservoir retained by an embankment, which supply the pumping station. Water from the Z'Mutt glacier is stored here, in this windy, silent place. The water joins that supplied by the Mischabel, Findelen, Obertheodul and Furgg glaciers which cross the dip in the valley via the Stafel siphon.

The pumping station drives the water from the glacier into the bend of the siphon to force it up to the collecting level some 250 m above. Year in year out, Stafel pumps an average of 100 million m³ of water.

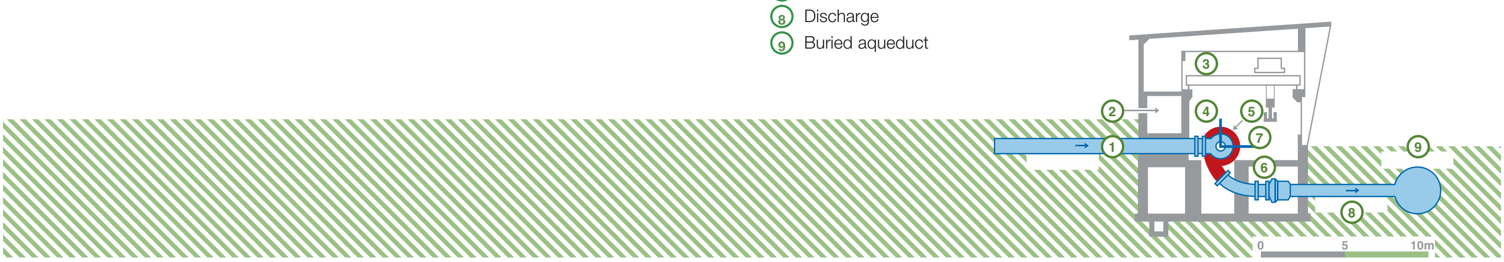


1. Impoundments
2. Water intake
3. Flood gate
4. Two sand traps, each 7.5 m³/sec.
5. Sand trap flushing tunnel
6. Reservoir feed canal
7. Winter headrace canal
8. Reservoir drawoff and spillway tunnel
9. Suction conduit, ø 1.80 m, discharge rate 9.9 m³/sec.
10. Torrent beds
11. Aqueduct crossing under torrents
12. Road
13. 130 kV line and switchyard
14. Heliport
15. Afterbay reservoir, useful volume 70,000 m³
16. Pumping station

Cross-section of station

3 units each comprising:
1 pump delivering 3,3 m³/sec.,
head 212 m, and 1 synchromotor, 9 MW
Total station discharge rate: 9.9 m³/sec.

1. Suction conduit, ø 1.80 m, discharge rate 9.9 m³/sec.
2. Switchgear
3. Overhead travelling crane
4. Transformer
5. High-pressure pump
6. Valve
7. Motor
8. Discharge
9. Buried aqueduct



Ferpècle **pumping station**

Unpredictable rages

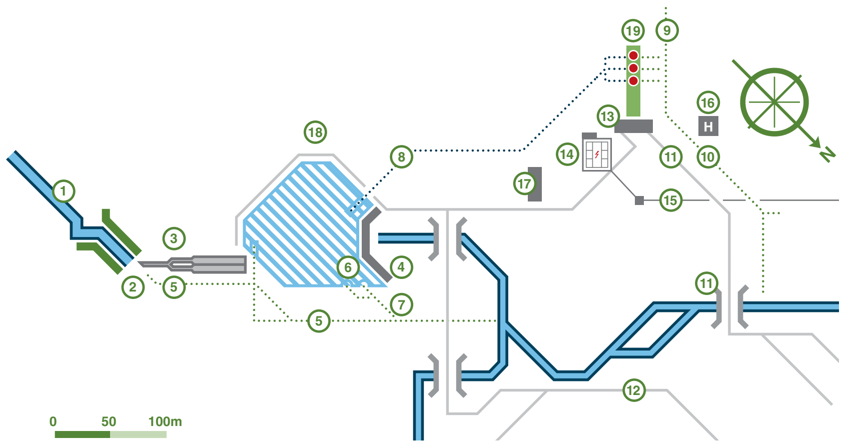
At Ferpècle, only a small 100 thousand m3 cubic metre dam and a sand trap, anchored to the rock and set amidst larches, are visible. That is all the eye can see. The genius of the Grande Dixence engineers knows how to be discreet. The power plant has been able to lose itself, hidden beneath the mountain again like the one at Z'Mutt.

This is a dangerous area. The Mount Miné and Ferpècle glaciers are unpredictable. If the mountain-dwellers are to be believed, these glaciers have a reputation for being hot-tempered. On several occasions in the past, the break up of the ice has been violent and turbulent.

To prevent a similar natural disaster from damaging the pumping station at Ferpècle, there is also an access limiter on the water intake sand trap. This clever device prevents excessively high flood water from entering the works.

Each year, the Ferpècle pumps drive 63 million m^3 of water towards the neighbouring Arolla valley and another pumping station, via the Maya reservoir, which is also hidden in the mountain.

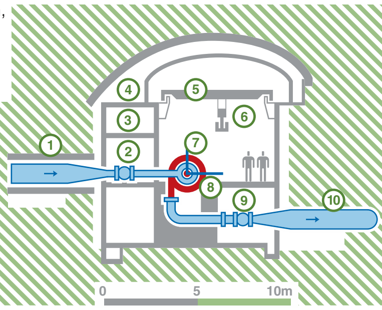
1 Forebay
2 Water intake
3 Two sand traps, total discharge rate 11 m^3/sec.
4 Arch dam, height 25.5 m
5 Flood relief works
6 Overflow weir
7 Reservoir drawoff and spillway tunnel
8 Suction conduit, ø 1.90 to 1.55 m
9 Discharge shaft, ø 1.55 to 1.90 m
Power plant drainage tunnel
Power plant access bridge and tunnel
Road
Service building with power plant access shaft
Switchyard
130 kV line
Heliport
Accommodation
Afterbay reservoir, useful volume 100,000 m^3
Pumping station



1 Suction conduit, ø 1.90 to 1.55 m
2 Low pressure control valve
3 5 kV busbars
4 130 kV cables
5 Overhead travelling crane
6 Machine hall
7 Transformer
8 Pump
9 High pressure control valve
Discharge shaft, ø 1.55 to 1.90 m

Cross-section of station

3 units each comprising:
1 pump delivering 2.8 m^3/sec, head 212 m,
and 1 synchromotor, 7.1 MW
Total station discharge rate: 8.4 m^3/sec.



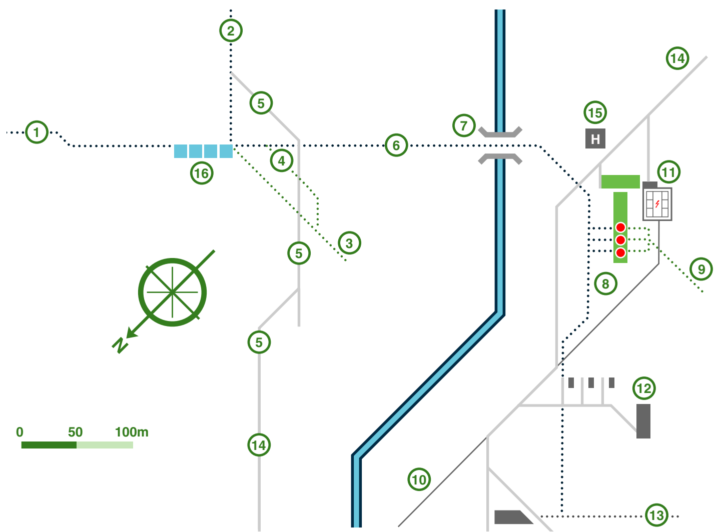
Arolla
pumping station

A high valley that is not… high enough

At the end of the water collecting works, the high Arolla valley is still… too low. It is more than 300 m away from the crucial spot height of 2400 and the main water conduit leading to Lake Dix.

Arolla receives the water already pumped by Ferpècle and adds the water contributed by the Tsidjiore Nouve and Bertol glaciers. Altogether, the pumping station at Arolla catches and discharges 90 million m³ of water. It is the most powerful pumping station in the scheme after the one at Z'Mutt. Three double suction pumps each with a capacity of 16.2 MW discharge their 4.2 m³ per second at a head of 312 m.

1 Ferpècle headrace tunnel, discharge rate 8.4 m³/sec.
2 Bertol Lower headrace tunnel, discharge rate 2.0 m³/sec.
3 Siphon spillway
4 Afterbay reservoir drawoff tunnel
5 Access tunnel
6 Pumping station suction shaft and conduit, ø 1.80 m
7 Conduit crossing under torrent
8 Tsidjiore-Nouve buried headrace tunnel, ø 0.80 m
9 Buried discharge conduit, ø 1.65 m to 1.90 m
130 kV line
Switchyard
Accommodation and canteen
Access cableway to main collector
Roads
Heliport
Maya afterbay reservoir



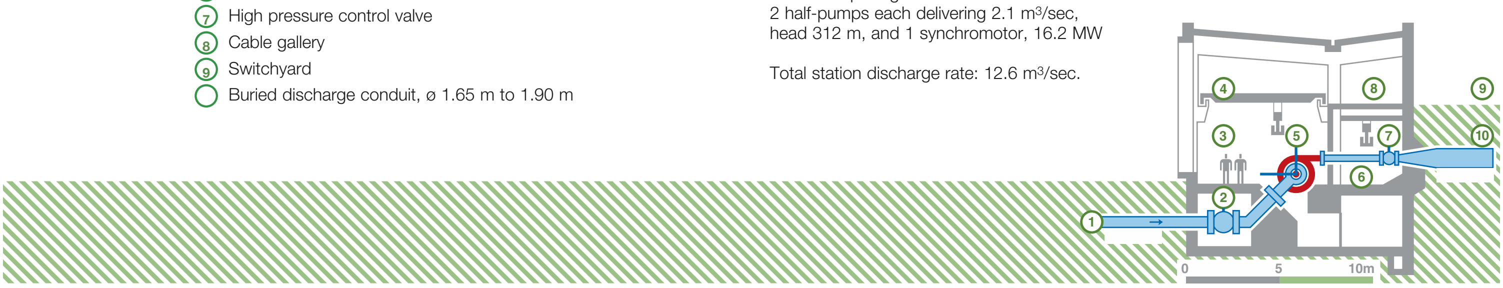
1 Pumping station suction shaft and conduit, ø 1.80 m
2 Low pressure control valve
3 Machine hall
4 Overhead travelling crane
5 Pump
6 Transformer
7 High pressure control valve
8 Cable gallery
9 Switchyard
Buried discharge conduit, ø 1.65 m to 1.90 m

Cross-section of station

2 units each comprising:
1 pump delivering 4.2 m³/sec, head 312 m, and 1 synchromotor, 16.2 MW

1 unit comprising:
2 half-pumps each delivering 2.1 m³/sec, head 312 m, and 1 synchromotor, 16.2 MW

Total station discharge rate: 12.6 m³/sec.



The real challenge: **managing the water**

Dual requirement

Building the collecting and pumping works to bring the water of 35 Valais Canton glaciers to Lake Dix was hard, dangerous work. Building a gravity dam capable of resisting the pressure of an artificial lake containing 400 million m^3 of water was a titanic undertaking. But all these efforts would be as nought if human beings were not able to manage this source of energy with meticulous care.

The real challenge lies in making the most of the Grande Dixence scheme – in being able to find the best possible match between the scheme's constraints, customer demands and market prices.

On paper, the requirements of Grande Dixence are straightforward: Lake Dix must be filled with as much water as possible during the limited period when glaciers and snow melt. But in reality, this is a proper headache. The capacity of the large water conduit, which must never be put under pressure, is one factor to take into account; attention must also be paid to changes in the water intake discharge rate, the weather forecasts and the short, medium and long-term water supply must be monitored and the water caught at favourable times in the neighbouring valleys must be pumped without forgetting the restitution of large quantities of water for ecological, tourism and contractual reasons.

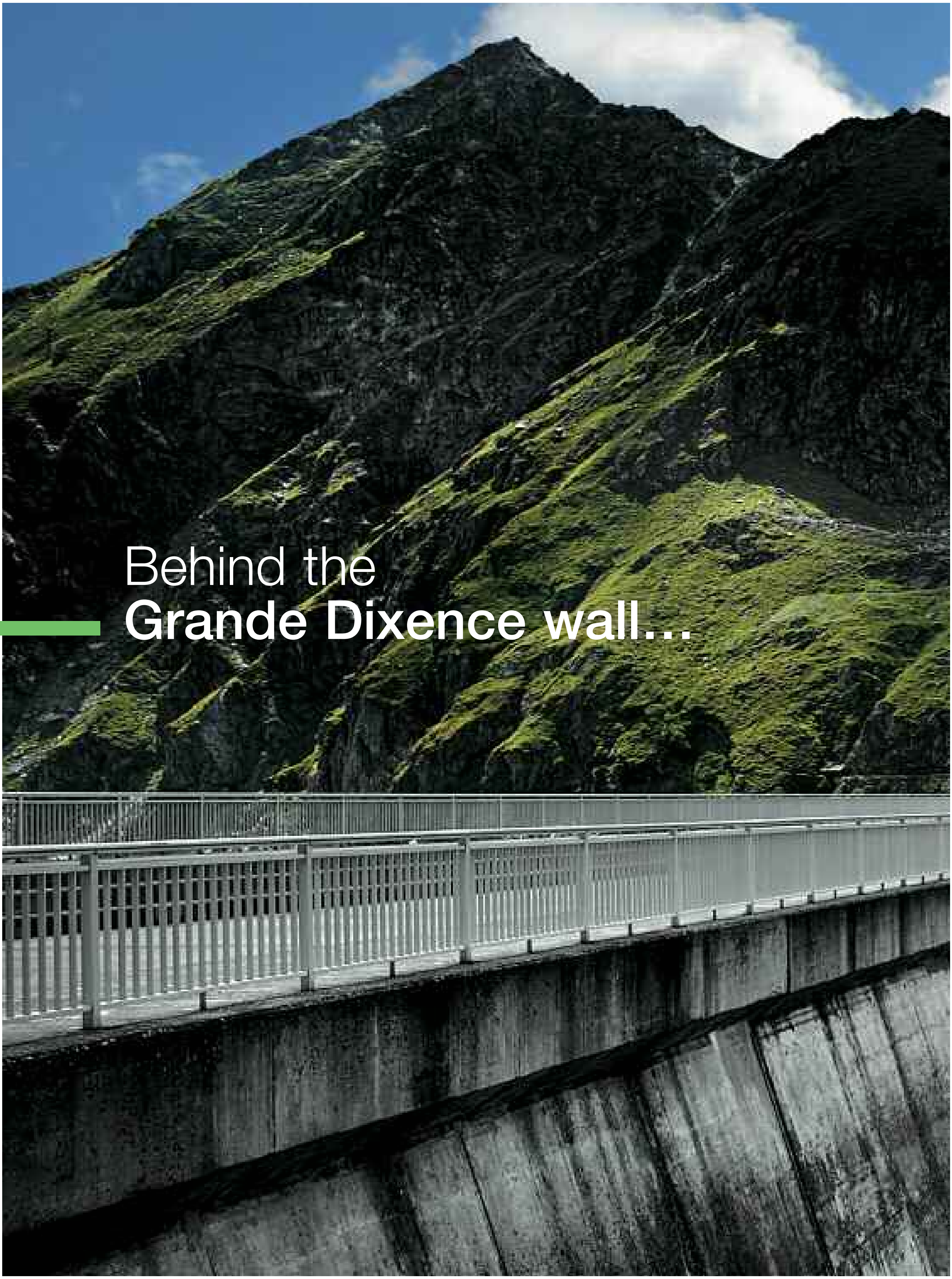
The economic dimension of Grande Dixence is of course a prime concern. The scheme is there to supply the market with high-quality energy at peak hours. The storage level of the scheme must be optimized to ensure maximum availability before the periods of high demand. In order to achieve a satisfactory organizational energy balance sheet, it is imperative to calculate continuously the cost of the energy consumed by the summer pumping and the yield from the energy produced in winter.

This dual requirement is essential to the profitability of the scheme. Only precise computer-aided management is capable of taking account of the multitude of parameters that change minute by minute. All the data captured in the thousand recesses of the Grande Dixence system are transmitted to the Water Management Centre at Sion, which is equipped to adjust any part of the collecting and pumping equipment at any time.

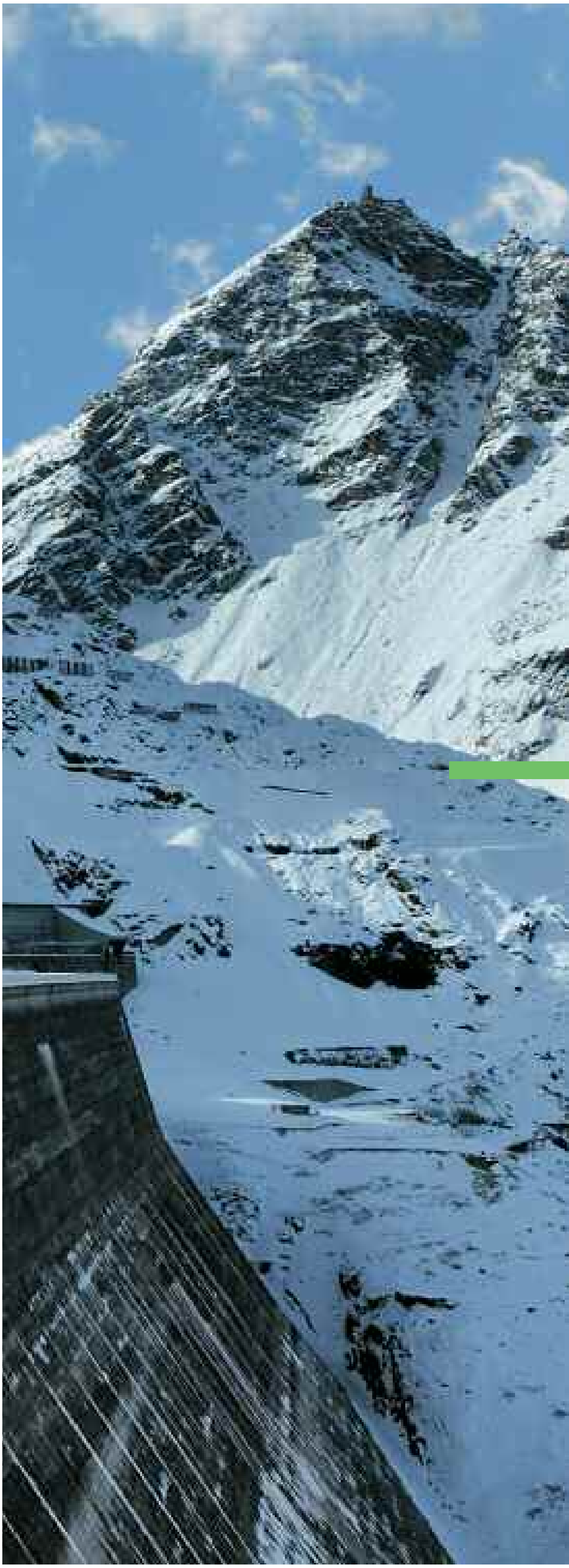
The Sion Centre is a laboratory, equipped to predict all the water supplies and flows that will be needed to fill the dam-lakes. Here probes and the electronic chip take their revenge on the concrete of the civil engineering structures. The remote control system gathers and transmits continuously to Sion some 400 measurements and 2500 signals. All the vital organs - pumps, valves, penstocks and main water conduit - are constantly monitored and remotely controlled. Information is transmitted in real-time using the high-voltage lines, beam power and fiber optics. Data are thus recorded and analysed day and night.

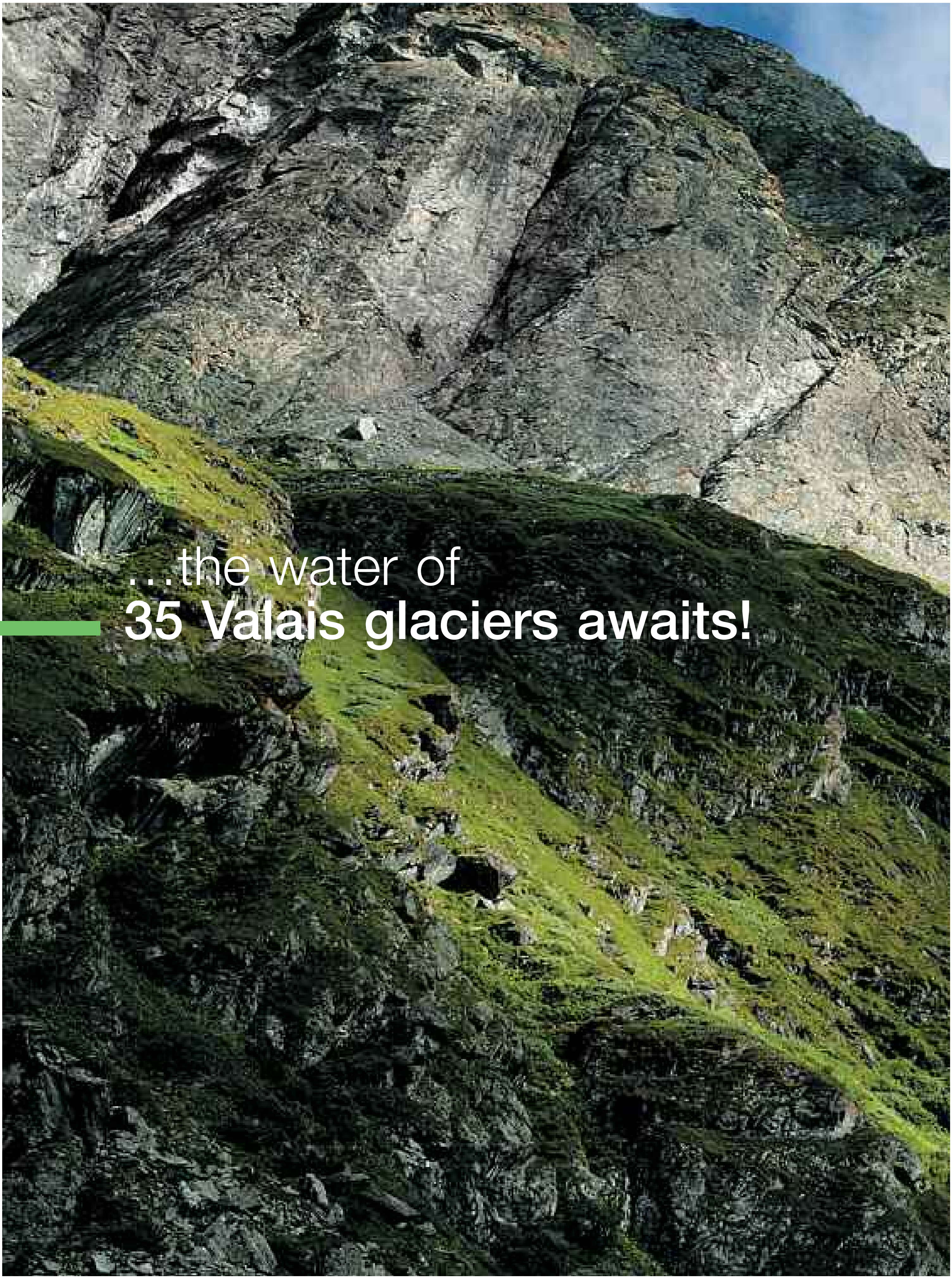
Glacier melt parameters are still very complex. However, the statistics recorded over many years allow the resources to be managed optimally.

The Water Management Centre is permanently connected to meteorological services and the operating partners in order to be able to take all necessary decisions at any time and in full possession of the facts. There is a great deal at stake with this method of high precision management: a million cubic metres of water lost means more than 4 million kWh less energy in the winter.

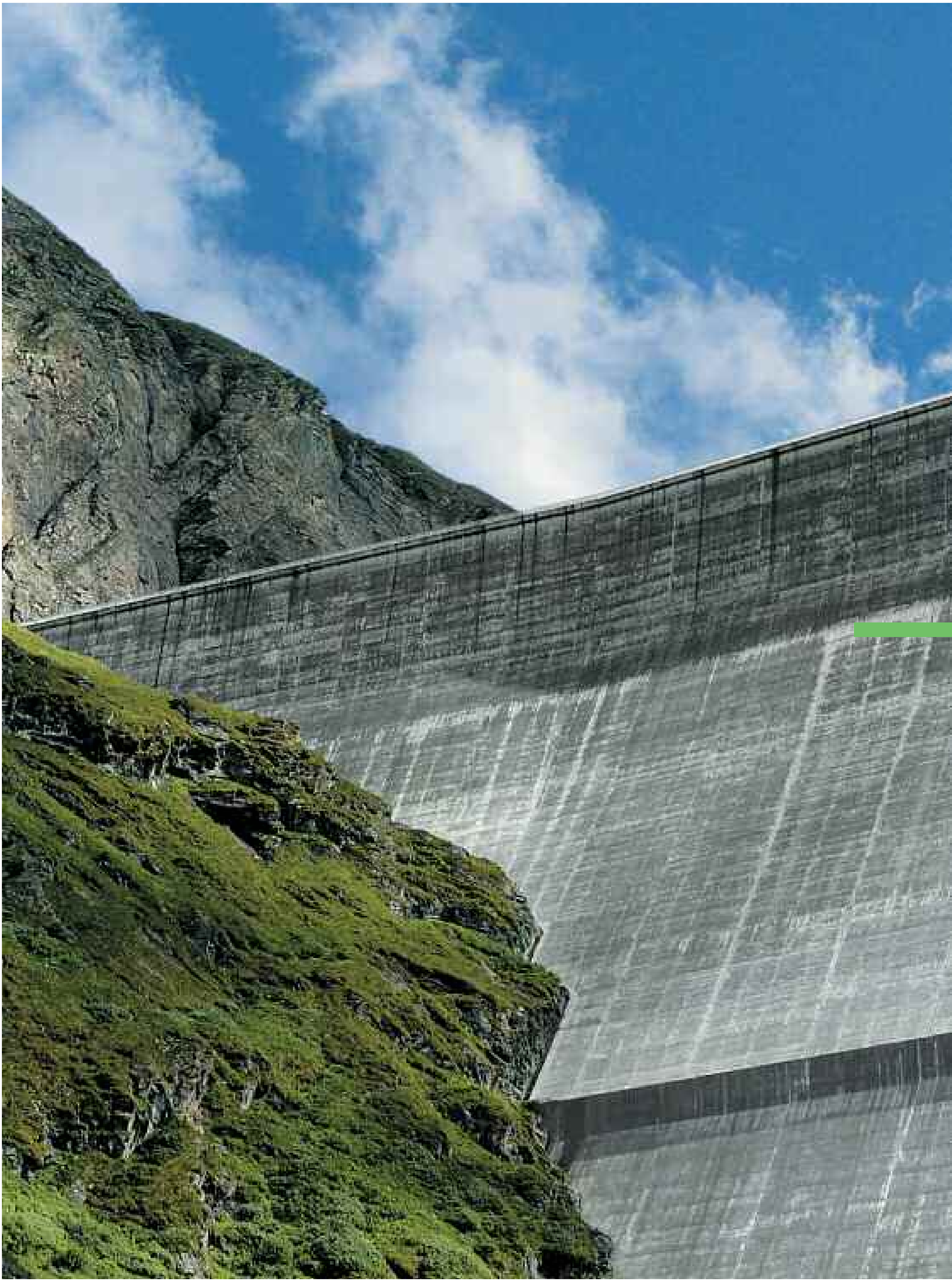


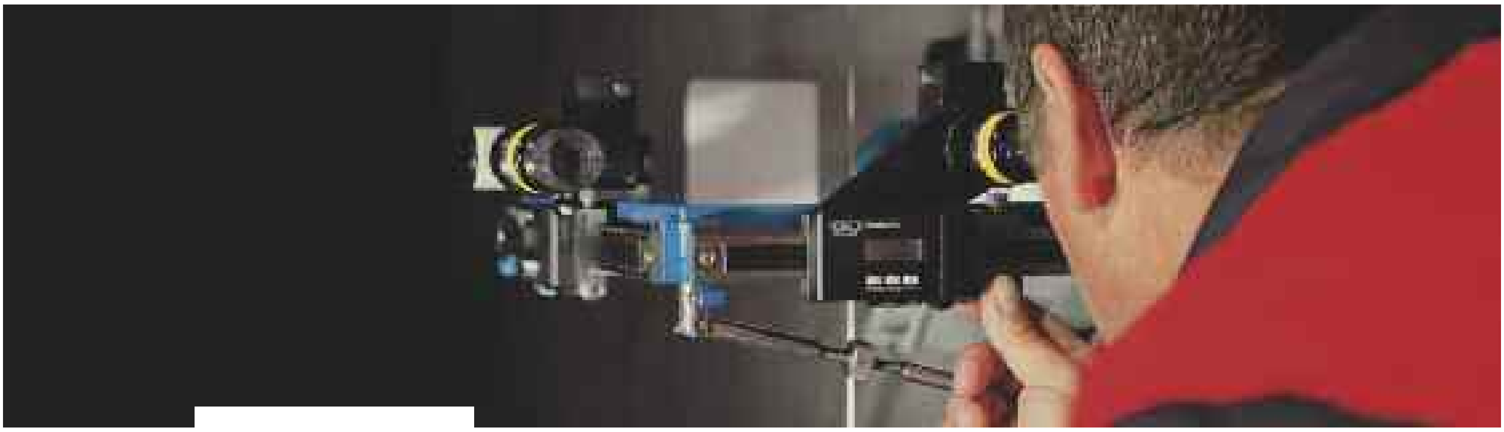
Behind the **Grande Dixence wall…**





...the water of
35 Valais glaciers awaits!





Safety

Moment-by-moment monitoring

Managing water means not only being capable of exploiting the quintessential nature of its power. It is also, and above all, a matter of monitoring it, domesticating it and controlling it to prevent accidents. Safety is the prime concern, the fundamental requirement that has presided over the construction of the dam from beginning to end.

The movements of the structure and the state of the neighbouring rock are continuously checked. The Grande Dixence dam is equipped with 32 kilometres of tunnels. These twisting, turning tunnels lead to the measuring points, and especially to the 7 vertical pendulums that plunge down from the crest across the entire depth of the wall and to the 3 inverted pendulums that check the dam and its foundations for deformation.

Surveillance is constant. Nothing is left to chance. There is geodesic and discharge rate measuring to monitor the structure and detect the slightest weakness. The dam has been designed to be strong enough to withstand a seismic shock of an intensity never recorded in Valais Canton.
Today, technology and the advances of remote measurement have considerably changed the life of the dam's surveillance officers. Their regular patrols and observations are simplified by the automated recording and transmission of all the data to the Sion Water Management Centre.

However, the simplest methods are sometimes the most effective. Throughout the valley, downstream from the dam, danger notices and audio alarms ensure the safety of the local population should water suddenly be released.

One thing is certain: after more than 40 years of operation, the builders' predictions have proved to be remarkably accurate. The impermeable 200 metre-deep grout curtain has been effective beyond all expectation. The total loss of water through lat-

To be able to use the Lake Dix water, **one new and three original power stations are needed**

2000 hours of turbining

The 400 million m^3 stored in the Grande Dixence storage reservoir represent a tremendous energy potential. They account for no more and no less than one fifth of all the stored energy in Switzerland.

In order to ensure the profitability of the hydropower concentrated in Lake Dix, Grande Dixence turbines the water in two stages. First, at an altitude of about 1490 m at the Fionnay plant. Second, by the Rhône, 1000 m lower down, at the Nendaz plant.

The Fionnay and Nendaz power plants relay each other, helped by the EOS-owned Chandoline power station, in order to transform this mass of water into electricity and tame this quiet power into producing billions of kWh of energy.

These three power plants have an overall generating capacity of 800 MW. With the existing turbines, running at full strength, it takes over 2000 hours to empty the lake created by the Grande Dixence dam.

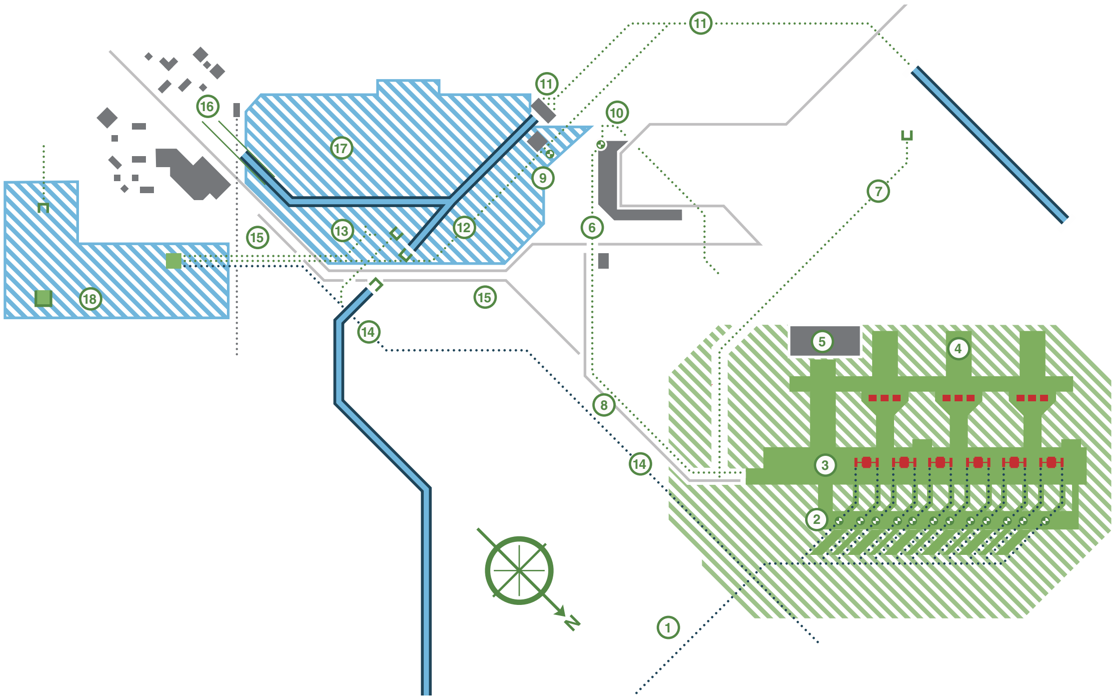
Fionnay
power plant

800 metres with a 73% gradient!

To bring the water from the Grande Dixence dam to the first turbines at the Fionnay power plant, a nine-kilometer underground tunnel had to be built and fitted out. This pressure tunnel slopes steeply: the average gradient is about 10%. When it was driven through, the labourers and engineers were faced with serious problems due in particular to water seepage.

The surge tank is at the end of the Louvie tunnel, in Bagnes valley; the tunnel then becomes a steel-lined shaft which plunges more than 800 m down a 73% incline! The shaft ends at the Fionnay power plant distributor, an enormous cavern hewn out of the rock.

Completely underground, the Fionnay plant has 6 generating units, each equipped with 2 Pelton turbines, total capacity 320 MW. The head varies between 680 m and 874 m, depending on the level of water in the Grande Dixence dam.



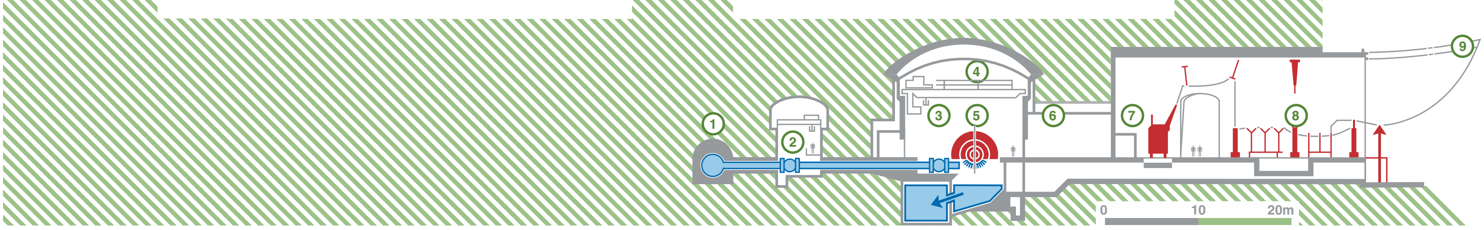
1 Louvie steel-lined penstock, ø 3.0 to ø 2.8 m
2 Valve chamber
3 Machine hall
4 Transformers and 220 kV equipment
5 Outside service buildings
6 Power plant tailrace canal
7 Tailrace spillway
8 Power plant access tunnel
9 Tailrace outlet in the reservoir and water intake for the Nendaz power plant
Nendaz tunnel guard gate, ø 3.0 m
La Dranse diversion, reservoir drawoff and spillway
Forces Motrices de Mauvoisin (FMM) reservoir drawoff tunnel
Water exchange tunnel between FMM and Grande Dixence
Champsec power plant headrace tunnel
Power plant winter access tunnel
Louvie gate access cableway
Grande Dixence afterbay reservoir
FMM afterbay reservoir

1 Louvie steel-lined penstock, ø 3.0 to ø 2.8 m
2 Valve chamber
3 Machine hall
4 Overhead travelling crane
5 Turbo-generating units
6 15 kV switchgear
7 15/220 kV transformer
8 220 kV equipment
9 220 kV line

Cross-section of power plant

6 horizontal units comprising:
1 alternator and 2 Pelton turbines
Total station discharge rate: 45 m³/sec.
Gross head: max. 874 m; min. 680 m
Installed capacity: 6 x 60 MVA = 360 MVA

3 blocks each with three 120 MVA single phase transformers



Nendaz
power plant

The biggest hydropower plant in Switzerland after Bieudron

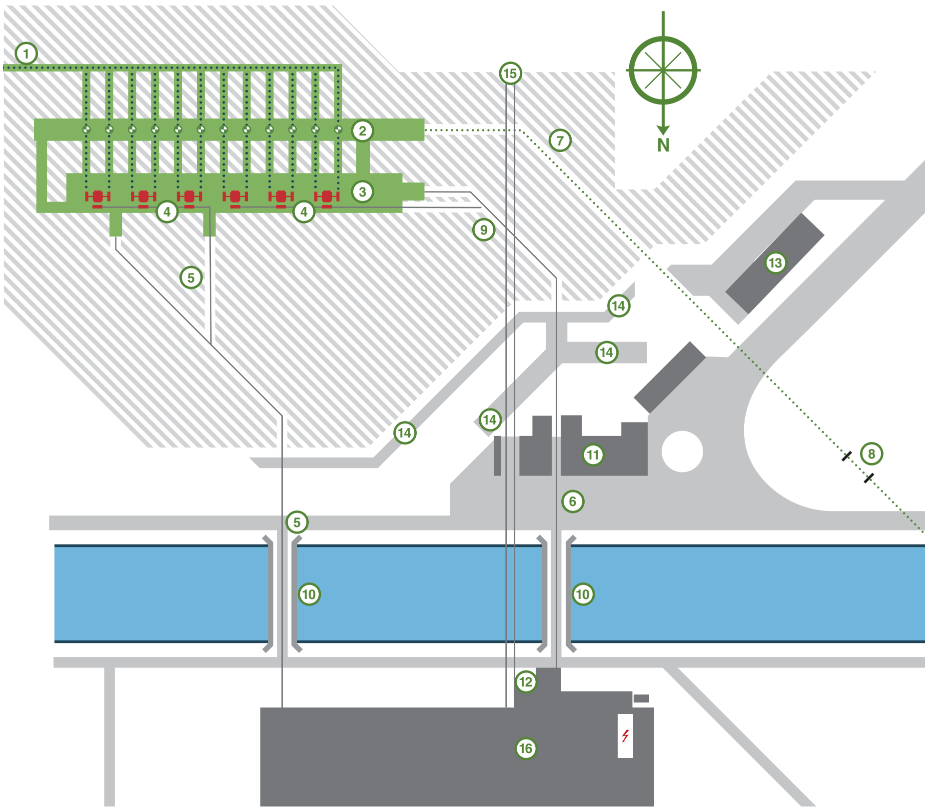
The waters of Grande Dixence, having been turbined a first time at the Fionnay plant in the Bagnes valley, dive back deep inside the rock. They cross the mountain again in the direction of the neighbouring Nendaz valley.

The precious water - the “white gold” - is again channelled into a pressure tunnel that ends in the Péroua surge tank, 1000 metres above the Nendaz generating station. This second power plant is just as discrete and invisible as the one at Fionnay, because it too is hidden inside the mountain. It lies between Aproz and Riddes, on the banks of the Rhône, 478 m. above sea level.

The tunnel linking Fionnay and Nendaz is 16 kilometres long and ends in another steel-lined penstock. On the way, water from the Fara, originating in the Isérables Valley, is added to the flow heading towards Nendaz.

The Nendaz generating station is the biggest hydropower plant in Switzerland after Bieudron. It works on the cascade principle with the Fionnay station, i.e. its capacity and discharge rate are modulated in tandem with Fionnay. Together, the two stations generate around 2 billion kWh per year.

The plant has 6 generating units each equipped with 2 Pelton turbines, giving a total capacity of 430 MW.



1. Nendaz steel-lined shaft. ø 2.9 m
2. Valve chamber
3. Machine hall
4. Transformers
5. Gallery and gangway of the 220 kV cables of the first 3 sets
6. 220 kV cables of the last 3 sets
7. Tailrace canal
8. Tailrace canal partial bulkhead
9. Power plant access tunnel

Rhône bridge
Service building, workshop and entrance to power plant
Chamoson switchyard control building
Workshop and central depôt
Protective fill
Fionnay-Chamoson 220 kV line
Chamoson 220 kV switchyard

1. Nendaz steel-lined penstock, ø 2.9 m
2. Valve chamber
3. Tailrace canal
4. Turbo-generating units
5. Machine hall
6. Overhead travelling crane
7. Transformers

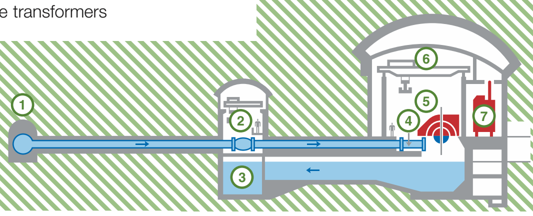
Cross-section of power plant

6 horizontal units comprising:
1 alternator and 2 Pelton turbines

Total station discharge rate: 45 m³/sec.
Gross head: max. 1008 m; min. 1002 m

Installed power: 6x80 MVA = 480 MVA

6x80 MVA three phase transformers



Cleuson-Dixence vital statistics

The Cleuson-Dixence scheme was built entirely underground between 1993 and 1998. It comprises the following main structures:

- New water intake built into the Grande Dixence dam at Le Chargeur.
- 15.8 km headrace tunnel between the dam and Tracouet.
- Surge tank at Tracouet, carved out of the Dent-de-Nendaz mountainside.
- 4.3 km sloping steel-lined penstock, from Tracouet to the Bieudron powerhouse.
- Underground power plant equipped with 3 vertical turbine generators, each comprising a 423 MW Pelton turbine and a 465 MVA alternator.

Gross head: 1883 m
Discharge rate: 75 m^3/sec.
Maximum generating capacity: 1200 MW
(For comparison, the Gösgen nuclear plant has a capacity of 970 MW and the Leibstadt nuclear plant a capacity of 1165 MW)
Costs (including finance charges): CHF 1.3 billion

Cleuson-Dixence complex: Output of a large **nuclear power plant available in 3 minutes**

Capacity more than doubled

The main function of a hydropower plant is to cope with fluctuations in demand. When demand is at its highest, for example on a winter morning between eleven and twelve a.m., the water retained behind the dams is turbined to complement energy produced elsewhere in the country or in Europe by run-of-the-river power plants and thermal or nuclear power plants. Production must equal consumption at any one time.

Before Cleuson-Dixence was built, emptying Lake Dix required around 2000 hours of turbining, from October onwards. With the new Bieudron power plant, it is possible, when operating at full capacity, to concentrate production over only 1000 hours.

The available capacity has been multiplied by a factor of 2.5. With the current facilities at Fionnay, Nendaz and Chandoline, the Grande Dixence complex has a total capacity of 800 MW. Cleuson-Dixence enables this capacity to be increased by 1200 MW, thus giving the complex a total capacity of 2000 MW.

Like Fionnay and Nendaz, the main mission of Cleuson-Dixence is to supply power instantaneously, on demand. In barely 200 seconds, the facility is capable of injecting the equivalent of a nuclear power plant's total output into the grid!

The energy produced by the whole Grande Dixence / Cleuson-Dixence facility is 2 billion kWh per year, or the annual average consumption of 400,000 households.


250/16t
ABB
2
ABB
3

Extreme pressures!

The penstock is the power enabler of the Cleuson-Dixence facility. The steel-lined shaft runs along the left bank of the Rhône between the foot of the Dent-de-Nendaz mountain at 2150 m altitude and the Rhône plain at 480 m, a difference of 1670 m over an inclined distance of 4.3 km.

Given the height of the dam, the static pressure is 190 bars at the turbine inlet. 190 times atmospheric pressure! From the beginning of the construction work, the plan was to fully line the shaft and encase it in concrete. The tube is 3 m in diameter at the base of the structure. The thickness of the lining is 6 cm.

A tragic accident caused the penstock to fail in December 2000. To restore the facility, a new steel tube will be inserted into the existing shaft.

The accident

A geyser spouted from the earth

The first command governing the actions of the dam builders and of those who built the power plants was always, and at all times, SAFETY. This constant concern to protect people and the environment translated into extremely high construction standards. Unfortunately, despite every effort, every calculation, it is not always possible to tame the savage power of nature and water.

On 12 December 2000, shortly after 20.00 hrs, the penstock bringing water from the Grande Dixence dam to the Bieudron power plant ruptured between Péroua and Condémines at a height of 1234 m. Despite the speed with which the scheme's safety systems came into operation, a large volume of water spouted up, like a geyser, and hurtled down the mountainside, a torrent of mud and rock. This moving mass took everything with it and devastated everything in its path: trees, orchards, barns, chalets… Three people were buried. The Sion - Riddes road on the left bank of the Rhône was cut off by the rockfall. The Rhône itself was blocked for a short while.

Since then, the Bieudron power plant has been at a standstill and its 1200 MW capacity lies dormant.

Having studied the causes of this accident at length, it was determined that the way the welds were done caused the steel-lined shaft to fail.

2005 was the year when the initial work to restore Cleuson-Dixence began. The entire section will be repaired by lining the existing shaft. This means that a new steel tube will be inserted inside the original conduit.

In the accident area, the ruptured part of the penstock has been abandoned. The chosen solution is to build a deep bypass. If everything runs to plan, Cleuson-Dixence will be brought back into service by the end of 2009.

The challenges **of hydropower**

Instant response to demand

The miracle is still there but no-one pays attention to it any more. No-one thinks about the technological prowess that enables a switch to be activated by just a click, so lighting a room or powering up a television set. Are consumers at all aware that power from the Fionnay and Nendaz plants is injected on the transmission grid at their demand?

In Switzerland, basic electricity is provided by nuclear energy, which covers 40% of the total consumption. Run-of-the-river power plants supply 25% of the requirements. Some conventional thermal power plants still account for 4 to 5%. The remainder, almost one third of consumption, is covered by stored energy plants (hydro). Clearly a much higher proportion than our neighbours, who are more reliant on nuclear and fossil energy.

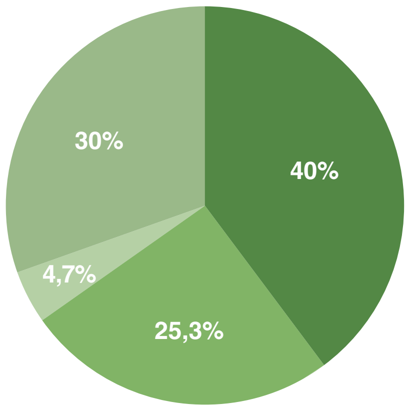
It was to cope with the increasing demand of consumers that dams like Grande Dixence were built. Although basic consumption is met by the electricity generated by nuclear and run-of-the-river power plants, the storage dams supply a reserve of energy that is delivered on demand.

The Grande Dixence version of the hydropower mission is therefore to cover consumption peaks. They occur in winter, mainly between January and March, and especially on weekdays between eight in the morning and eight in the evening, when there is the highest concentration of human activity. Maximum peaks are generally reached at mealtimes.

Because electricity cannot be stored, except in very small quantities, the hydropower plants play an essential role. They are the only generating plants capable of injecting considerable power into the grid within a few minutes. They are also the only plants able to hold in reserve the energy surpluses needed to meet a demand that varies from hour to hour, from day to day, from season to season.

The dams are the only "canned" variety of electricity. Production occurs only on demand, and there are no environmentally harmful emissions. This green energy is a security for future generations.

Electricity generation in Switzerland – 2004
Contribution of the different types of plants



- Nuclear power plants
- Hydropower plants (stored water)
- Run-of-the-river power plants
- Conventional thermal power plants

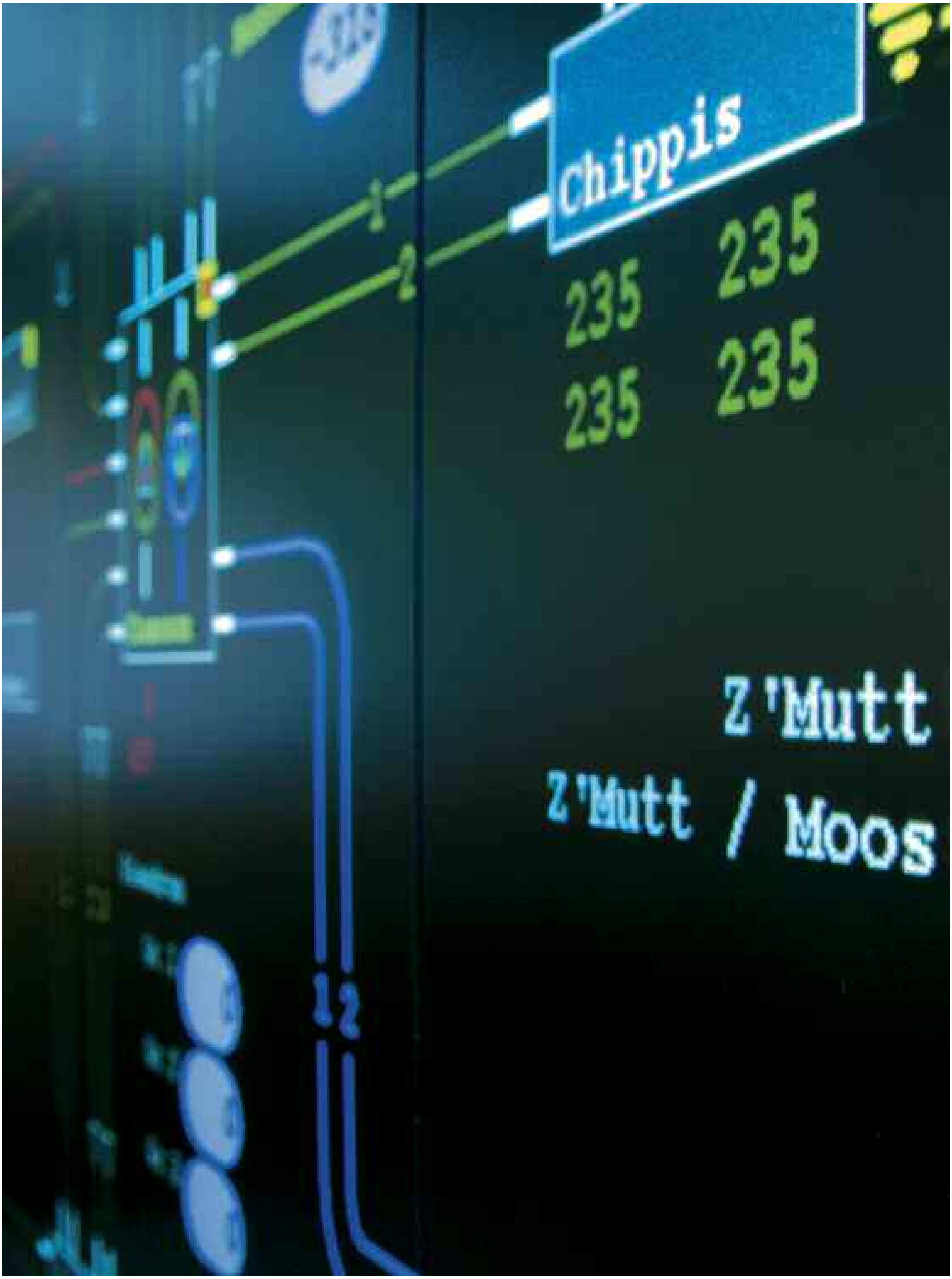
A sense **of balance**

The Dispatching Centre (CEG)

All those involved in supplying electric energy are very aware of one thing: their job is akin to that of a tightrope walker. Absolutely dependent on consumer demand and the whims of the weather, completely caught by production constraints and grid congestion, needing to pay attention to many other factors, energy suppliers and distributors must juggle with an essential rule, a basic axiom: at any one moment, the electricity generated must equal the electricity consumed. So every kWh must be produced at the precise moment it is consumed!

EOS (Energie Ouest Suisse) has been mandated by the shareholders of Grande Dixence to manage the energy flows produced by the Grande Dixence complex with a view to maintaining the flexibility of the scheme in the best possible way.

To enable it to perform its task properly, EOS has a Dispatching Centre (CEG or Centre d'Exploitation et de Gestion). From there, EOS manages and coordinates its electricity generating fleet in real time, in close cooperation with the Grande Dixence Water Management Centre at Sion. This control centre is the brain of the operation. It enables generation management, transmission operation, energy exchanges and the constant balancing of the electricity grid to be controlled 24 hours a day, 365 days a year.


Chippis
235
235
235
235
Z'Mutt
Z'Mutt / Moos

The CEG enables a large number of operations to be remotely controlled at all times. Its remit covers all aspects of the energy chain.

Generation: the CEG supervises and controls the power plants. The start-up, shutdown and loading of the generating units are remotely controlled from Lausanne.

Transmission: once generated, the electricity must be routed to the distributor or the consumer, via very high and high voltage networks. Operating, supervising and remotely controlling the network are key tasks. The management of the transmission network also implies an ability to respond instantaneously to the slightest incident (overload, overvoltage, activation of alarms, equipment alerts etc).

Control area: the CEG must ensure a balance at all times between what is produced or received over the grid and what customers need. Because electricity cannot be stored, this means checking that the quantity of energy produced always matches the quantity consumed.

Sales: each shareholder of Grande Dixence SA manages the commercialization of its share of the electricity generated by Grande Dixence. Using the tremendous asset constituted by the flexibility of the storage dams, it gives instructions each day about the use to be made of the generating stations, as a function of demand and the price of electricity.

Electricity prices vary enormously during the year. In general, they are lower in summer than in winter. They are highest during peak periods of consumption.

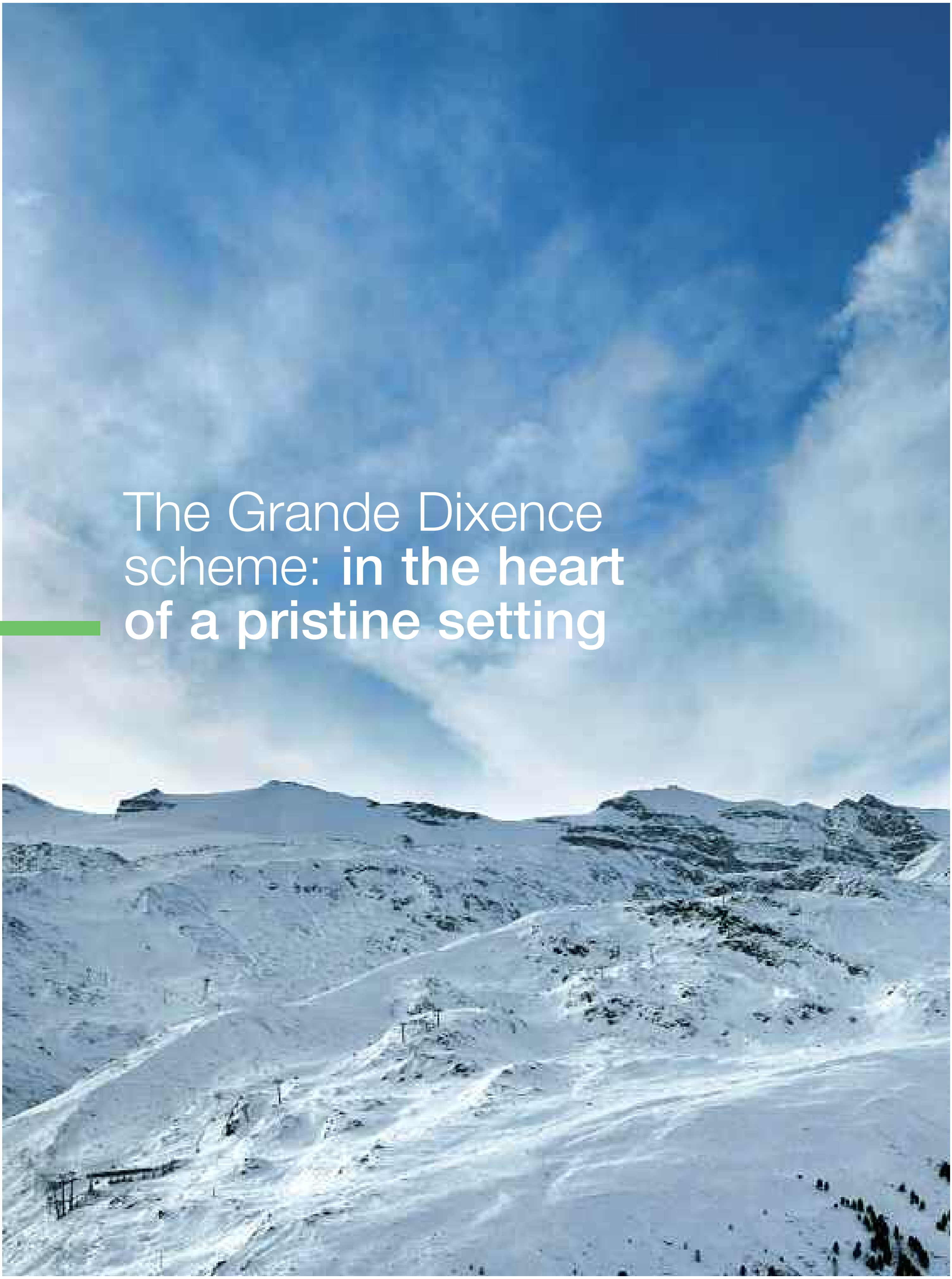
Many factors account for these fluctuations, mainly:

- Changes in primary energy prices (oil, gas, coal).
- Production costs of the latest power plants to be brought into service to meet demand.
- Meteorological conditions (very cold and very hot weather pushes prices up).
- Stored water reserves, which vary from year to year.

In the longer term, other factors will also influence electricity prices. Constantly rising demand and reducing reserve capacity everywhere in Europe will play a fundamental role, as will the increasing problems of congestion given the notable lack of cross-border transmission capacity. Other unknowns will also have an influence. How far will the markets open up in fact? Are we moving towards general liberalization or oligopolisation?

It can only be said that setting electricity prices has become a complex matter. Surviving in this uncertain world means being flexible. More than ever it is better to be a very good… tightrope walker.

The Grande Dixence scheme: **in the heart of a pristine setting**



The environment: **a constant concern**

The future belongs to white gold and green energy

What a paradox! Self-sufficient for so long, and even an exporter of electricity, Switzerland is poised to become a net importer of electricity.

Under these circumstances, with energy becoming rarer and fears about global warming, hydropower is more than ever a form of energy that should be given priority.

Those who initiated the Grande Dixence construction project were always aware of this. Could there ever be a finer source of environmentally-friendly energy! But apart from the fact that this is a clean and renewable source of electricity, the design engineers paid particular attention to the environment. In the 1950s, ecology may not yet have been a core concern, but those who built Grande Dixence were ahead of their time when it came to mountain conservation. Their constant endeavour was to preserve the natural environment, to blend completely into the grandiose Alpine setting. Water pipes, power plants, pumping stations, everything that could be hidden away beneath the surface, was buried. The earthworks were returned to their natural state.

Nonetheless, energy production, transmission and consumption are not neutral for the environment. Even if the energy comes from a renewable source, as hydropower does, with no release of greenhouse gases into the atmosphere, great care must be taken all along the chain of activity that leads from a drop of water to the electron that is supplied to the electric power socket. The design, realization and operation of structures and facilities are consequently the subject of detailed attention. Safety and respect for the environment, a major priority everywhere and at every moment, can thus be ensured.

Aware of the value of the environment, Grande Dixence has chosen to maintain and improve its generating equipment and structures in order to optimize the use of the natural resource. To that end, it has a number of committments, including:

- Respect for the legal requirements, and for the terms of the concessions and permits.
- Ensuring that operations are carried out in a way that limits as far as possible the impacts on water courses and their ecosystems (flushing operations, etc.) and preventing pollution.
- Minimizing the impact on the landscape caused by the carrying out of civil engineering works.
- Maintaining a constructive dialogue with partners, the public and communities affected by the facilities.
- Promoting cooperation with service providers and suppliers that have a concern for the environment.
- Constantly improving its environmental performance through action programmes.

As a result, an environmental management system was established in Grande Dixence SA in 2000. In 2001, the efforts were rewarded by ISO 14001 certification. Furthermore, the electricity produced by Grande Dixence has been awarded the TÜV EE 002 (April 2000) and naturemade basic (January 2002) energy quality labels.

In July 2003, the operation of the Grande Dixence SA hydropower generation facilities was entrusted to a new company, HYDRO Exploitation SA, founded a year earlier. This new company has made respect for the environment one of its priorities from the start. On 4 July 2004, it obtained triple certification for Quality, the Environment, and Health/Safety.

Grande Dixence SA **financial interests**

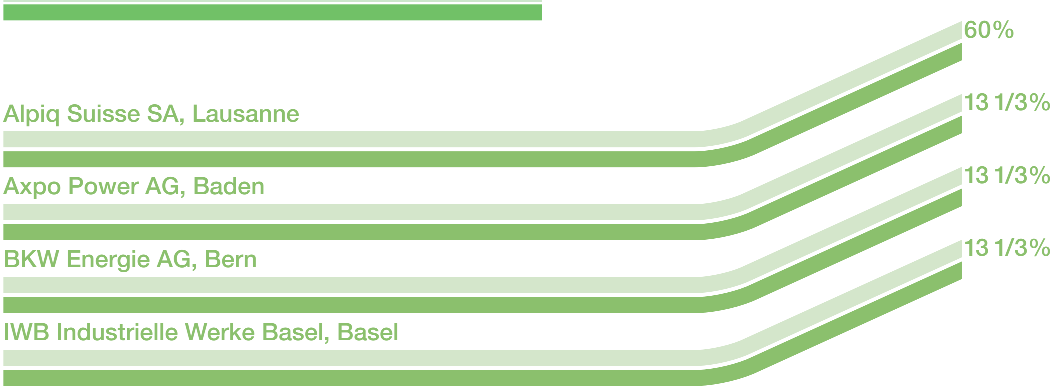
Elektrizitätswerk Zermatt AG (EWZ), industrial services for the municipality of Zermatt, with 45% of the share capital held since November 2001. This partnership has allowed EWZ and Grande Dixence SA to develop synergies to exploit and process the water in the Zermatt basin.

HYDRO Exploitation SA, created in June 2002 jointly by EOS Holding and FMV SA, to manage their installations. Grande Dixence SA holds 35% of the share capital. Established in 2003, HYDRO Exploitation SA was one of the first companies to focus entirely on the use of hydroelectric energy. Primarily designed for its shareholders, the company's services could also be offered to the owners of other hydraulic facilities in Valais or elsewhere.

Cleuson-Dixence, an ordinary partnership created jointly with EOS in 1992 to increase the capacity for electricity production. Grande Dixence SA's holding is 15/22.

Forces Motrices de la Borgne SA (FMdB), with 29% of the share capital since January 2009. FmdB owns the Bramois development, located downstream of the Grande Dixence installations, and uses the waters of the Borgne river. FmdB's other shareholders are the communes of Hérémence, St-Martin, Vex, Mont-Noble and Sion (51%) and the company FMV SA (20%).

Grande Dixence SA **shareholders**



UNITS OF ENERGY

1 kWh = 1 Kilowatthour = 3600 Kilojoules [kJ]

1 MWh = 1 Megawatthour = 1000 kWh = 3 600 000 Kilojoules [kJ]

1 GWh = 1 Gigawatthour = 1 million kWh = 3.6 Terajoules [TJ]

1 TWh = 1 Terawatthour = 1 billion kWh = 3600 Terajoules [TJ]

UNITS OF POWER

1 kW = 1 Kilowatt = 1000 Watts [W]

1 MW = 1 Megawatt = 1000 Kilowatts

UNIT OF VOLTAGE

1 kV = 1 Kilovolt = 1000 Volts [V]

TRANSFORMATION CAPACITY

1 kVA = 1 Kilovoltampere

1 MVA = 1 Megavoltampere

Graphic design and photos:	essencedesign
Médiathèque Valais-Martigny photos:	
Frank Gygli	6-7, 13, 14
Unknown	8
Grande Dixence	11, 15, 24
Henri Germond	12, 13, 17 (left), 23, 24-25
Charles Paris	16, 19, 20, 24 (bottom left)
Jacques Thévoz	17 (right)
Joseph Couchepin	18
Heinz Preisig	48
Text:	Jean Luqué / EOS – Grande Dixence

Further details from:
Grande Dixence SA, Sion

027 328 43 11

www.grande-dixence.ch