HYDRO POWER SCHEMES AND LARGE DAMS IN AUSTRIA

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Preface

For eight decades the construction of large dams and large river barrages in Austria has almost exclusively been undertaken by electricity supply companies, which at present produce approximately 70 per cent of the country's power requirements from hydro. It is only for the power stations on the Danube that the government pays a subsidy to construction costs as a compensation for the resulting improvement of navigation on this important trans-European waterway. The multi-purpose benefits from the large Alpine seasonal-storage schemes, including substantial improvement of flood control, are offered free of charge.

The 45th Executive Meeting of the International Commission on Large Dams, held in Salzburg in 1977, gave rise to the publication of a systematic description of all the Austrian dams in operation and under construction which are defined as "large" according to the I. C. O. L. D. criteria (116 in total in the World Register of Dams, Edition 1984).

A similar occasion is now afforded by the XVth World Congress of the International Commission on Large Dams to be held in Lausanne and by the subsequent Study Tours to Austria, the more so as Switzerland, Austria's neighbour in the Alps, is much alike in terms of economic importance and technical characteristics of hydro power. Advantage has been taken of this occasion to devote one number of this series of publications, normally dealing with large dams only, to a synoptic description of hydro development as a vehicle for large dam construction in Austria.

The first report will present a survey of the eleven largest seasonal storage schemes and their importance for Austria's electricity supply, describing their overall design concepts and main features, and will also deal with the environmental effects involved.

Whereas the seasonal storage schemes with their large heads, high dams and extensive diversion systems represent the prevailing type of development in high-lying Alpine valleys, development of the rivers is almost only by low-head run-of-river stations. To an increasing degree, the latter have come to form continuous series in developable river reaches, on the basis of master plans separately prepared for each river. These series of power stations on seven rivers will be the subject of the second report, with particular attention being given to the power stations on the Danube, which account for more than one-third of total hydro generation in Austria.

In developing Austria's hydro resources, Austrian engineers have been able to draw upon and apply the latest expert knowledge and experience available, thanks to the free exchange of opinion on a worldwide basis as is traditional to engineering and cultivated in such an outstanding manner by international organisations like I. C. O. L. D. On the other hand, however, they have also made their contribution towards hydro power engineering and have introduced a number of innovations in this field. This will be the subject of the third report.

The editors, the Austrian National Committee on Large Dams in conjunction with the Österreichische Staubeckenkommission and the Österreichische Wasserwirtschaftsverband, would like to express their thanks to the two authors, who, having devoted their lives' work to, and put their stamp on, the development of hydro power in Austria, are particularly competent to report on this subject.

Thanks are also due to many renowned firms within the Austrian construction industry which, inseparably linked with hydro power development and dam construction by the great engineering feats they have accomplished for many decades, have kindly made possible the publication of this Issue.

Dr. Wolfgang Pircher

Chairman
Austrian National Committee
on large Dams

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Austria's Seasonal Storage Schemes

(Power Schemes and Groups of Schemes of more than 80 MW Capacity)

By **H. Lauffer**
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This Report is an attempt to present a comparative survey of Austria's major seasonal storage schemes and to discuss their overall arrangements and main features, with due regard to environmental effects. Chapter headings will be as follows:

1. The Importance of Water Power for the Austrian Electricity Supply Industry
2. Hydro Development in Austria in General
3. Austria's Seasonal-Storage Schemes of more than 80 MW Capacity:
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   C Kaunertal Scheme Owned by TIWAG (see Table III)
   D Sellrain-Silz Power Scheme Owned by TIWAG (see Table III)
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Supplement: Tables I to X with power scheme data

1. The Importance of Water Power for the Austrian Electricity Supply Industry

Austria is fortunate in being able to satisfy the greater proportion of her generating requirements from her own hydro power, which, as an ever renewing source of energy, counts among Austria's most valuable resources. Figure 1 is a diagram showing electricity generation and consumption patterns since 1920. It is seen that, despite the abundance of development possibilities, it has never been possible to meet electricity requirements from hydro alone. Taking five-year means to neglect short-term fluctuations, the proportion of total annual generation accounted for by hydro reached its maximum of 80 per cent during the periods 1931 to 1935, 1936 to 1940 and 1946 to 1950. These are all periods during which consumption was low as a result of economic crisis or war. During the following decade 1951 to 1960, the share of hydro ranged around a constant value of 75 per cent, and then dropped to 62.5 per cent by the 1971—1975 period, because the development of hydro resources fell short of consumption growth. Ranging around 66 per cent in the period 1976 to 1980, the share of hydro has

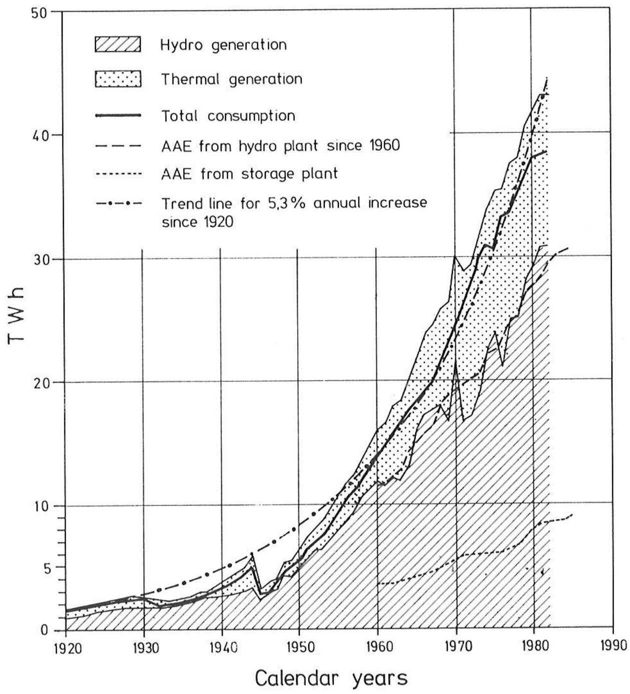


Fig. 1. Austria's electricity production and domestic consumption since 1920 as well as average annual energy (AAE) generated by hydro plant since 1960

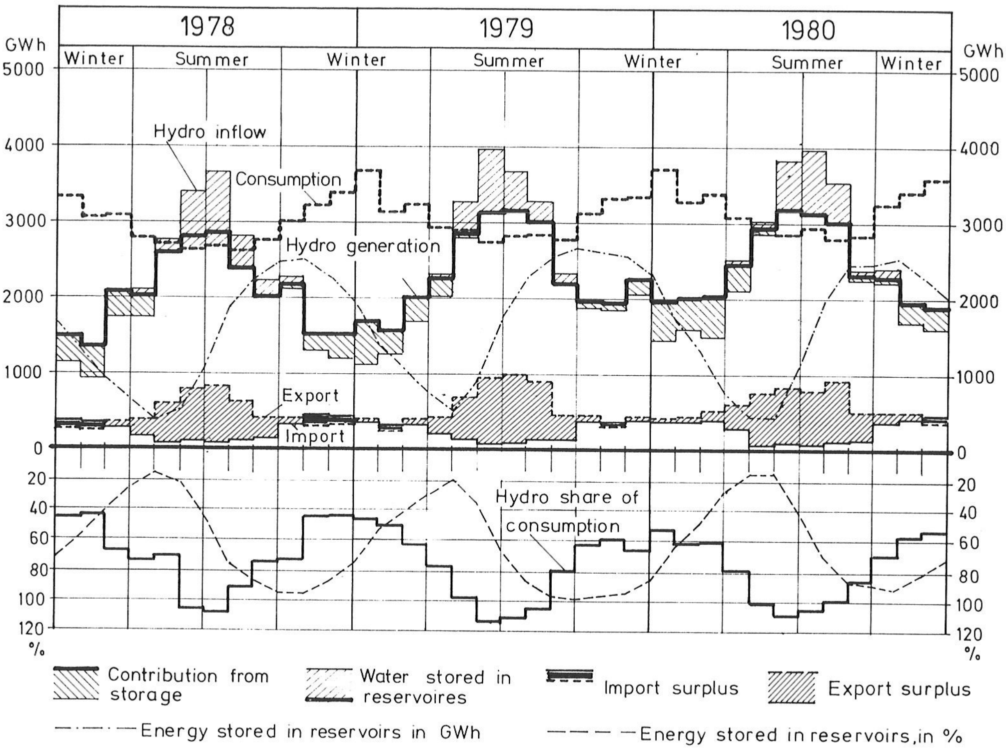


Fig. 2. Monthly electricity consumption, hydro generation and effects from reservoir storage in the years 1978, 1979 and 1980

since exhibited an upward trend, which however is partly a result of decreasing consumption growth rates. Since 1977, consumption growth has been substantially below the 5.3 per cent annual growth trend line, which up to then had corresponded in the long term to the development of consumption ever since 1920.

In 1983, hydro generation amounted to 30.6 TWh, which accounted for 72 per cent of a total generation of 42.6 TWh. With total consumption including losses being 39.1 TWh, one is tempted to conclude that 78 per cent of the total electricity requirements could have been met from hydro. However, apart from the large regional differences in generation and consumption patterns, simple comparison of annual values tends to be misleading, because the seasonal distributions of hydro generation and electricity consumption vary in opposite directions. This is clearly demonstrated by the monthly values of the years 1978 to 1980, shown plotted in Figure 2 along with the effects of reservoir storage.

Whereas in summer, hydro generation substantially exceeds electricity consumption, especially during wet years, winter generation may fall below 50 per cent of total consumption. Better compensation could be accomplished if a much larger storage capacity were available, as for instance in Switzerland, where favourable financing possibilities have rendered possible the provision of ample storage facilities. Thus, as can be seen from Figure 2, while there is a large export surplus during the summer months, exports and imports are practically equal in terms of kWh in winter, with imports even tending to exceed exports during periods of low flow.

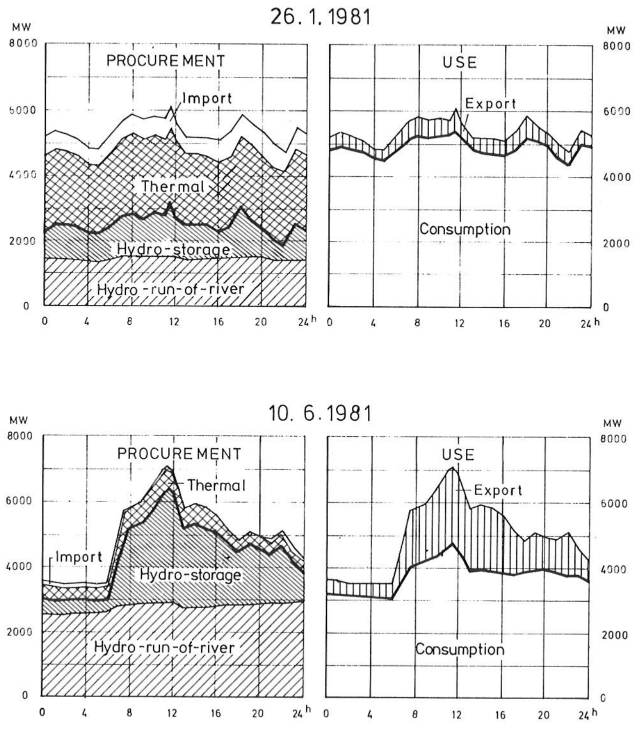


Fig. 3. Daily load curves of public electricity supply for January 26, 1981 (winter day) and June 10, 1981 (summer day)

[based on Federal System Control Centre: Statistics 1981]

Table 1. Developed and developable hydro potential in Austria, 1982
(based on A. Götz and G. Schiller, ÖZE, 35. Jg., October 1982)

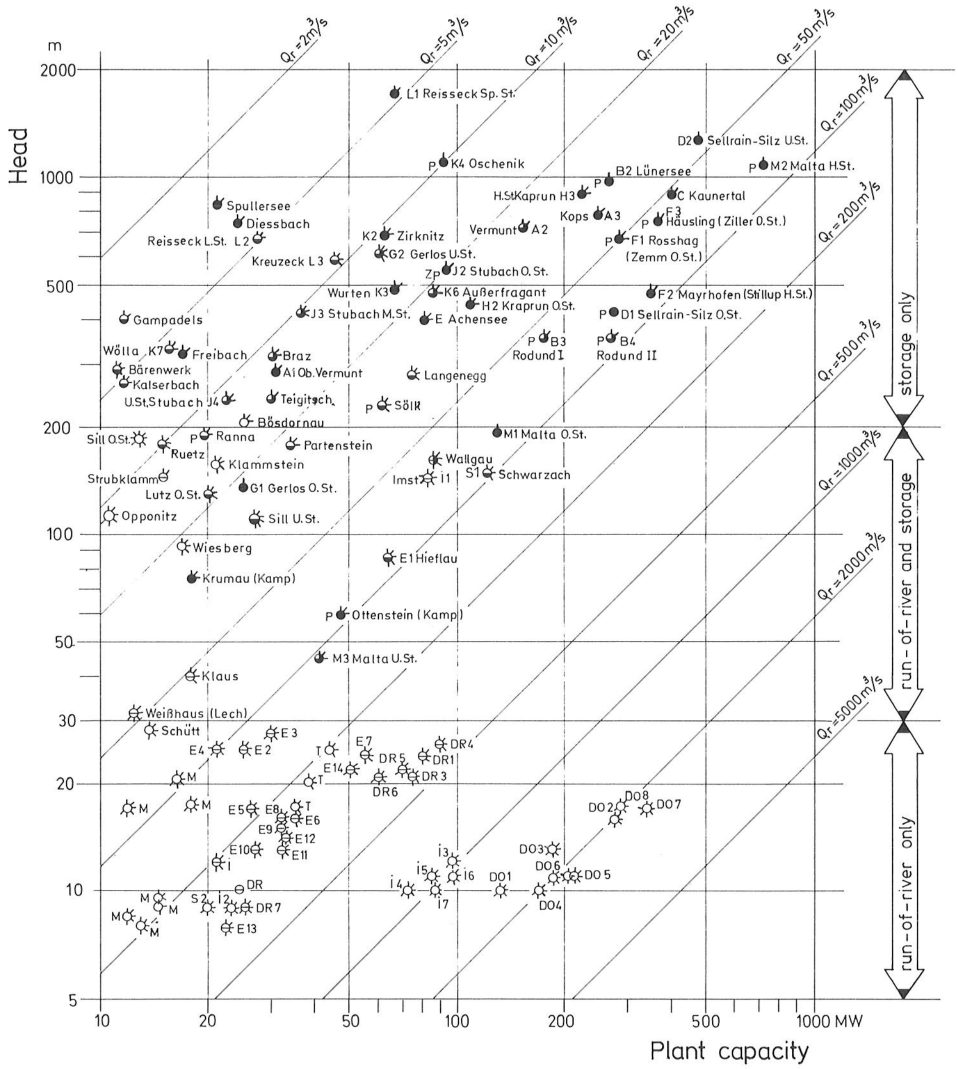
	Average annual energy production in TWh (developed percentage of the respective total potential)		
	Run-of-river plant	Storage plant	Total
In operation	19.37 (52.2%)	8.68 (52.5%)	28.05 (52.3%)
Under construction	3.53 (9.5%)	0.66 (4.0%)	4.19 (7.7%)
Balance of development possibilities	14.26 (38.3%)	7.20 (43.5%)	21.46 (40.0%)
Total potential	37.16 (100.0%)	16.54 (100.0%)	53.70 (100.0%)

The daily load curves for a summer day and a winter day, shown in Figure 3, demonstrate even more clearly the decrease in hydro generation along with a rising total consumption during the winter months. This increased demand must be met from increased thermal generation and imports. The balancing effect of storage schemes on load changes is clearly seen. What cannot be inferred from this diagram is the storage schemes' function as a reserve in the case of transmission or generation failures, in particular those of the much more vulnerable thermal plant, as well as in the case of sudden load fluctuations as may be caused for instance by radio and TV.
The energy supplied by the electricity generating companies is a service rather than an article that can be kept in stock, because every consumer is served at the instand of his cutting in. In order to ensure a reliable supply it is necessary that—apart from sufficient transmission capacity—generating capacity suited for immediate start-up be available. This requirement is best met by storage schemes.
Recent studies have estimated the developable hydro potential at 53.7 TWh in total (Table 1), of which 69 per cent accounts for run-of-river plant and 31 per cent, for storage plant including daily and weekly storage. Whereas by 1982 the developed share of total developable potential was nearly equal for run-of-river plant and storage plant, i. e. 52.2 per cent and 52.5 per cent, respectively, construction of storage schemes will continue at a lower rate than that of run-of-river schemes in the years to come. That means that the winter shortage of hydro, due to reduced inflows, will increasingly have to be made up for by thermal generation or imports.

2. Hydro Development in Austria in General

Figure 4 is a diagram showing Austria's hydro schemes of more than 10 MW capacity plotted against plant capacity and head as well as rated discharge. Symbols indicate mode of operation and approximate equivalent utilisation period at maximum output capacity as an indication of energy generated p. a.
Run-of-river stations, which lack the possibility of regulation, are used for generating base load. They exhibit large equivalent utilisation periods, ranging from 4000 to 6000 h p. a. In contrast, most of the storage schemes have equivalent utilisation periods of between 500 h and 2000 h. Thus, a 100 MW-capacity power station will generate an annual energy of 400 GWh to 600 GWh if it is of the run-of-river type, and only 50 GWh to 200 GWh if it is a storage station.
Heads less than 30 m are found only in run-of-river schemes in Austria, whereas heads greater than 200 m to a maximum of about 1800 m (Reisseck storage scheme) are found only in storage schemes. This latter head range comprises rated discharges of between 5 m^3/s and 100 m^3/s, which is evidence of the great differences among the storage schemes. Until some 40 years ago, the head ranges shown in the diagram used to correspond approximately to the preferred applications of the three turbine types, i. e. Kaplan turbines for low heads, Francis turbines for medium heads and Pelton turbines for high heads. But meanwhile these applications have all moved up the head scale. Examples of this are the St. Martin station of the Teigitsch scheme, where Kaplan turbines work under a head of 75 m, and the Häusling power station on the Ziller, now under construction, where Francis turbines will be used for a head of 740 m, whereas unregulated multi-stage pump turbines have recently come to be used for the top head ranges.
In terms of hydrology, Austrian streams exhibit substantial differences. Shown plotted on Figure 5, for comparison, are examples of annual curve of specific run-off. The upper row refers to streams harnessed by storage schemes, the lower one, to typical streams in run-of-river development. Apart from the Kamp river, all the examples shown in the upper row belong in the region of the Central Alps, where run-off is characterised by a very small winter proportion, reaching not more than 8 per cent to 14 per cent of the annual volume of flow. This decreases with increasing glaciation, because run-off from glaciers is practically zero in winter. In such cases, a reservoir storage equal to 30 per cent or 40 per cent of the annual volume of flow is required for full compensation.
Figure 6 presents the existing Austrian storage reservoirs arranged in order of active storage and top water level in terms of metres above sea-level. Stored energy reserves are shown related to a uniform altitude of 200 m above sea-level. Kölnbrein ranks highest by far in terms of active storage and energy reserve and is followed by Gepatsch and Schlegeis. Three preferred ranges of altitude may be distinguished:

1. An upper range situated between 2200 m and 2500 m a. s. l.:
   Mainly impounded cirque lakes, used for seasonal



● with annual storage — ● short-term storage with remote annual storage — Equivalent utilisation period at max. output:

● with short-term storage — P with pumped storage — ZP with feeder pumping station — ○ to 500 h — to 3000 h — to 6000 h

⊖ run-of-river with pondage — to 1000 h — to 4000 h — to 7000 h

○ run-of-river without pondage — to 2000 h — to 5000 h

DO = Danube DR = Drau; E = Enns; I = Inn; M = Mur, T = Traun

Fig. 4. Heads and capacities of Austria's hydro schemes with indication of mode of operation and equivalent utilisation period at maximum output capacity

storage. Most of them need pumping for filling because natural catchment areas are too small.

2. A medium range extending from 1650 m to 2050 m a. s. l.:
   Wide high-lying valleys of glacial origin. Most of the large seasonal storage reservoirs are situated at such sites.

3. A lower range between 400 m and 1100 m a. s. l.:
   Impounding possibilities mainly situated in the foothills of the Alps and in the Calcareous Alps, and natural lakes utilised by means of water level drawdown. These include the small number of developed gorges on streams, as for instance the Klaus reservoir on the Steyr and the Ottenstein and Dobra reservoirs on the Kamp. Klaus and Ottenstein are the only true dam power stations in Austria, with the power plant directly below an arch dam, whereas all the other reservoirs discharge to diversion-type power stations.

The reservoirs of the two higher ranges of altitude, accounting for the greater part of the total storage capacity available in Austria, are all situated in Western Austria (Fig. 41), with the Tauern motorway forming an approximate boundary. The tributary valleys in the partly glaciated Central Alps obviously afford the best conditions for seasonal storage. Among the eleven power schemes and groups of schemes of more than 80 MW capacity, discussed in greater detail in the following chapter, the Lünersee reservoir (belonging in B2) and the whole Achensee scheme (E) are the only ones not to be situated in the Central Alps, but in the adjoining Northern Calcareous Alps.

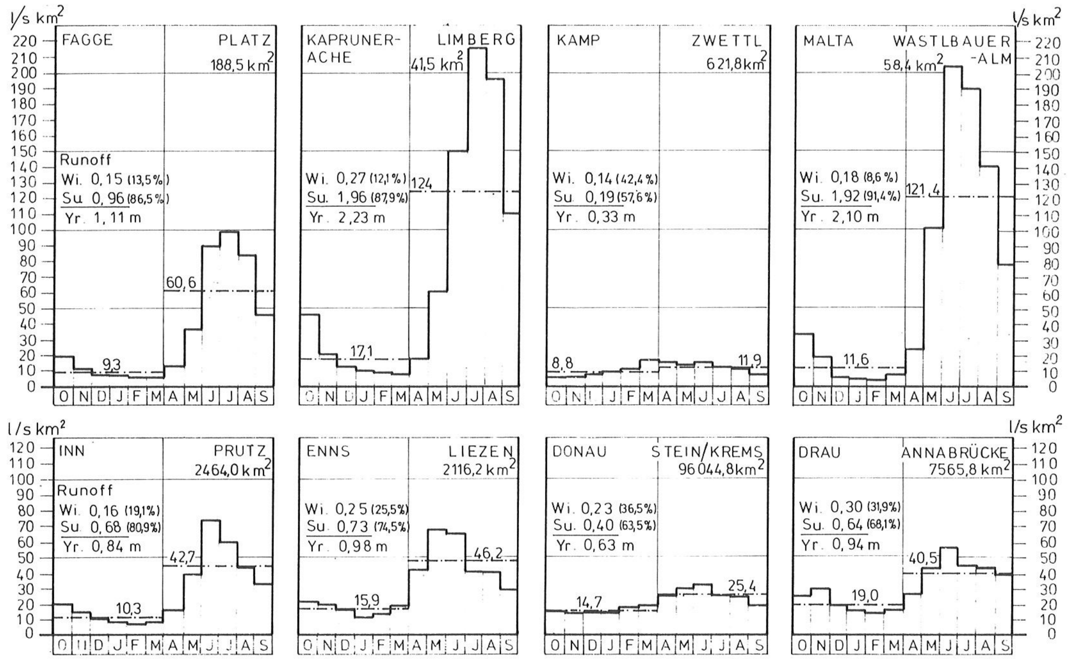


Fig. 5. Examples of annual hydrograph of specific runoff, in terms of 1/s × km², for Austrian streams and rivers

The great distance of this region from the population and load centres in the Linz – Vienna – Graz area and the fact that most of Austria's run-of-river stations and in particular all the river stretches developed by continuous chains of power schemes as well as all the thermal power stations are situated east of the above boundary line have led to entirely different developments in the East and West of Austria. This applies to an even larger degree to the provinces of Vorarlberg and Tyrol.

This is also demonstrated by Table 2, comparing consumption with generation from hydro and thermal power and the balance of power interchanges with foreign countries, in the individual groups of provincial supply areas and Vienna. To accentuate the substantial seasonal differences, primarily between the consumption and hydro generation patterns, this table is based on the relatively wet Hydrological Year 1980/81, rather than a calendar year. Percentages in brackets behind con-

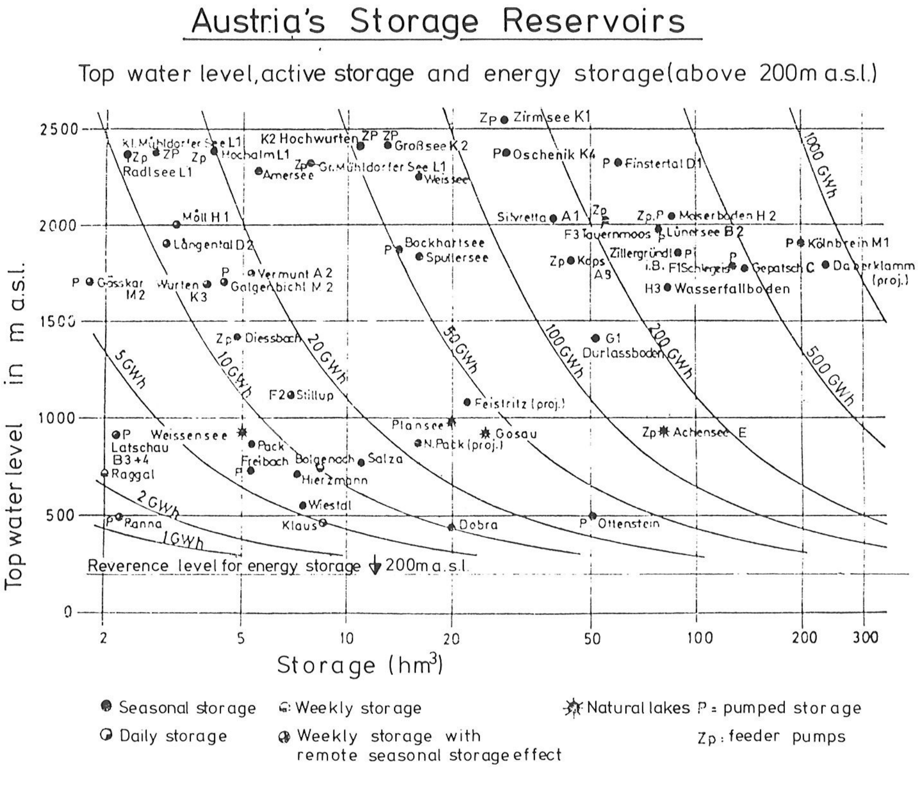


Fig. 6. Top water level, active storage and energy storage of the Austrian reservoirs

Table 2. Electricity consumption and generation (not including ÖBB) in provincial supply areas in the hydrological year 1980/81 (Wi = winter half-year 1980/81, Su = summer half-year 1981)

Provincial supply area[1]		Consumption incl. losses		Generation (perc. of consumption)						Balance of interchanges with foreign countries (export ·/. import)
				hydro		thermal		total		
		GWh	(% of h.yr.)	GWh	(% of C.)	GWh	(% of C.)	GWh	(% of C.)	GWh
1. Vienna	Wi	3803	(56.8)	52	(1.4)	2509	(65.9)	2561	(67.3)	—
	Su	2898	(43.2)	49	(1.7)	1481	(51.1)	1530	(52.8)	—
	H. yr.	6701	(100.0)	101	(1.5)	3990	(59.6)	4091	(61.1)	—
2. Niederösterreich, Burgenland, Oberösterreich, Steiermark	Wi	10467	(54.3)	6821	(65.2)	5415	(51.7)	12236	(116.9)	− 981
	Su	8805	(45.7)	8692	(98.7)	2173	(24.6)	10865	(123.4)	+ 1173
	H. yr.	19272	(100.0)	15513	(80.5)	7588	(39.4)	23101	(119.9)	+ 192
3. Kärnten, Salzburg	Wi	2906	(51.6)	2758	(94.9)	759	(26.1)	3517	(121.0)	+ 97
	Su	2724	(48.4)	3444	(126.4)	396	(14,5)	3840	(140.9)	+ 155
	H. yr.	5630	(100.0)	6202	(110.2)	1155	(20.5)	7357	(130.7)	+ 252
4. Tirol, Vorarlberg	Wi	2617	(52.3)	2113	(80.8)	23	(0.8)	2136	(81.6)	+ 1073
	Su	2384	(47.7)	4601	(193.0)	12	(0.5)	4613	(193.5)	+ 2625
	H. yr.	5001	(100.0)	6714	(134.3)	35	(0.7)	6749	(135.0)	+ 3698
5. Austria	Wi	19792	(54.1)	11744	(59.3)	8706	(43.9)	20450	(103.3)	+ 189
	Su	16811	(45.9)	16786	(99.9)	4062	(24.1)	20848	(124.0)	+ 3953
	H. yr.	36603	(100.0)	28530	(77.9)	12768	(34.9)	41298	(112.8)	+ 4142

[1] Boundaries of provincial supply areas do not coincide with provincial boundaries.

sumption values are related to the respective annual totals to make evident consumption variations. Generation percentages in brackets are related to consumption levels in the respective periods to indicate the proportions contributed by hydro and thermal for satisfying regional electricity requirements.
Vienna has always met the greater part of her demand from thermal generation, which accounts for more than 50 per cent of the total consumption even in summer. As to the other groups, there is a continuous increase in hydro from east to west along with a decrease in thermal generation to near zero in Group 4 (Tirol and Vorarlberg). It is only in Group 3 (Kärnten and Salzburg) that hydro production during the winter half-year approaches the consumption level, whereas Group 4 suffers from a severe shortage, mainly of midwinter base load, which must be met by transfers from other provincial supply areas, and from abroad in exchange for peak power from seasonal storage schemes.
As can be seen from the last column of Table 2, electricity interchanges with foreign countries in the period considered are practically balanced during the winter half-year. The export surplus is limited to the summer half-year. If periods of low flow (dry year) had occurred in 1980/81, assuming the same consumption level, there would have been a substantial import surplus in winter and a much smaller export surplus in summer, as it actually happened in subsequent years.

3. Austria's Seasonal Storage Schemes of more than 80 MW Capacity

The following description of existing schemes includes new plant and plant extensions under construction, but no planned projects. The 80 MW limit encompasses all major seasonal storage schemes, which account for about 95 per cent of total storage plant capacity and for about 97 per cent of total stored energy in Austria. The plant capacity of the daily and weekly storage schemes, not treated in this report, accounts for not more than 10 per cent of the seasonal storage schemes.
Description of the schemes (symbolised by A to M for convenience) will in each case start with a list of main reservoirs and power stages (symbolised by A1, A2, etc.) with the following indications and abbreviations:

Reservoir:
Top water level in terms of metres above sea-level.
Active storage in terms of hecto cubic metres ($1\ hm^3 = 10^6\ m^3$).
Power stage:

- Q_r rated discharge in terms of cubic metres per second,
- max H_{gr} maximum gross head, in terms of metres,
- AAE average annual generation in terms of gigawatt-hours ($1\ GWh = 10^6\ kWh$),
- T maximum plant capacity in the generating mode, in terms of megawatts ($1\ MW = 10^3\ kW$),

P — maximum power take in the pumping mode, in terms of megawatts (1 MW = 10^3 kW),

wi. share — winter share of AAE, in per cent of AAE,

full-load-h — equivalent utilisation period at maximum output capacity (AAE/T), in terms of hours,

PE — annual pumping power requirements, in terms of gigawatt-hours (1 GWh = 10^6 kWh).

Values without short-term pumping include average seasonal pumping that may be necessary to fill the reservoir, whereas values in brackets with short-term pumping include pumped storage operation superimposed on seasonal pumping.

To avoid a detailed description of the individual plant features, main plant data have been summarised in tabular form (see Tables I to X in the Supplement). Each Table covers two pages. Part 1 lists catchments utilised, reservoirs with dams as well as diversions to reservoirs and diversions discharging into power conduits. The lines reserved for feeder pumping stations may also contain minor intermediate power stations. Part 2 gives power stage data (power conduit and station) and generating data.

The great variety of plant features characterising Austria's power schemes has in some cases not allowed other than summary data to be presented, and departures from the uniform concept of the tables have been necessary. Hydrological and geological data, although important, have been omitted for lack of space.

The individual power companies and the Austrian Federal Railways (ÖBB) have been kind enough to make available, or check, the drawings, photographs and data presented in this report.

A + B: Upper Ill-Lünersee Group of Power Schemes
(Vorarlberger Illwerke AG, Bregenz)

Symbol / Initial operation in year	**Reservoir** Name / T.W.L./Active storage (m a.s.l. / hm³)	**Power stage** Name / Q_r/max H_{gr} (m³/s / m)	**Capacity** T / (P) MW	**AAE** GWh	Wi. share/full-load-h without short-term pumping (values in brackets with short-term pumping) % / h	**PE** GWh
A1	Silvretta	Obervermunt	31	45	58 / 1450	—
1950	2030 / 38.6	14 / 311	(—)	—	no short-term pumping	—
A2	Vermunt	Vermunt	148	260	37 / 1760	—
1930/53	1743 / 5.3	26 / 727	(—)	—	no short-term pumping	—
A3	Kops	Kops	245	392	34 / 1600	9
1969	1809 / 43.5	38 / 780	(—)	—	no short-term pumping	—
A4	Rifa compens. res.	Rifa	9	—	only short-term pumping	—
1969	1000 / 0.7	30 / 37	(9)	(8)	50 / 1000	(13)
A	Upper Ill group	without short-term pumping	433	697	37 / 1610	9
		(with short-term pumping)	(9)	(705)	(37 / 1630)	(22)
B1	Partennen compens. res.	Latschau	8	22	34 / 2750	—
1950	1024.7 / 0.1	44 / 28	(—)	—	no short-term pumping	—
B2	Lünersee	Lünersee	230	170	100 / 740	220
1958	1970 / 78.3	32 / 975	(220)	(371)	(78,5 / 1615)	(541)
B3	Latschau	Rodund I	173	212	41 / 1220	—
1943/52	992.25 / 2.3	60 / 364	(40)	(332)	(52 / 1920)	(58)
B4	(Latschau)	Rodund II	270	311	41 / 1150	—
1976		90 / 364	(286)	(486)	(52 / 1800)	(359)
B	Lünersee-Rodund group	without short-term pumping	681	715	55 / 1050	220
		(with short-term pumping)	(546)	(1211)	(62 / 1780)	(958)
A+B	Upper Ill-Lünersee group	without short-term pumping	1114	1412	46 / 1270	229
		(with short-term pumping)	(555)	(1916)	(53 / 1720)	(980)

As suggested by the location map and schematic section (Figs. 7 and 8), this development consists in fact of two power schemes connected by a conduit, 18.7 km long and mainly of the free-surface flow type, leading from Partennen to Latschau. Scheme A, Upper Ill (Table I), without pumped storage, includes two large seasonal storage reservoirs. The Silvretta reservoir (Fig. 9), situated at a higher elevation, is filled by natural inflow and a single diversion, which supplies flow from the Biel valley. The much smaller Vermunt reservoir is fed by several diverted tributary streams. The Kops reservoir (Fig. 46) is fed by long-distance diversions from the Paznaun valley (Trisanna stream) in Tyrol and from the upper course of the Rosanna. 90 per cent of the total reservoir inflow at Kops, and 10 per cent of the total inflow at Silvretta, come from the Inn basin, which causes an annual volume of 226 hm³, i. e. 56 per cent of the power water discharged from the Vermunt and Kops stations, to flow to the North Sea instead of the Black Sea.

Stored water released from the Silvretta reservoir is utilised in two high-head stages, and that from the Kops reservoir, in a single stage (Fig. 58), both ending in a

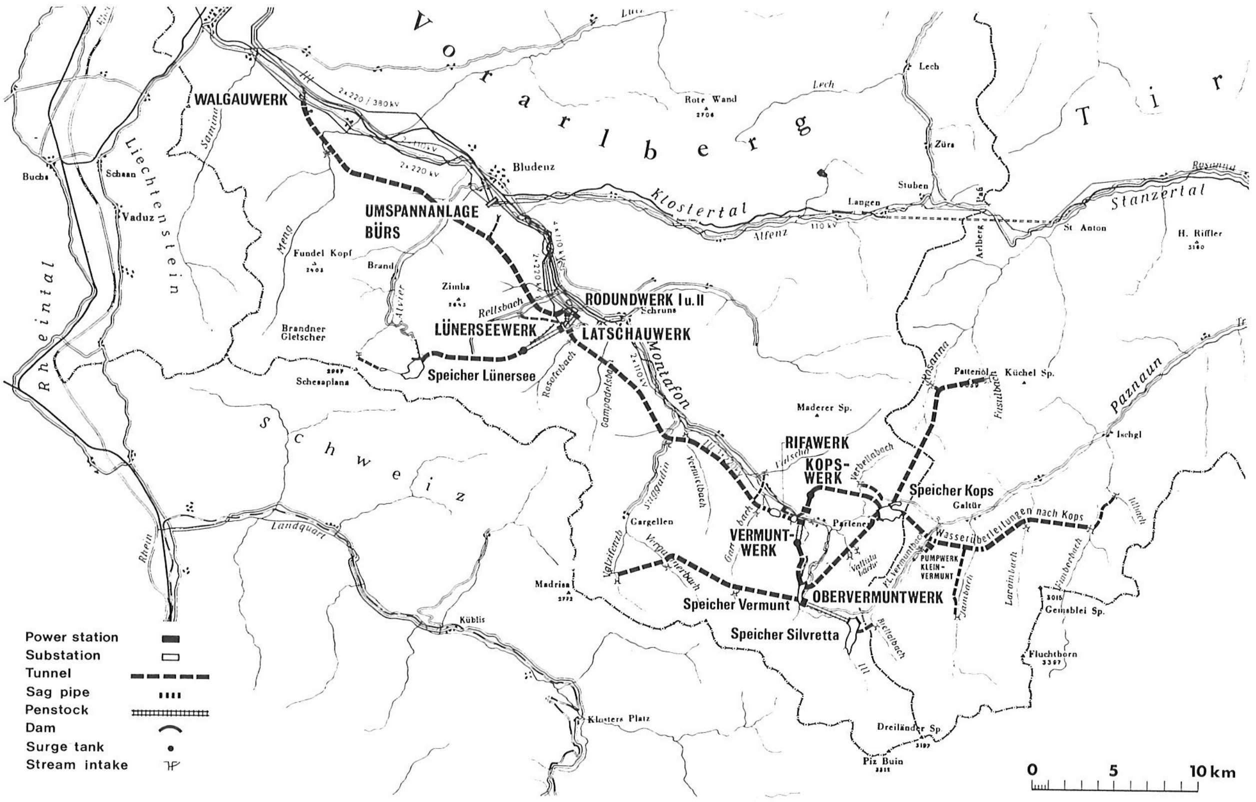


Fig. 7. Location map of VIW-owned Upper Ill-Lünersee group of power schemes (A+B)

common compensation reservoir at Partennen. This is connected to the Rifa compensating basin situated immediately downstream via a low-head pumped storage plant, which enables flow to be controlled to suit the limited transport capacity of the conduit towards Latschau, which in turn receives additional flows from a second water intake in the Ill and from its tributaries.

Scheme B, Lünersee-Rodund (Table II), is situated further downstream. Lake Lünersee acts as a high-level seasonal storage reservoir (Fig. 45) and is capable of storing 225 GWh of energy. Apart from a great amount of sealing works, construction of this reservoir required not more than 41 000 m³ of concrete. 83 per cent of the total reservoir capacity must be filled by pumping. For this purpose, the Lünersee power station, situated next to the Latschau reservoir, and the parallel Rodund I and

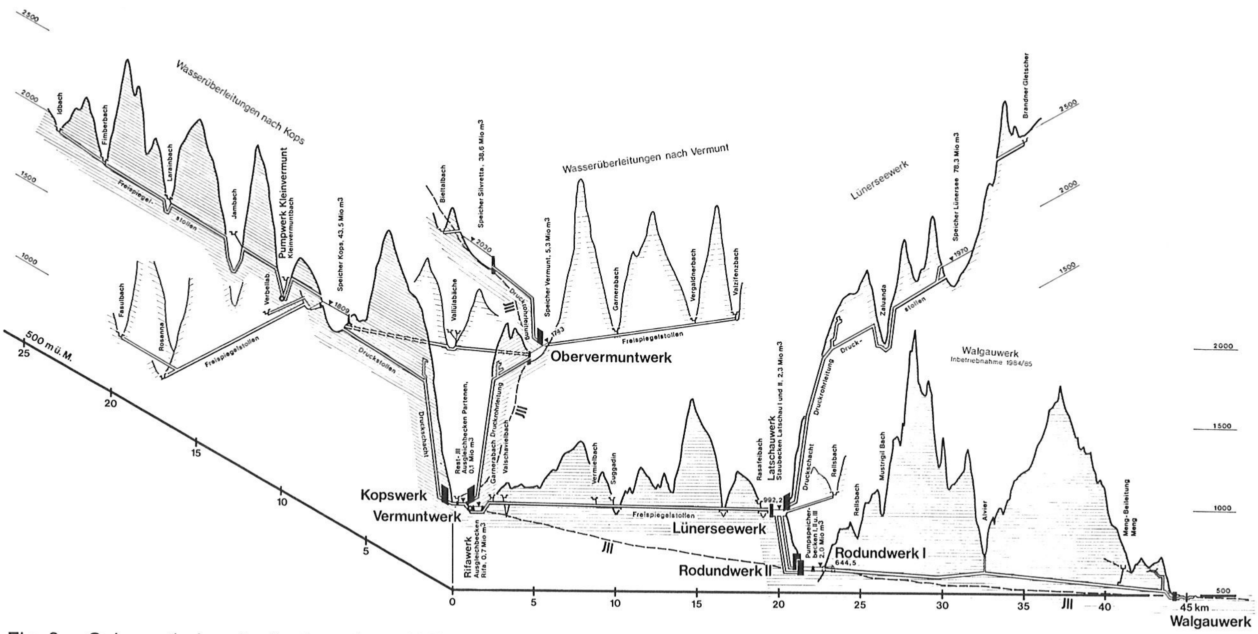


Fig. 8. Schematic longitudinal section of VIW-owned Upper Ill-Lünersee group of power schemes (A+B)

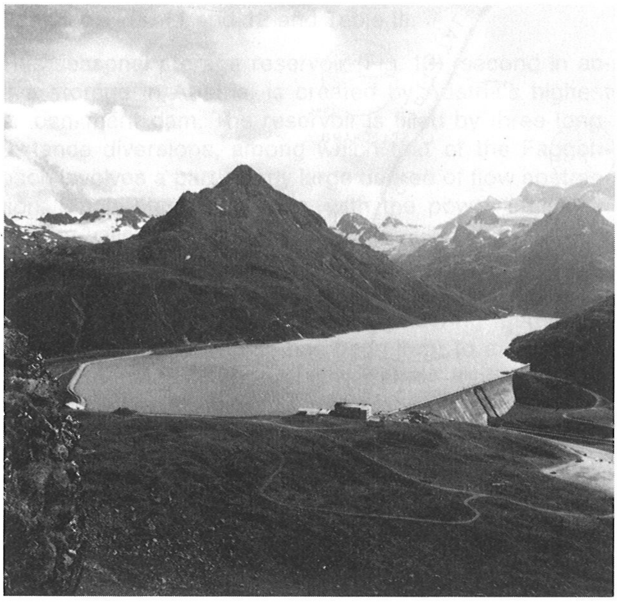


Fig. 9. Silvretta reservoir (A1) with Silvretta gravity dam and Biel embankment dam

Ill stations following downstream (Fig. 10) have been equipped for pumped storage operation. With a pumping head of about 1 000 m from Latschau and a total head on turbines of approximately 1 300 m at Rodund, seasonal pumping to the Lünersee reservoir involves relatively high pumping power requirements. This may affect seasonal storage operation during periods of pumping power shortage.

Downstream of the existing Rodund lower reservoirs, a further power project, Walgau, with a 21 km-long power tunnel, was commissioned in 1985. Utilising once more the flows of the Ill and the diverted flows of the Meng stream, this station will have an output capacity of 86 MW and generate 356 GWh p. a. under a gross head of 165 m. The winter generating proportion will be 38 per cent. As a medium-load station, it will not be included in the data given in this report.

Construction of the Upper Ill-Lünersee power schemes was started with the Vermunt scheme (of 80 MW capacity in a first phase) in 1925. The present state—with a capacity 14 times as large—was reached with the commissioning of Rodung II[1] in 1975. Consistent pursuance of a basic project idea combined with constant adaptations to answer requirements as they emerged, over a construction period of 50 years with some interruptions, has helped to maintain the uniformity of the main concept.

Adverse environmental effects from the construction of the four large reservoirs, eight power stations and more than twenty stream intakes have been very small indeed owing to a careful embedding of the structures into the terrain and an exemplary conservation of the landscape in the areas concerned. On the other hand, the impetus coming from power project construction has made an important contribution to the Montafon region's economic development, and the new traffic routes, as for instance the Silvretta Alpine Highway, as well as several cableways and lifts have brought lasting benefits to tourist trade, in spite of the long construction periods (Fig. 42).

Fig. 10. Penstock and powerhouse of Lünersee scheme (B2), Latschau compensation reservoir with Rodund I (B3) and Rodund II (B4) and the respective lower reservoirs

[1] The 270 MW-capacity pump turbine at Rodund is the most powerful hydraulic machine in Austria.

C: Kaunertal Scheme
(Tiroler Wasserkraftwerke AG, Innsbruck)

Symbol / Initial operation in year	Reservoir Name / T.W.L./Active storage (m a.s.l. / hm³)	Power stage Name / Q_r/max H_{gr} (m³/s / m)	Capacity T / (P) MW	AAE GWh	Wi. share/full-load-h without short-term pumping (values in brackets with short-term pumping) % / h	PE GWh
C / 1964	Gepatsch / 1767 / 138	Kaunertal / 53 / 895	390 / (—)	620 / (—)	59 / 1520 / no short-term pumping	— / —

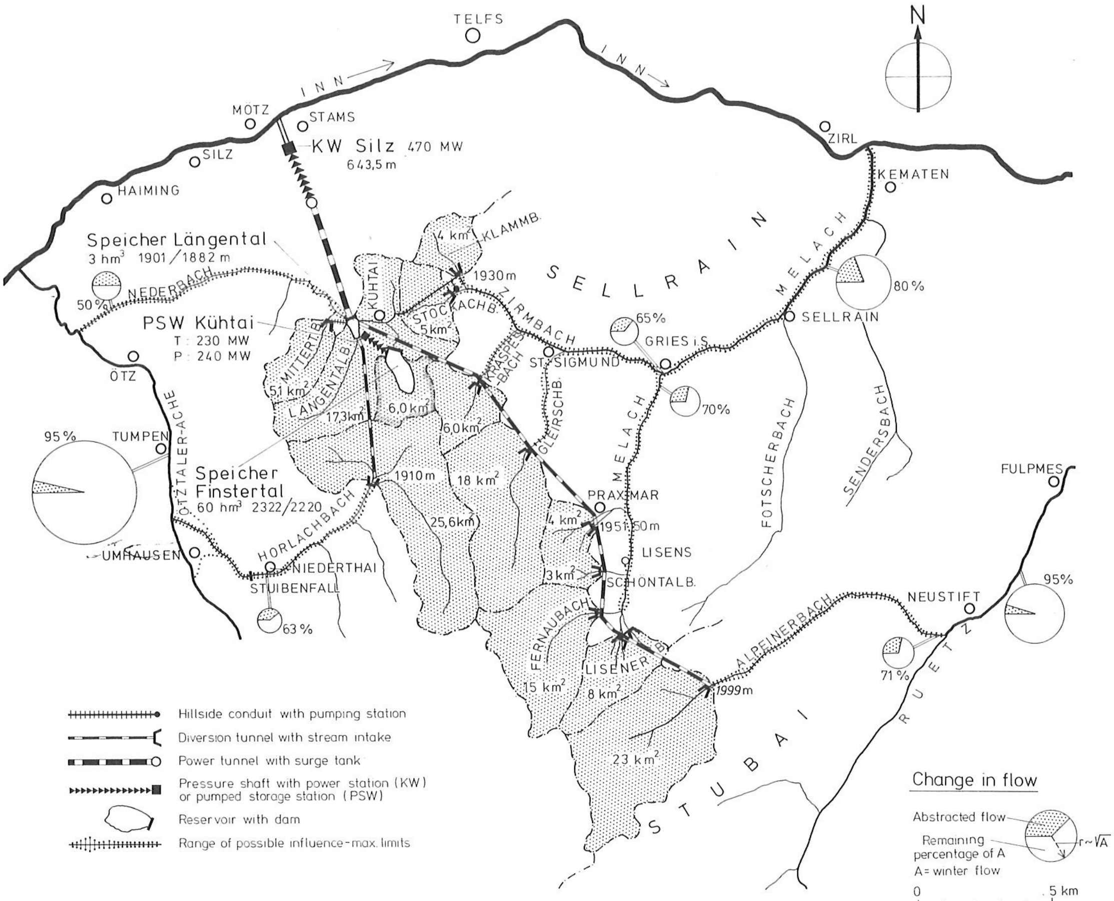


Fig. 14. Location map of TIWAG-owned Sellrain-Silz scheme (D)

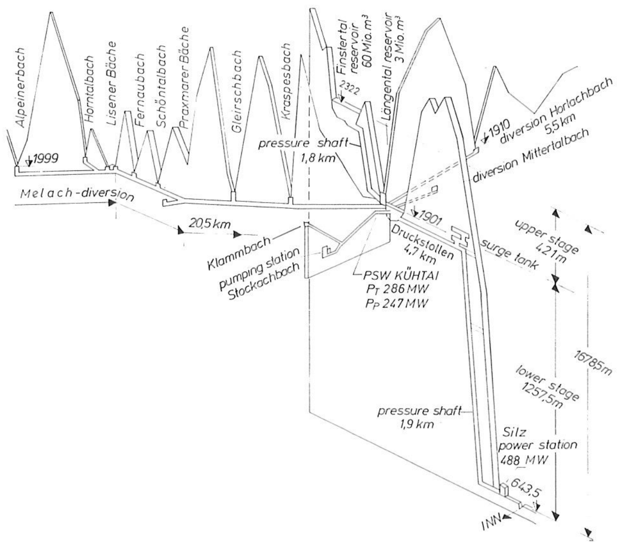
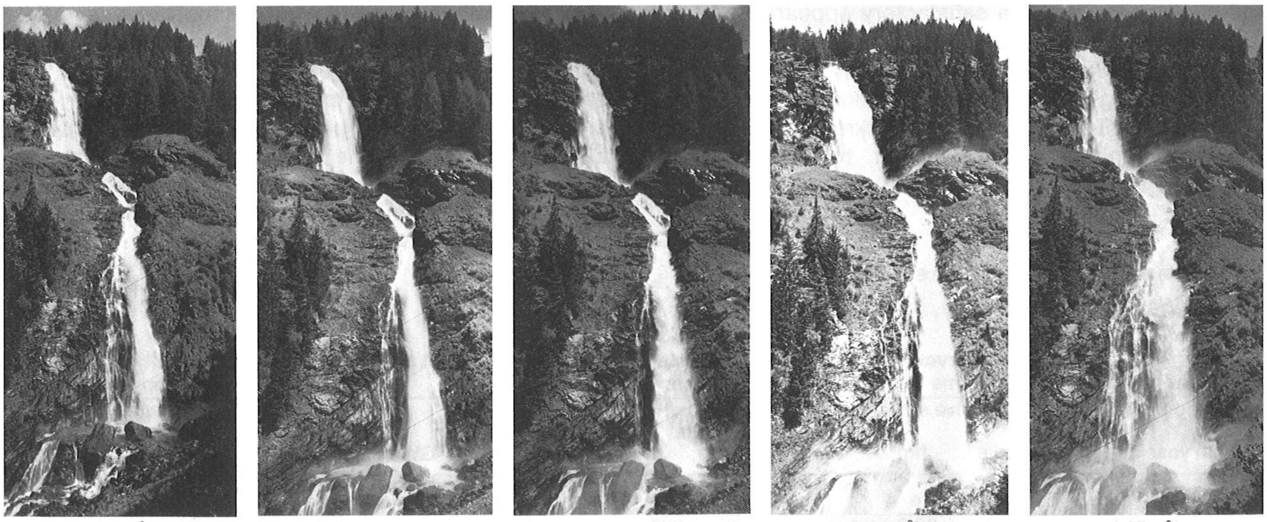


Fig. 15. Schematic longitudinal section of TIWAG-owned Sellrain-Silz scheme (D)

Fig. 16. Finstertal reservoir and rockfill dam (D1) as well as Längental reservoir and embankment dam (D2) with Kühtai power station (D1)



1,43 m³/s — 1,85 m³/s — 2,25 m³/s — 3,30 m³/s — 4,35 m³/s

Fig. 17. The Stuiben Falls of the Horlach stream, which is affected by the Sellrain-Silz group (D); viewed at different rates or flow

This plan was finally abandoned, because it was realised that the ratio of pumping head to total gross head on turbines, i. e. approximately 1100 m to 1600 m or 1700 m, was too unfavourable to warrant implementation. The Sellrain-Silz scheme in its present form in no way prejudices development possibilities in the Ötz valley.

Serious opposition was encountered only in regard of the Stuiben Falls near Umhausen, which are affected by the Horlach stream diversion. The compromise which was finally adopted consisted in fixing, on the basis of detailed photographic documentation, of which Fig. 17 shows a selection, minimum flows (2 m³/s in summer, 1.5 m³/s in spring and autumn) to be maintained during

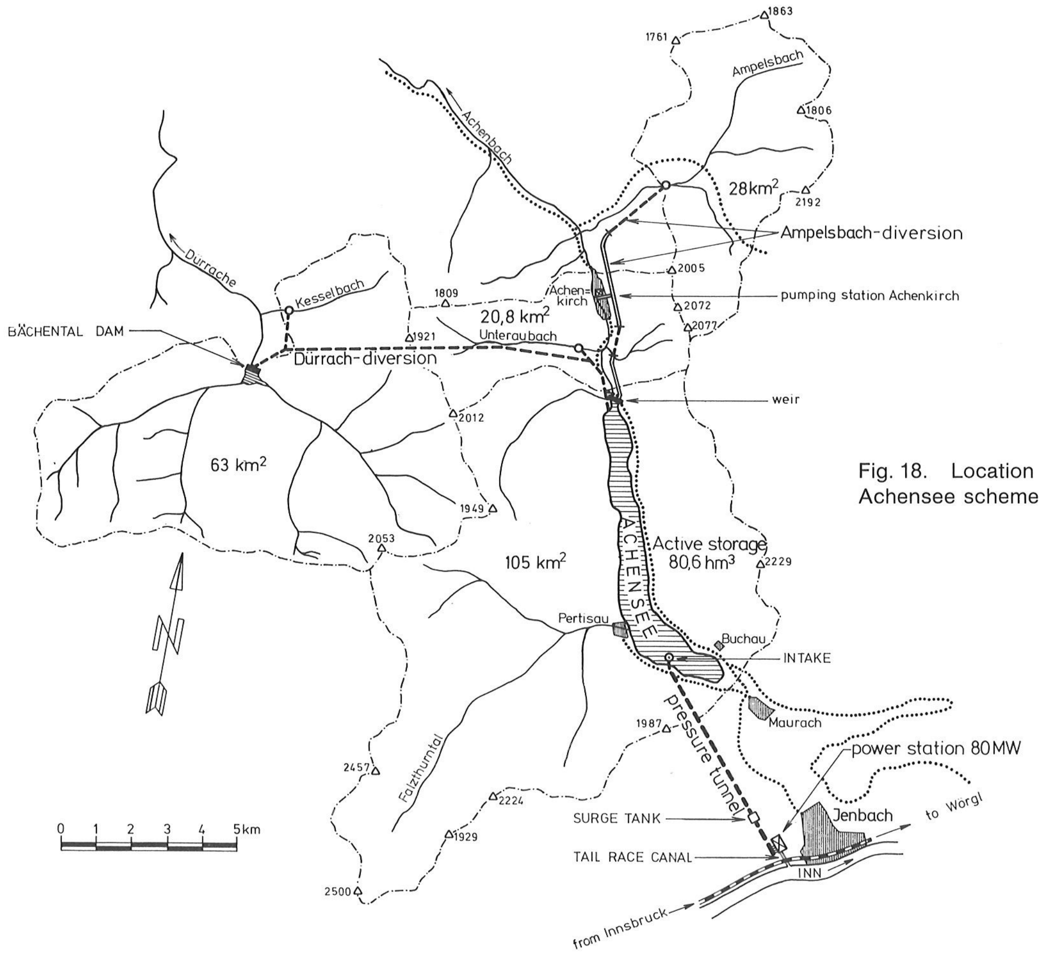


Fig. 18. Location map of TIWAG-owned Achensee scheme (Group E)

the daytime to ensure a satisfactory appearance of the landscape.
The concentration in the close vicinity of Kühtai, a renowned skiing resort, of construction activities comprising the sites for both embankments, the upper power station with pressure shaft, two diversion galleries and three stream intakes with a few kilometres of hillside pipelines (Fig. 16), had been feared to affect tourist trade and to lead to a reduction in the number of visitors during the four year construction period. This fear proved unfounded. Roads improved and newly constructed for the power project as well as the interest taken by the public in the individual features of the project brought many visitors so that the advantages by far outweighed potential disadvantages (Fig. 63).

E: Achensee Power Scheme
(Tiroler Wasserkraftwerke AG, Innsbruck)

Symbol / Initial operation in year	Reservoir Name / T.W.L./Active storage (m a.s.l. / hm³)	Power stage Name / Q_r/max H_{gr} (m³/s / m)	Capacity T / (P) MW	AAE GWh	Wi. share/full-load-h without short-term pumping / (values in brackets with short-term pumping) % / h	PE GWh
E	Achensee	Achensee	80	214	53 / 2700	4
1927/52	829.6 / 80.6	28 / 397	(—)	(—)	no short-term pumping	—

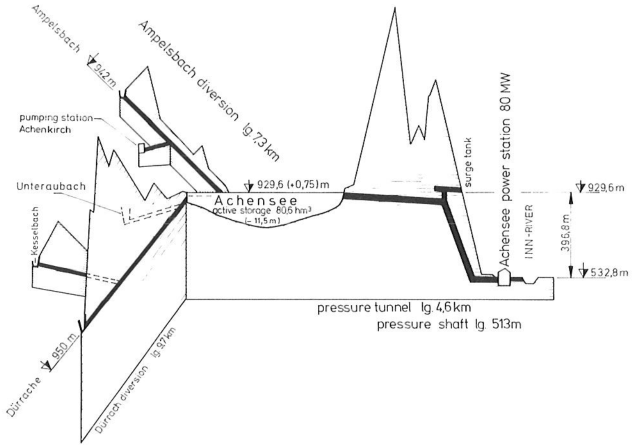


Fig. 19. Schematic longitudinal section of TIWAG-owned Achensee scheme (Group E)

For further details, see Figs. 18 and 19 as well as Table III.

Construction of the Achensee scheme was commenced in 1924. With all its features being situated below 1000 m a. s. l., it is the only one among the power schemes described in this Report not to extend to high-mountain regions. Achensee, a natural lake in the Isar river basin, is utilised by water level drawdown. Flow is utilised in the Inn valley, over a head of approximately 400 m. For more than two decades, Achensee was the largest reservoir in Austria in terms of both active storage and stored energy.
Apart from the tapping of the lake with the help of caissons, the pressure shaft and the Ampelsbach diversion, constructed during a first phase, represented technical feats that set examples for the hydro development projects that followed.
The experience gathered during the 58 years of operation of the Achensee scheme has shown that lake water level drawdown and water abstraction have had no uncontrollable detrimental effects, but have in fact improved the quality of the water. Contrary to all the apprehensions prior to the construction of the Achensee scheme, tourist trade has taken a very favourable course in this region as well.

F: Zemm-Ziller Power Scheme
(Tauernkraftwerke AG, Salzburg)

Symbol / Initial operation in year	Reservoir Name / T.W.L./Active storage (m a.s.l. / hm³)	Power stage Name / Q_r/max H_{gr} (m³/s / m)	Capacity T / (P) MW	AAE GWh	Wi. share/full-load-h without short-term pumping / (values in brackets with short-term pumping) % / h	PE GWh
F1	Schlegeis	Zemm upper stage	230	284	76 / 1230	—
1970	1782 / 128	50 / 676	(240)	(534)	(59 / 2320)	(362)
F2	Stillup	Main stage	345	613*	51 / 1780	—
1971	1120 / 7	92 / 476	(—)	—	no short-term pumping	—
F3	Zillergründl	Ziller upper stage	360	176	91 / 490	7
1986	1850 / 89	65 / 744	(360)	(684)	(56 / 1900)	(726)
F	Zemm-Ziller group	without short-term pumping	935	1073*	64 / 1150	7
		(with short-term pumping)	(600)	(1831)	(55 / 1960)	(1088)

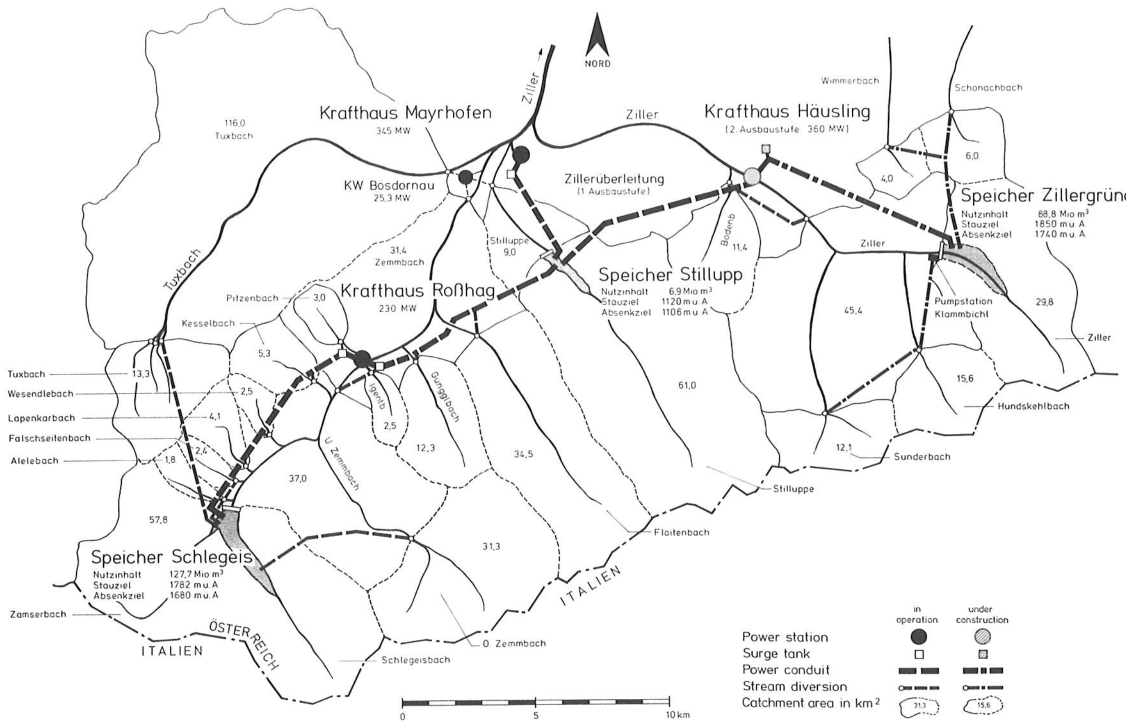


Fig. 20. Location map of TKW-owned Zemm-Ziller scheme (F)

As can be seen from Figs. 20 and 21 and Table IV, this group will include, when the Ziller upper stage is complete, two seasonal storage reservoirs holding 560 GWh of energy. Both reservoirs are formed by large arch dams. The Schlegeis reservoir is filled, without pumping, by the diverted flows of the Tux streams and the upper Zemm, and further tributary streams are diverted into the pressure tunnel of the upper stage power plant following downstream. Filling of the Zillergründl reservoir by diversions from the Gerlos valley and by diverted tributary streams of the Ziller is not always ensured, so that pumping from the Stillup reservoir is necessary in dry years. In addition to the turbine discharge from the upper stages, Stillup is filled by additional tributary streams and by diversion of the remaining flows of the Zemm and Ziller streams. The developed percentage of total flow is, therefore, high, especially in the case of the Zemm, whereas in the Tux valley, diversions are all situated at high elevations so that downstream effects are much less felt.

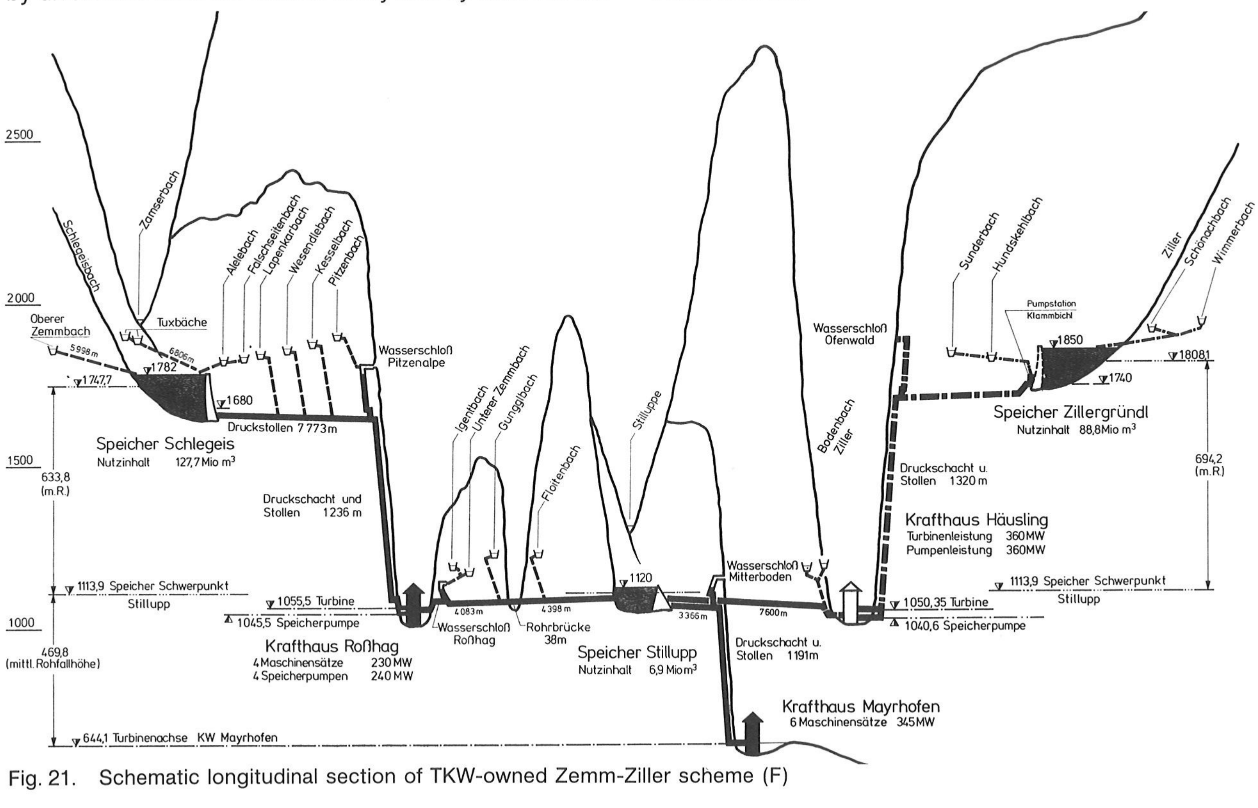


Fig. 21. Schematic longitudinal section of TKW-owned Zemm-Ziller scheme (F)

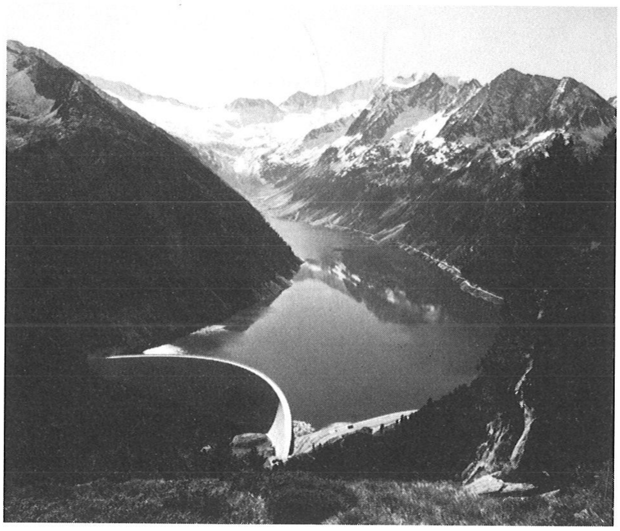


Fig. 22. Schlegeis reservoir and arch dam (F1)

As both upper stages are equipped for pumped storage, the connexion galleries of major length, i. e. those leading from the Rosshag power station in the Zemm valley (Fig. 56) and the Häusling power station in the Ziller valley (under construction) to the Stillup reservoir are operated as pressure tunnels. The power units, equipped with Francis turbines and two-stage pumps, are remarkable for the high geodetic head under which they work. This is a maximum of 672 m at Rosshag and a maximum of 740 m at Häusling, with particularly high unit capacities in the latter station.
The power station of the main stage, situated at Mayrhofen, works under a much smaller head and is equipped with Pelton turbines.
The construction of roads including a great number of road tunnels as part of the power project has afforded new or improved access to large mountainous areas. An example is the Schlegeis reservoir (Fig. 22), which is now easily accessible by a small road, and has come to attract large numbers of visitors. The same is anticipated for the Zillergrund valley after completion of the work.
The permit for the implementation of this second development phase in the upper Ziller valley, now under construction, was obtained from the authorities in agreement with the local population after long debates. But the very fact that the inhabitants of this world-famous tourist region have given their consent, in the light of their experience gathered during a long period of construction and operation, shows that the beneficial effects of such a project are valued above the inevitable nuisance involved, which is mainly felt during construction.

G: Gerlos Power Scheme
(Tauernkraftwerke AG, Salzburg

Symbol Initial operation in year	**Reservoir** Name T.W.L./Active storage m a.s.l. hm³	**Power stage** Name Q_r/max H_{gr} m³/s m	**Capacity** T (P) MW	**AAE** GWh	Wi. share/full-load-h without short-term pumping (values in brackets with short-term pumping) % h	**PE** GWh
G 1 1967	Durlassboden 1405 / 51	Gerlos upper stage 26 / 135	25 (—)	56 —	74 / 1000 no short-term pumping	— —
G 2 1945/48	Gmünd 1190 / 0.7	Gerlos lower stage 13.5 / 614	65 (—)	294 —	45 / 4520 no short-term pumping	— —
G	Gerlos group	without short-term pumping (with short-term pumping)	90 (—)	319 —	47 / 3540 no short-term pumping	— —

For further details, see Figs. 23 and 24 and Table IV.

The lower stage of the Gerlos scheme was built for weekly storage by TIWAG. The great war-time difficulties experienced during construction were partly responsible for the subsequent pressure shaft damage.
The small weekly storage reservoir at Gmünd is formed by Austria's first arch dam, which had subsequently to be reinforced as a precaution against the risk of rockfall. To avoid rapid reservoir sedimentation, a bed load diversion facility was provided for the first time in Austria.
Under the Second Nationalisation Act, the Gerlos lower stage was taken over by TKW, which then constructed the Durlassboden seasonal storage reservoir as an upper stage to this project. This is not directly followed by the lower stage. In between is a fairly flat reach, which was not included in the development. The Durlassboden reservoir blends very well with the surrounding landscape (Fig. 25). Filling is ensured by diversions from the Salzach basin. The dam is of the earthfill type. Very difficult foundation conditions called for a deep grout curtain.

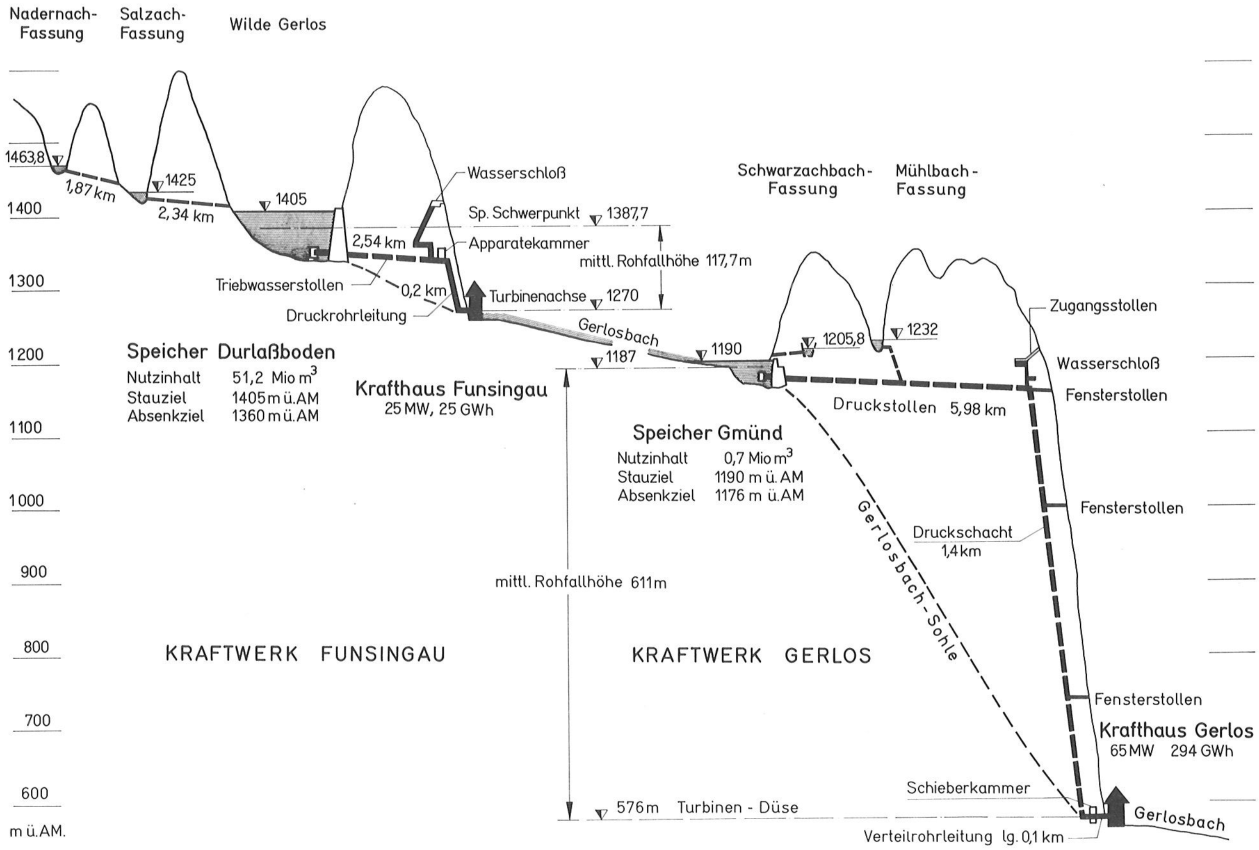


Fig. 23. Schematic longitudinal section of TKW-owned Gerlos scheme (G)

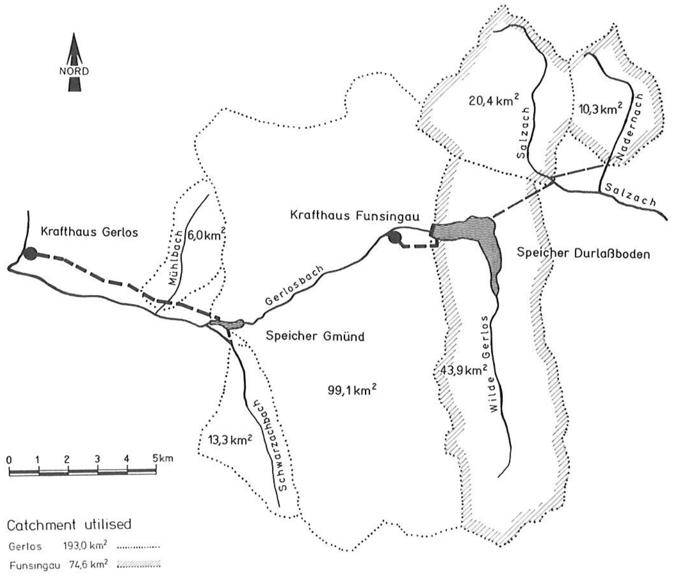


Fig. 24. Location map of TKW-owned Gerlos scheme (G)

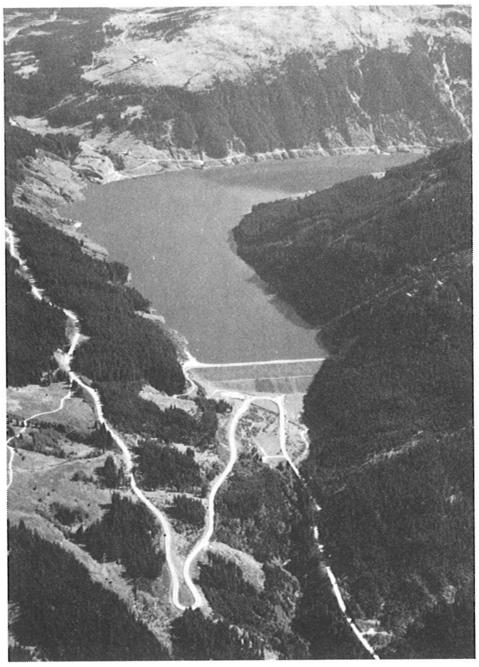


Fig. 25. Durlassboden reservoir and embankment dam (G1) with Federal Road 165 (released for publication by the BMfLV under Zl. 13080/61 — 1. 6./81)

H: Glockner-Kaprun Power Scheme
(Tauernkraftwerke, Salzburg)

Symbol Initial operation in year	Reservoir Name T.W.L./Active storage m a.s.l. hm³	Power stage Name Q_r/max H_{gr} m³/s m	Capacity T (P) MW	AAE GWh	Wi. share/full-load-h without short-term pumping (values in brackets with short-term pumping) % h	PE GWh
H1 1952	Margaritze 2000 / 3.2	Möll pumping stage (20) / 36	— (13)	— —	pumping only no short-term pumping	15 —
H2 1955	Mooserboden 2036 / 85.5	Kaprun upper stage 36 / 446	112 (130)	152 (252)	53 / 1360 (58 / 2250)	— (156)
H3 1944/53	Wasserfallboden 1672 / 83	Kaprun lower stage 36.5 / 891	220 (—)	454 —	85 / 2060 no short-term pumping	— —
H	Glockner-Kaprun group	without short-term pumping (with short-term pumping)	332 (130)	606 (706)	77 / 1825 (75 / 2130)	15 (171)

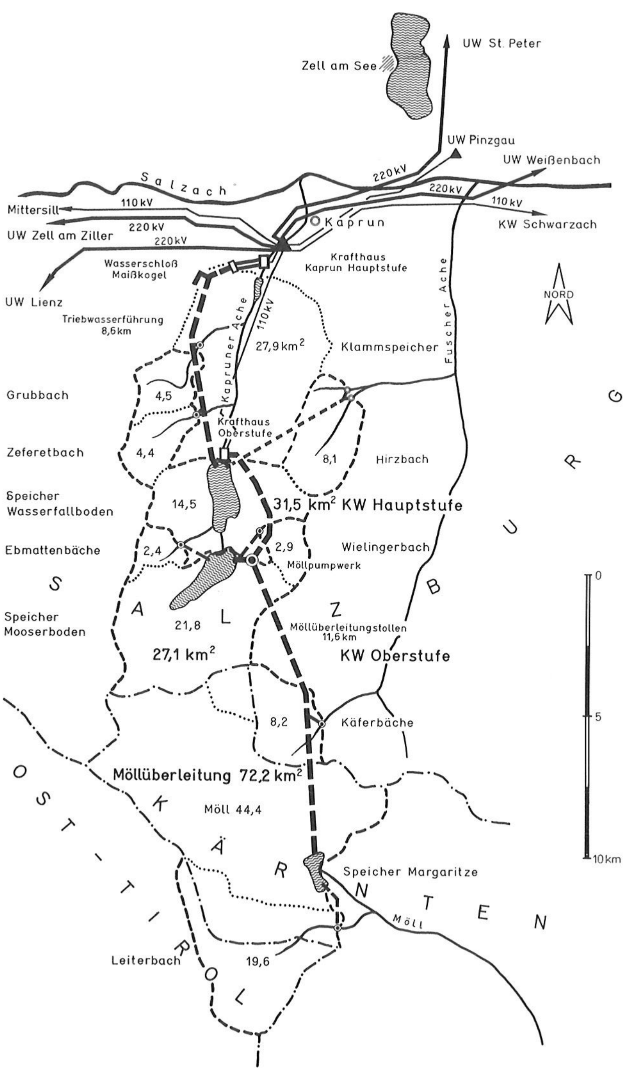


Fig. 26. Location map of TKW-owned Glockner-Kaprun scheme (H)

For further details, see Figs. 26 and 27 as well as Table V.

This is a rare example of two large seasonal storage reservoirs being located in one high-level valley. They are formed by Austria's first large arch dams (Fig. 28).
Natural inflow is by far insufficient in spite of the substantial runoff from the northern flank of the Tauern mountains. The only possibility of extension was to the south, because to the east there is the deeply incised Fusch valley, and the catchments situated to the west are utilised by the ÖBB-owned Stubach group of schemes (J). The Möll diversion, providing more than half the scheme's power water, takes off from the Margaritze reservoir situated below the Pasterze glacier. As at the time of construction, the glacier tongue extended to a much lower level, it was not possible to site the water intake at a higher elevation so as to allow gravity flow to the Mooserboden reservoir. Therefore, the diversion was constructed as a pressure tunnel with a pumping station below the Drossen dam, one of the two dams forming the Mooserboden reservoir.
Water is utilised in two stages. The upper stage is equipped for pumping between the two reservoirs. The power station of the lower stage was not built on the Salzach, but in the Kaprun valley (Fig. 52) below the first steep rise in the valley, where better foundation conditions were found.
Hydro development planning in the Hohe Tauern mountains is based on a concept elaborated by H. Grengg in 1938, and carried through against unrealistic but at that time rather influential attempts at excessive centralisation. This concept has remained unchanged except for some raising of the top water levels and the addition of the Hirzbach diversion from the Fusch valley, and another minor diversion from the west, presently under construction and thus not yet included in the Tables.
Constructed under the most adverse war and post-war conditions, this project involved pioneer work in many respects and led to an undreamt-of economic development in the Kaprun valley. The traffic facilities provided for the construction of the project made accessible one of the finest high-mountain sceneries in the Eastern Alps, which now attracts about 300 000 visitors a year and has encouraged further development also in adjoining regions.

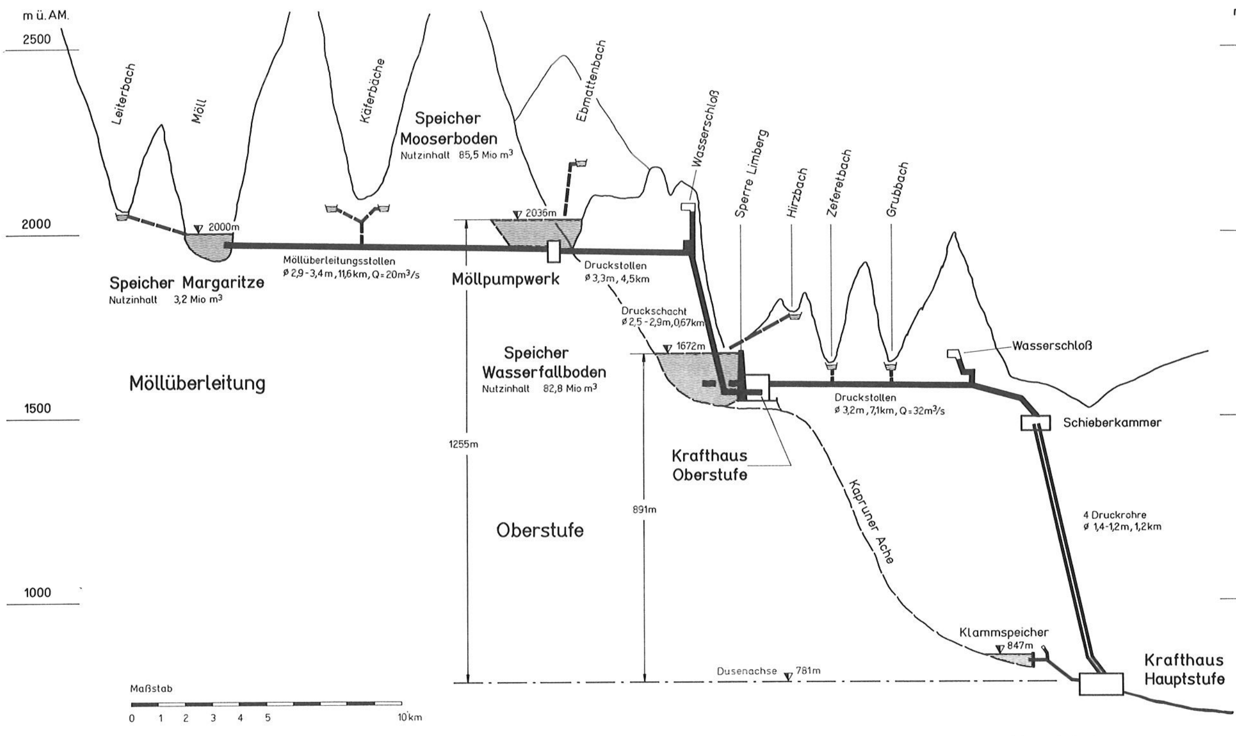


Fig. 27. Schematic longitudinal section of TKW-owned Glockner-Kaprun scheme (H)

Fig. 28. Mooserboden reservoir with Drossen and Mooser dams (H2) as well as Wasserfallboden reservoir with Limberg dam (H3) and upper power station (H2) (released for publication by BMfLV under Zl. 13080/347 — 1. 6./82)

J: Stubach Power Scheme
(Österreichische Bundesbahnen, Generaldirektion, Vienna)

Symbol Initial operation in year	Reservoir Name T.W.L./Active storage m a.s.l. hm³	Power stage Name Q_r/max H_{gr} m³/s m	Capacity T (P) MW	AAE GWh	Wi. share/full-load-h without short-term pumping (values in brackets with short-term pumping) % h	PE GWh
J1 1952/59	Weißsee + another 2 2250 / 16+7	none at present — / —	— —	— —	remote reservoir for J2	— —
J2 1929/74	Tauernmoossee 2023 / 55	upper stage 17.6 / 558	81.2 (—)	120 —	79 / 1480 no short-term pumping	— —
J3 1940/64	Enzingerboden 1463.5 / 0.3	middle stage 10.5 / 428	35.4 (—)	115 —	65 / 3250 no short-term pumping	— —
J4 1948/50	Stauwehr 1035.7 / —	lower stage 15.0 / 244	27 (—)	75 —	53 / 2880 no short-term pumping	— —
J	Enzingerboden group	without short-term pumping (with short-term pumping)	143.6 (—)	310 (—)	68 / 2160 no short-term pumping	— —

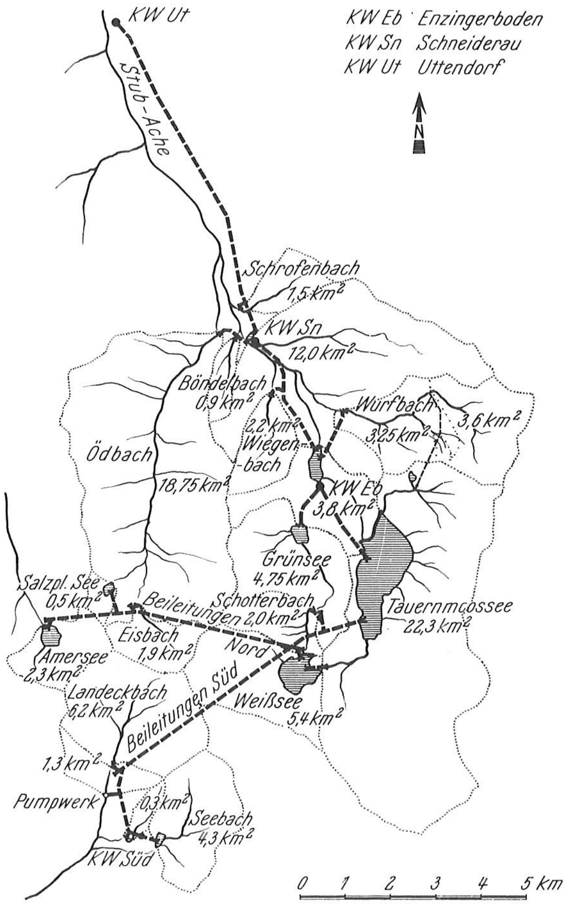


Fig. 29. Location map of ÖBB-owned Stubach scheme (J)

For further details, see Fig. 29 and 30 as well as Table VI.

This scheme supplies peak energy to the railway electricity system (single-phase, 16⅔ Hz). First development of lake Tauernmoos and construction of the upper stage was started in 1925. This was for a long time the only seasonal-storage reservoir in the Hohe Tauern mountains. Another remarkable feature was the fact that an active storage of as much as 21 hm³ was created by a concrete volume of only 28 500 m³. With subsequent additions by the construction of a middle stage and a lower stage and by the inclusion of the Weissee lake as a remote seasonal-storage reservoir, the scheme remained limited to the Stubach valley. Later on, the Stubach development has further been extended by the construction of a North diversion conveying water from the Amersee lake in the Felber valley to the Weissee, and by a South trans-basin diversion delivering water from the Landeck stream (Isel system) to lake Tauernmoos.
The storage of lake Tauernmoos has been more than doubled by the construction of a new dam (Fig. 31). With the Grünsee lake being utilised for station service supply, this development comprises five diversion levels, which allows a very large proportion of flow in the Stubach stream to be utilised.
The traffic facilities provided for the power project, combined with the construction of an Alpine Centre on the shore of the Weissee reservoir, at an altitude of 2300 m a. s. l., by the Austrian Alpine Club have provided an impetus for tourist trade. The success of this project can be regarded as a demonstration of the fact that mountaineering and hydro power development are compatible.

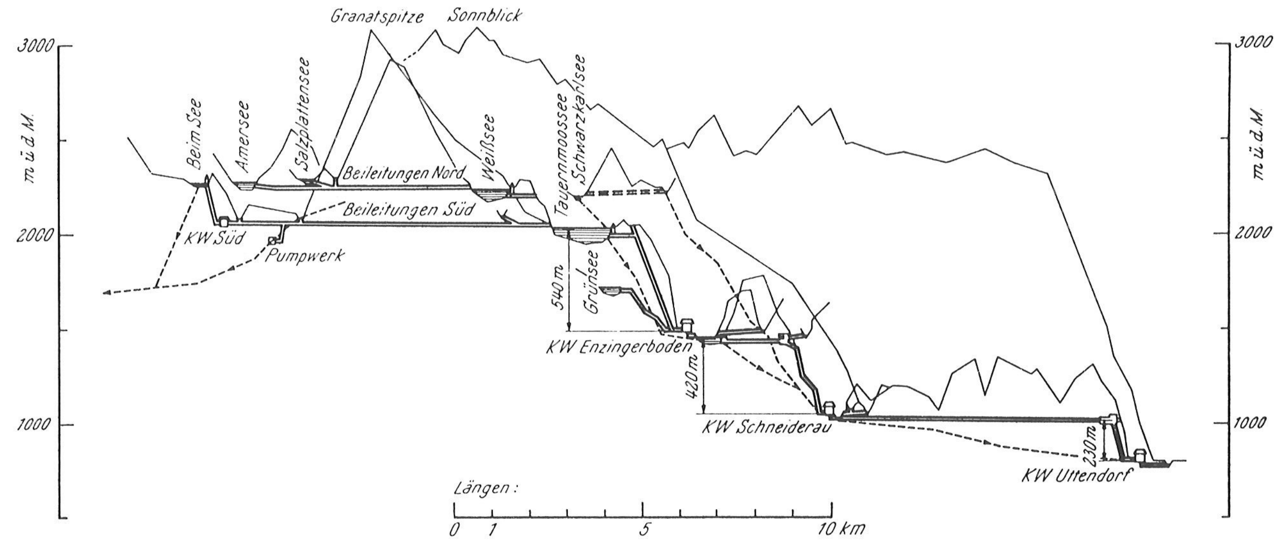


Fig. 30. Schematic longitudinal section of ÖBB-owned Stubach group of schemes (J) [based on Wohlgemuth, J.: EuM, 89. Jg. (1971), H. 2]

Fig. 31. Tauernmoossee reservoir and dam (J2), with Weissee dam (J1) below the large snow-field in the background (Photo: D. I. Öhreneder)

K: Fragant Power Scheme
(Kärntner Elektrizitäts-AG, Klagenfurt)

Symbol / Initial operation in year	Reservoir Name / T.W.L./Active storage (m a.s.l. / hm³)	Power Name / Q_r/max. H_{gr} (m³/s / m)	Capacity T / (P) MW	AAE GWh	Wi. share/full-load-h without short-term pumping (values in brackets with short-term pumping) % / h	PE GWh
K1	Zirmsee	none at present	—	—	remote res. for K2	—
1982	2529.5 / 8.7	— / —	—	—	—	—
K2	Großsee + Hochwurten	Zirknitz	32	55	91 / 1720	10.3
1974	2417 / 26.7	11.4 / 689	(—)	—	no short-term pumping	—
K3	Wurtenalm + Feldsee	Wurten	66	99	57 / 1500	—
1969	1695 / 2.7 + 1.6	16 / 490	(—)	—	no short-term pumping	—
K4	Oscheniksee	Oschenik	108	82	100 / 760	64
1968/80	2391 / 33	10 / 1186	(100)	—	pumping from K3 + K5	—
K5	Haselstein	Haselstein	4	9	33 / 2250	see
1968	1470.5 / 0.04	1.7 / 276	(5)	—	short-term p. possible	K4
K6	Innerfragant	Ausserfragant	96	236*	49 / 2460	—
1968/84	1201 / 0.18	23 / 488	(—)	—	no short-term pumping	—
K7	Wölla	Wölla	17	40	25 / 2370	—
1982/84	1542 / 0.1	6 / 326	(—)	—	no short-term pumping	—
K	Fragant group	without short-term pumping	323	521	61 / 1610	74.3
		(with short-term pumping)	(105)	—	short term p. possible	—

* after completion of K7

See also Figs. 32 and 33 as well as Tables VII and VIII.

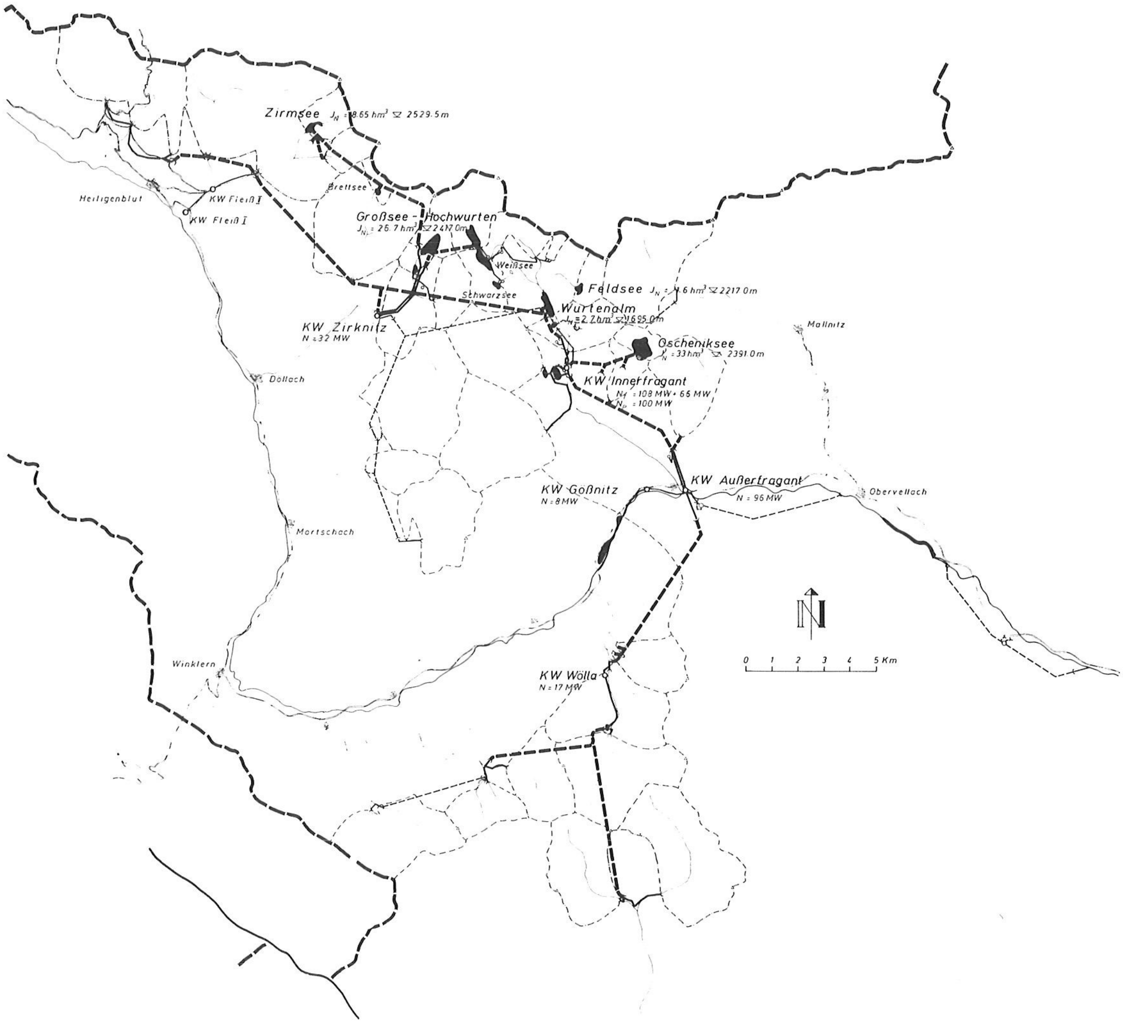


Fig. 32. Location map of KELAG-owned Fragant scheme (K)

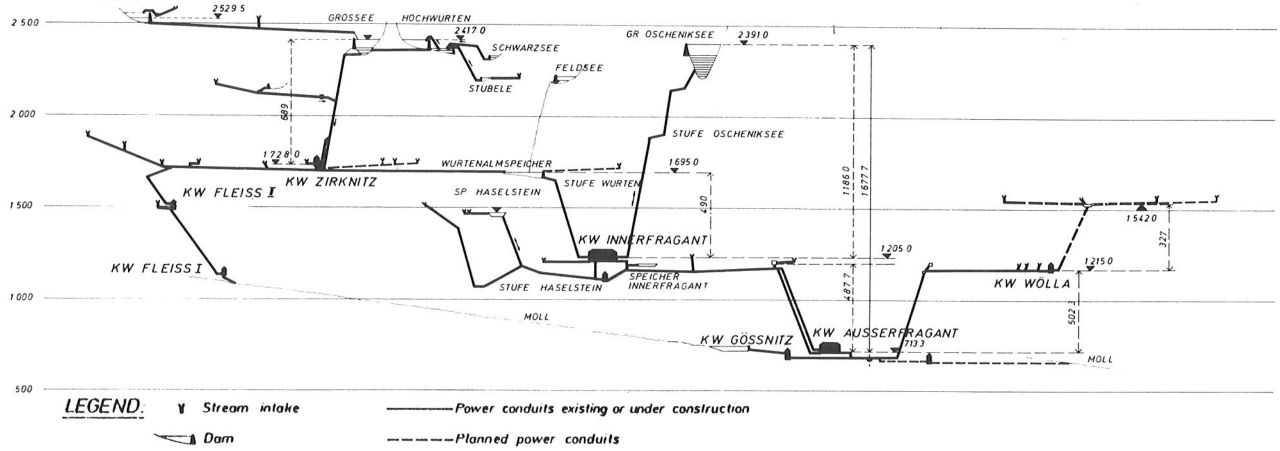


Fig. 33. Schematic longitudinal section of KELAG-owned Fragant scheme (K)

Characterised by great variety, the Fragant development utilises for seasonal storage four natural cirque lakes situated at very high elevations along the main ridge of the Tauern mountains. Total storage is 90 hm³. The special features of this scheme have made possible phase-wise development conceived to meet the provincial electricity company's growing requirements. Planned extensions will take another two decades to realise. Reservoirs are formed by embankment dams with asphaltic concrete facings. Heightening in several phases has allowed stepwise enlargement of storage.

The Zirmsee reservoir and the interconnected Grossee and Hochwurten reservoirs can for the most part be filled by stream diversions and several feeding pumps so that pumping from the Wurtenalm reservoir, situated at an intermediate level, will not be needed until the Zirmsee reservoir is enlarged. The Oscheniksee reservoir in turn (Fig. 47) relies for filling almost entirely on pumping from the Wurtenalm reservoir and an artificial basin at Haselstein. Pumping heads are approximately 670 m and 870 m, respectively, whereas total head on turbines is as much as 1 670 m. 1 200 m of this is accounted for by the Oscheniksee stage, from which a pressure shaft descends to the Innerfragant power station, which Oscheniksee shares with the Wurten stage. Both the power station and the Innerfragant compensation reservoir are situated in a hanging basin (Fig. 34) threatened by avalanches and mudslides. From there the Ausserfragant stage descends to the Möll valley. Additional flow is brought to this stage, through a sag pipe, by the Wölla trans-basin diversion from the mountains south of the Möll, with an upper stage collecting streamflow from tributaries of the Möll and the Drau.

The construction of this scheme involved large-scale development of the southern flank of the Goldberg massif, which on this side is little frequented by tourists. The roads, most of which are single-lane to ensure minimum impact on the landscape, afford access to new areas for alpinists and tourists.

Fig. 34. Innerfragant valley head. From the top downwards: Hochwurten reservoir (K2), Wurtenalm reservoir with penstock of Wurten stage (K3) as well as powerhouse (K3 + K4) and Innerfragant compensation reservoir (K6) and Haselstein stage (K5); construction road to the Oscheniksee reservoir (K4) in the bottom right-hand corner (released for publication by the BMfLV under ZL. 13080/254 — 1. 6./79)

L: Reisseck-Kreuzeck Power Scheme

(Österreichische Draukraftwerke AG, Klagenfurt)

Symbol Initial operation in year	**Reservoir** Name T.W.L./Active storage m a.s.l. hm³	**Power stage** Name Q_r/max H_{gr} m³/s m	**Capacity** T (P) MW	**AAE** GWh	Wi. share/full-load-h without short-term pumping (values in brackets with short-term pumping) % h	**PE** GWh
L 1 1957/60	Gr. and Kl. Mühld.-See and another 2 res. 2319 till 2399 / 17.2	Reisseck storage stage 4.5 / 1772.5	68 (18)	73 —	100 / 1 070 no short-term pumping	26 —
L 2 1950/52	Gondelwiese 1 288 / 0.04	Reisseck run-of-river scheme 5 / 678.5	23 (—)	62 —	27 / 2 700 no short-term pumping	— —
L 3 1958/60	Roßwiese 1 195 / 0.2	Kreuzeck run-of-river scheme 9 / 587.5	45 (—)	163 —	27 / 3 600 no short-term pumping	— —
L	Reisseck-Kreuzeck group	without short-term pumping (with short-term pumping)	136 (18)	298 —	45 / 2 190 no short-term pumping	26 —

See also Figs. 35 and 36 as well as Table IX.

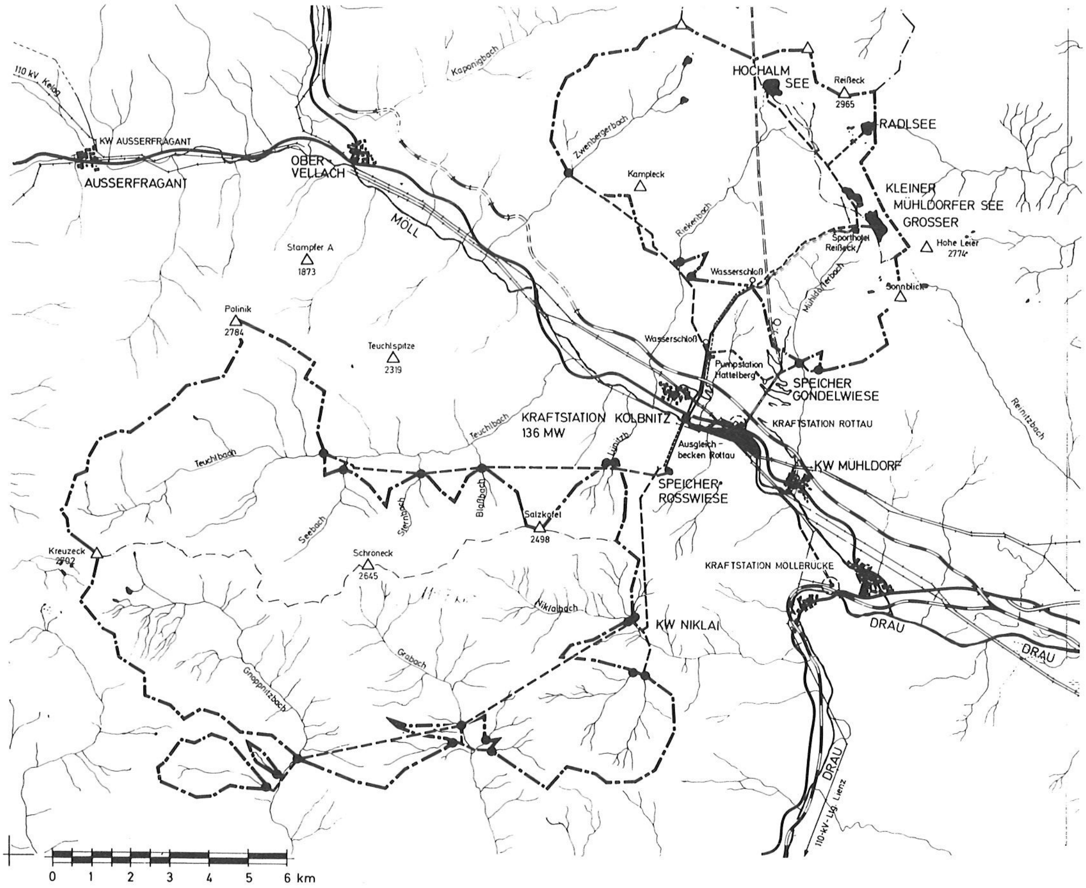
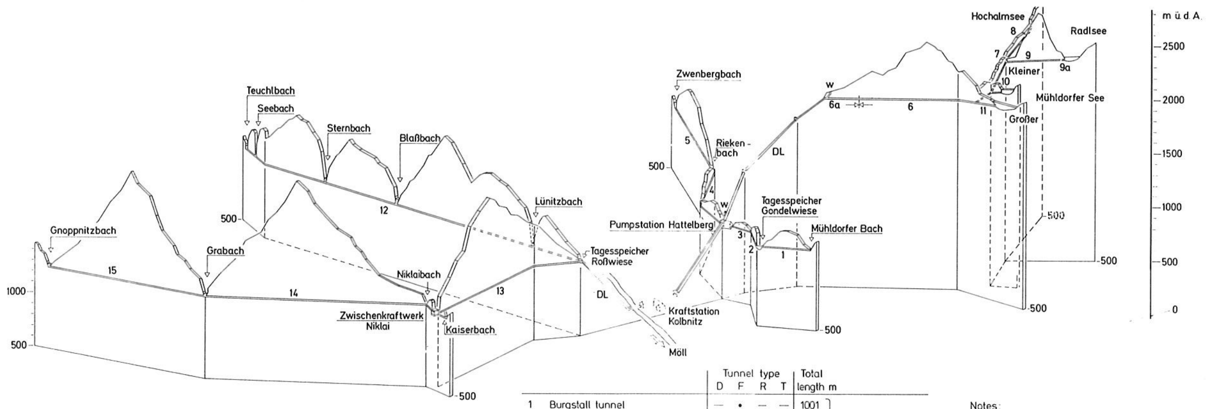


Fig. 35. Location map of ÖDK-owned Reisseck-Kreuzeck scheme (L)



		Tunnel type D	F	R	T	Total length m	
1	Burgstall tunnel	—	•	—	—	1001	Reisseck daily storage stage
2	Leithen tunnel-east	—	—	•	—	922	
3	Leithen tunnel-west	—	—	•	—	563	
4	Rieken tunnel	—	—	•	—	2113	
5	Zwenberg	—	•	—	—	3797	
6	Under main tunnel	—	—	•	•	2162	Reisseck seasonal storage stage
6a	Schober tunnel	—	—	•	—	634	
7	Upper main tunnel	—	—	•	•	2770	
8	Tunnel from lake Hochalmsee	•	—	—	•	519	
9	Radlsee tunnel	—	—	•	•	1093	
9a	Tunnel from lake Radlsee	•	—	•	—	237	
10	Tunnel from lake Kl. Mühldorfer See	•	—	•	—	121	
11	Tunnel from lake Gr. Mühldorfer See	•	—	•	—	432	
12	Teuchl tunnel	—	•	—	—	8236	Kreuzeck daily storage stage
13	Niklai tunnel	—	•	—	—	4194	
14	Grabach tunnel	—	•	—	—	5091	
15	Gnoppnitz tunnel	—	•	—	—	4296	

Notes:
DL Penstock
D Power tunnel
F Free-flow tunnel
R Pipeline tunnel
T Transport tunnel
W Surge tank

Fig. 36. Schematic lontitudinal section of ÖDK-owned Reisseck-Kreuzeck scheme (L)

Development of four natural cirque lakes situated around an elevation of approximately 2300 m a. s. l., in the Reisseck massif, has created an active storage of 17.2 hm^3. Three of these lakes are impounded by gravity dams with enlarged base galleries and one, by a rockfill dam with a reinforced-concrete core. Each of the four reservoir lakes can be drawn down through low-level intakes, and alternatively connected through steel piping laid for the most part in galleries, to the penstock of the storage stage descending to the Möll. This offers a maximum head of 1772.5 m, which is the largest natural head in the world. About one-third of the required water must be pumped over a head of about 1100 m from the intake level of the Reisseck run-of-river stage, which has a small daily storage reservoir. The pumping station is situated at an elevation of about 1100 m a. s. l. and is connected to the pressure pipe of the run-of-river stage and to that of the storage stage (Fig. 37). On the opposite valley slope, the tributaries of the Möll are diverted at an elevation of about 1200 m a. s. l. and those of the Drau, around 1260 m. Flows are conveyed directly, through an intermediate power station, to the daily storage reservoir of the Kreuzeck run-of-river scheme, from which a penstock leads to the common Kolbnitz power station.
The inclined hoists along the penstocks and a tunnel railway leading from the surge tank of the storage stage to the reservoirs afford access to an Alpine region for summer and winter tourists without disrupting the landscape.

Fig. 37. Penstock of Reisseck stages (L1 + L2) with Kolbnitz power station to the left as well as penstock from Malta main stage (M2) with Rottau power station and compensation reservoir of the Malta lower stage (M3) to the right

M: Malta Power Scheme
(Österreichische Draukraftwerke AG, Klagenfurt)

Symbol / Initial operation in year	**Reservoir** Name / T.W.L./Active storage (m a.s.l. / hm^3)	**Power stage** Name / Q_r/max H_{gr} (m^3/s / m)	**Capacity** T / (P) MW	**AAE** GWh	Wi. share/full-load-h without short-term pumping (values in brackets with short-term pumping) % / h	**PE** GWh
M 1	Kölnbrein	Malta upper stage	120	76	94 / 630	52.4
1978	1902 / 200	44—70 / 222	(116)	—	no short-term pumping	—
M 2	Galgenbichl + Gösskar	Malta main stage	730	715	83 / 980	138
1978	1704 / 6	80 / 1102.5	(290)	(1155)	(k. A. / 1580)	(740)
M 3	Rottau	Malta lower stage	42	114	45 / 2780	—
1978	598 / 0.5	110 / 45	(—)	—	no short-term pumping	—
M	Malta group	without short-term pumping	892	905	79 / 1015	190
		(with short-term pumping)	(406)	(1345)	(k. A. / 1510)	(792)

See also Figs. 38 and 39 as well as Table X.
The Malta development was constructed between 1971 and 1978, after lengthy studies and several modifications of the project.
The dominating feature of this development is the Kölnbrein seasonal storage reservoir situated in the upper Malta valley. With an active storage of 200 hm^3 and an energy storage of almost 600 GWh, this is by far the largest in Austria. This superlative also applies to the Kölnbrein dam, 200 m in height and with a relatively wide span in its lower portion (Fig. 40). The water load acting on the valley cross section (nominal load after Grengg) is 3.8 million t, i. e. 2.3 times the nominal load of the Schlegeis dam, which as an arch dam is second in size. As natural inflow and flow from the neighbouring catchments that can be included at top water level (1902 m a. s. l.) are insufficient, flow is mainly collected at the level of two intermediate reservoirs situated some 200 m below. These are Galgenbichl on the Malta stream and Gösskar on the Göss stream. Diversions to these bring additional flows from the upper Lieser stream and from tributaries of the upper Malta and Göss streams.

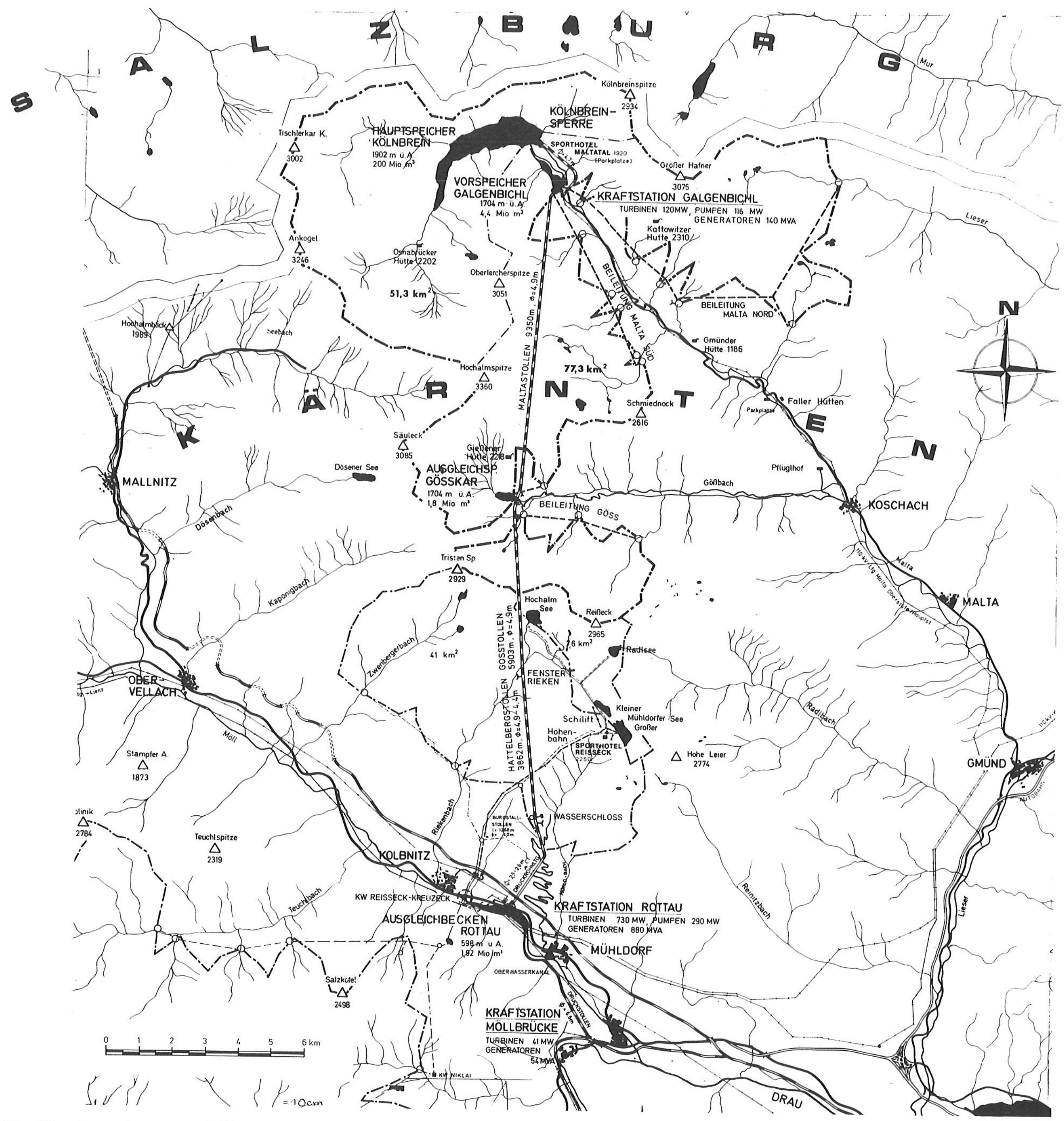


Fig. 38. Location map of ÖDK-owned Malta scheme (M)

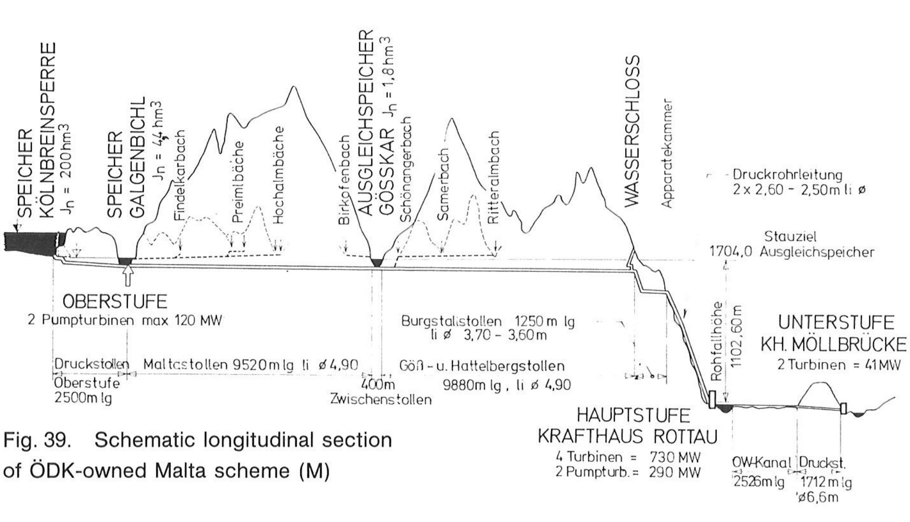


Fig. 39. Schematic longitudinal section of ÖDK-owned Malta scheme (M)

Almost half the power water needed in the upper stage must be obtained by pumping over a head of between 50 m and 200 m depending on reservoir water level. Mean total head on turbines is about 1 300 m.
The upper stage power house (Fig. 40), situated below the Galgenbichl intermediate reservoir, is equipped with Isogyr pump turbines with two speeds to allow adaptation to fluctuating heads. In the main stage leading to Rottau in the Möll valley, intermediate reservoirs were provided to avoid excessive loading of the almost 20 km-long power tunnel. A short pressure shaft leads from the surge tank to the two above-ground penstocks (Fig. 37) which rank among the most highly loaded in the world. The main stage is also highest in capacity among Austria's hydro stations. Out of the four power units with Pelton turbines in the Rottau power station (Fig. 55), two are equipped with four-stage pumps for pumped storage operation, mainly on a short-term basis, but also for seasonal pumping in dry years.
The rated flow of the main stage, 80 m^3/s, is discharged to the Rottau compensation reservoir on the Möll. Together with the flow of the Möll river, to which the discharge from the Kolbnitz power station of the Reisseck-Kreuzeck scheme is fed a short way upstream, this is utilised by the low-head lower stage discharging into the Drau river. In this way, the riverbed of the Möll remains unaffected by the surges resulting from peaking.
Flow abstraction mainly affects the upper Malta valley. Its picturesque gorge has always been a favourite sight for visitors. Owing to the access that has been provided to the reservoirs in an otherwise unaffected high-mountain region, the number of visitors is now 20 or 30 times larger than that prior to the construction of the power scheme.

Fig. 40. Kölnbrein reservoir and arch dam (M1) as well as Galgenbichl intermediate reservoir and embankment dam (M2) with power station of Malta upper stage (M1)

4. General Survey of Design Concepts and Economic Repercussions

Fig. 41 is a schematic map of western Austria showing hydro power schemes with special emphasis on seasonal storage. Study of this map will confirm what has been said in chapter 2 in respect of all the important seasonal storage schemes being situated to the west of the Tauern motorway.
It can also be seen from the map that most of the power schemes cover substantial areas, but differ perceptibly in character, as the basic design concept of each group calls for different combinations of reservoirs, diversions and head stages. The following list classifies seasonal storage schemes according to the number of seasonal storage reservoirs and high-head stages they contain. The fact that no more than two schemes fall under a certain combination possibility demonstrates the great variety of project arrangements.
Due to the differences in area, flow and head, the energy produced also varies substantially from scheme to scheme. Table 3, listing the groups of power schemes in order of average annual energy generation (AAE), suggests a division into two groups, the lower group consisting of four groups of power schemes with a maximum annual energy of 320 GWh, and the upper group comprising seven groups of power schemes generating between 500 GWh and 1 400 GWh p. a. If the VIW-owned A+B installations figuring at the top were regarded as two separate schemes generating 697 GWh and 715 GWh, respectively, six developments would generate an annual energy of between 500 GWh and 700 GWh, and there would be one development with an annual energy of about 950 GWh and one with an energy of 1 100 GWh. Groups of seasonal storage schemes

Classification of Groups of Power Schemes A to M

Per scheme	Number of reservoirs for seasonal storage 1	2	3	4
1 stage	C, E	—	—	—
2 stages	D, G	—	—	—
3 stages	(B), M	(A), F	J	L
4 stages and more	—	—	A+B	K

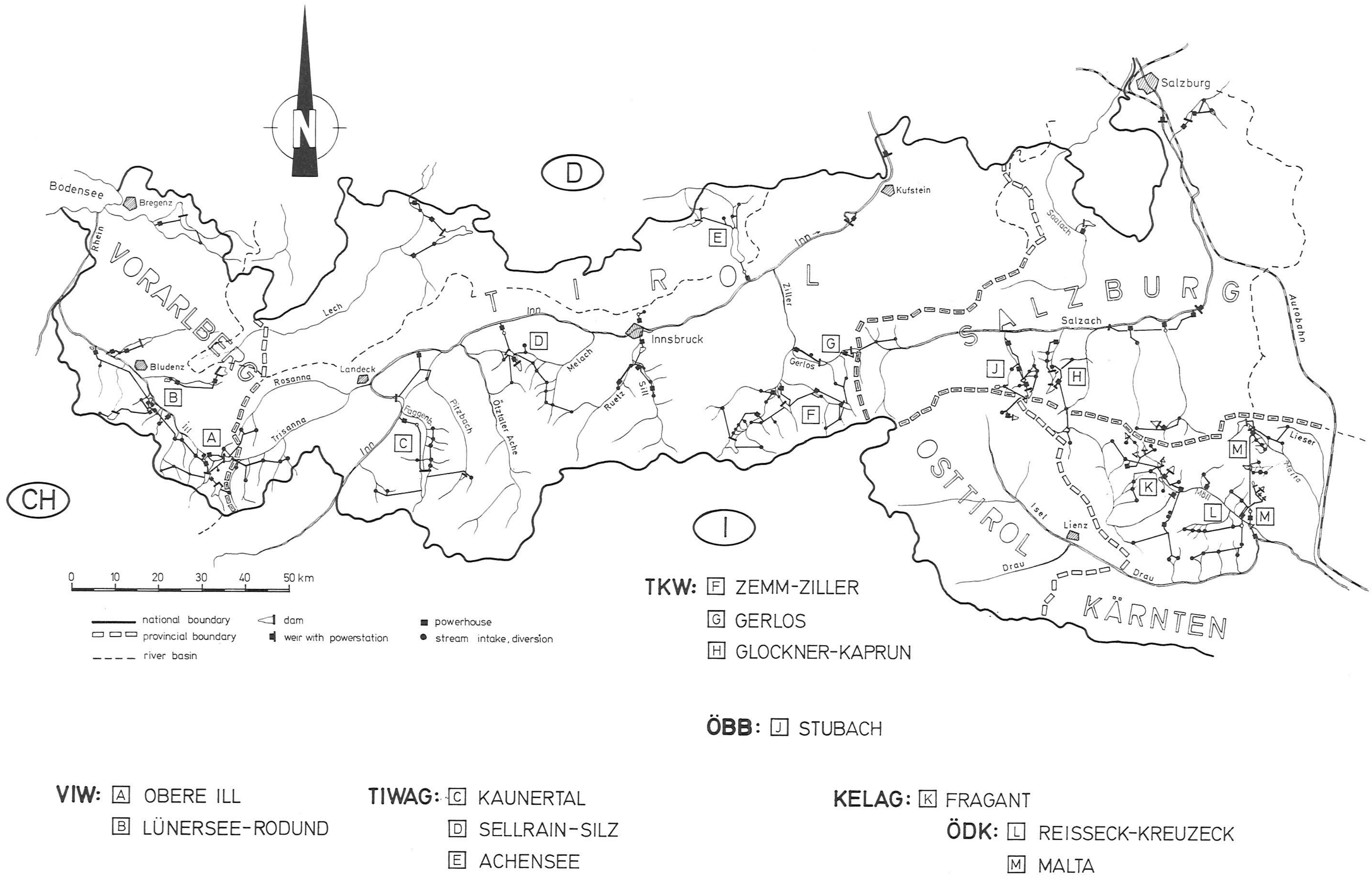


Fig. 41. Schematic map of western Austria showing locations of seasonal-storage schemes A to M and most of the other hydro plants of more than 10 MW capacity

Table 3. Energy data of the Austrian seasonal-storage schemes of more than 80 MW capacity, including extensions under construction, ranked in order of AAE not including short-term pumping

Rank	Power schemes	Capacity T/P MW	Energy without short-term pumping AAE GWh	Wi. share %	Full-load h	Pumping energy PE GWh	% of AAE	Energy with short-term pumping AAE GWh	Wi. share %	Full-load h	Pumping energy PE GWh	% of AAE
1	Upper Ill-Lünersee (A+B)	**1114/555**	**1412**	46	1270	229	16	1916	53	1720	980	51
2	Zemm-Ziller (F)	**935/600**	**1073**	64	1150	7	0.7	1831	55	1960	1088	59
3	Malta (M)	**892/406**	**905**	79	1015	190	21	1345	k. A.	1510	792	59
4	Kaunertal (C)	**390/ —**	**620**	59	1590	—	—	no short-term pumping				
5	Glockner-Kaprun (H)	**332/130**	**606**	77	1825	15	2.5	706	75	2130	171	24
6	Fragant (K)	**323/105**	**521**	61	1610	74	14	some short-term pumping possible				
7	Sellrain-Silz (D)	**765/247**	**515**	46	680	65	13	719	54	950	336	47
8	Gerlos (G)	**90/ —**	**319**	47	3540	—	—	no short-term pumping				
9	Stubach (J)	**144/ —**	**310**	68	2160	—	—	no short-term pumping				
10	Reißeck-Kreuzeck (L)	**136/ 18**	**298**	45	2190	26	8.5	no short-term pumping				
11	Achensee (E)	**80/ —**	**214**	53	2700	—	—	no short-term pumping				

generating more than 1 TWh p. a. are rare, even in the Western Alps. This is due to the ramified relief of the Alps, which renders difficult the combination of major areas for hydro power development.

Another result of this closely spaced structuring of the Alps is the fact that utilisation of none of the seasonal storage reservoirs can rely on natural inflow only, additional flows being supplied by diversions, including trans-basin diversions, or pumping from lower levels, in particular to the high-lying reservoirs. This is accomplished either by providing intermediate pumping stations which, where major capacities are involved, may resemble power stations (schemes H and L), or by equipping downstream power stations for pumped storage operation. The latter applies to at least one stage of six developments in the upper group. In these cases, daily or weekly pumping (short-term pumping) can be superimposed on the seasonal pumped storage operation necessary for reservoir filling.

The high pumping energy requirements substantially reduce the net production of primary energy. This even applies to seasonal pumped storage where the ratio of required pumping head to useful total head on turbines is unfavourable. Table 3 shows pumping energy requirements, PE, both in terms of GWh, and as percentages of average annual energy, AAE. The latter may be as much as 21 per cent without short-term pumping and almost 60 per cent with short-term pumping, which adds to the fact that the extra generation calculated to be obtained from the assumed short-term pumping is seldom utilised to the full.

The energy generated by the individual seasonal storage schemes varies in quality, depending on reservoir storage and on power station capacity storage which are both determined more or less at random, by the designer. The respective parameters mentioned in Chapter 3 and Table 3 above, i. e. winter share and equivalent utilisation period at maximum output capacity, exhibit substantial variations. In the upper group, winter generation varies between 46 per cent and 79 per cent of the respective AAE, whereas the equivalent period of utilisation at maximum output capacity is between 680 h and 1825 h. The winter percentage generated by the schemes situated in the east of Western Austria tends to be higher than in the west, whereas the number of full-load hours tends to be smaller in the younger schemes, which have higher capacity ratings.

In spite of these differences, arrangement in order of scheme capacity, ranging from 323 MW to 1114 MW, would bring about practically no change, except for Sellrain-Silz, which would advance to the fourth rank. If the groups of schemes were arranged in order of power range, which is important for system regulation, i. e. the sum of turbine output plus pump output, with a peak value of almost 1700 MW, Sellrain-Silz (D) and Kaunertal (C) would change places and the rest remain the same.

Each of these power schemes is a special case and results from attempts to combine in an optimal manner natural site conditions with power system requirements and environmental conditions. The fact that the preservation of environment and landscape has always been an important factor is demonstrated by the vehement discussions held 50 years ago in respect of hydro development planning in the Hohe Tauern mountains (H. Grengg, 1952) and other projects as well as by the records of the water-right licensing proceedings, which treat this problem in great detail. Conservation problems will also be the subject of the following chapter.

As to economic repercussions in the communes, valleys and regions affected by the construction and operation of power schemes, decades of experience have shown that, in the case of the schemes discussed here, interference tends to be limited in space and time and, in the long run, is usually more than outweighed by the beneficial consequences.

Apart from considerable tax receipts for the communes, the creation of skilled jobs for operation and maintenance, involving also trade and industry, as well as contributions and funds paid by many power companies for the improvement of infrastructure have brought lasting economic advantages.

An important factor is the influence on tourist trade. In

the mountain valleys, where our reservoirs are situated, this is usually the only additional source of income apt to counteract rural exodus and as such will help to preserve cultivated land as is typical of the Alpine landscape. Traffic facilities newly provided or improved for the construction of hydro projects are of particular importance for tourist trade, not only by affording easier access to high-lying regions for mountaineers and alpinists, but also by rendering sites of scenic beauty accessible and by creating features of technical interest, which have a great attraction for the public, so as to promote tourist trade within a large radius.
As suggested by the list of power schemes discussed in this article, there are many renowned holiday resorts in the immediate vicinity of such developments, most of which have existed for a long time. Such regions are the Montafon valley, the Tyrolean Paznaun valley, the upper Ziller valley, the Gerlos valley, the upper Pinzgau valley with the Zell am See – Kaprun region, the upper Möll valley, etc. Their popularity has remained unabated and is obviously in no way inferior to that of neighbouring areas, where no power schemes exist.
The development of the population in the Montafon valley since 1837, shown on Fig. 42, demonstrates an impressive rise from a previously distressed area owing to hydropower development and tourist trade.

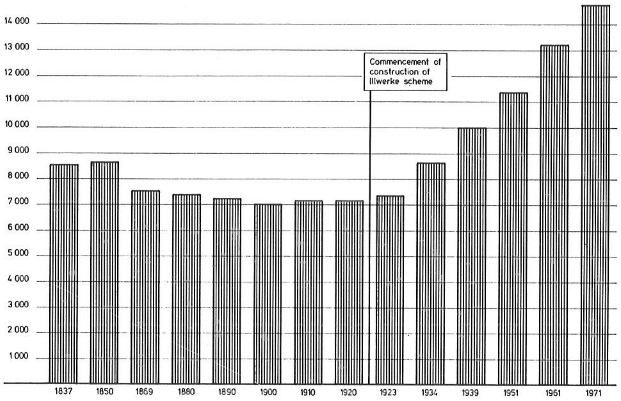


Fig. 42. Development of population in the Montafon valley since 1837 [based on Strom aus Vorarlberg, 50 Jahre VIW (1924—1974)]

5. Main Features and Environmental Effects

A. Basic Procedure

It is a well-known fact that hydro development produces no waste, noxious matter, or other emissions. The water driving the turbines is not consumed or polluted and is of unchanged quality and quantity when returned to the riverbed after utilisation. Neither is the heat balance of the earth affected, because the energy utilised for electricity production would otherwise also be converted into heat, through hydraulic friction and the crushing work involved in erosion and bed load breakage. Hydro development primarily causes physical change, which is easily observed or measured by simple means.
Thus it is natural that discussion of environmental effects should be based on the main project features, which, as components hardly affecting one another and roughly alike for all schemes, form our storage schemes in varying combinations.

These Aare:

1. Storage reservoirs and compensation basins, with dams,
2. Trans-basin diversions and simple stream diversions with intakes and conveyance structures, mainly consisting of free-flow galleries and pipelines,
3. Power stages, consisting of power conduit and power station, the former usually consisting of pressure tunnel, surge tank, and penstock or pressure shaft,
4. Tailrace canals and tailwater compensation basins where necessary.

Discussion of environmental impact will logically consist of two parts, one part treating physical change and one part studying resulting effects of such physical change on the various spheres of the environment. Fig. 43 is a matrix which has proved expedient in the study of environmental effects. Listed under A, to the left, are main project features. Column B in the middle indicates physical changes caused, whereas the principal spheres of the environment are given in column C to the right, which could be extended and subdivided as necessary. Symbols at the intersections of A and B, or B and C, respectively show expected or apprehended relationships and are mainly intended to prevent important relationships from being overlooked. Relationships and feedback among parameters whose intersection points are not marked by a symbol are regarded as being of minor importance.
Further discussion will be in the same order as the list of physical changes under B in Fig. 43, without going into technical details.

B1. Main Features and their Impact on the Landscape

Reservoirs and dams

The dominating components of storage schemes are the seasonal storage reservoirs with their dams. When sufficiently full, reservoirs can hardly be distinguished from natural mountain lakes, generally considered features of particular charm adding to the beauty of a landscape. Apart from the water level variations, to be discussed later, experience has shown the effects of reservoir lakes to be mainly favourable. The concrete and fill dams forming these lakes, however, are major engineering structures that cannot possibly pass unnoticed in a landscape even if they are most carefully designed and adapted to their surroundings. The degree of interference changes with the local conditions.

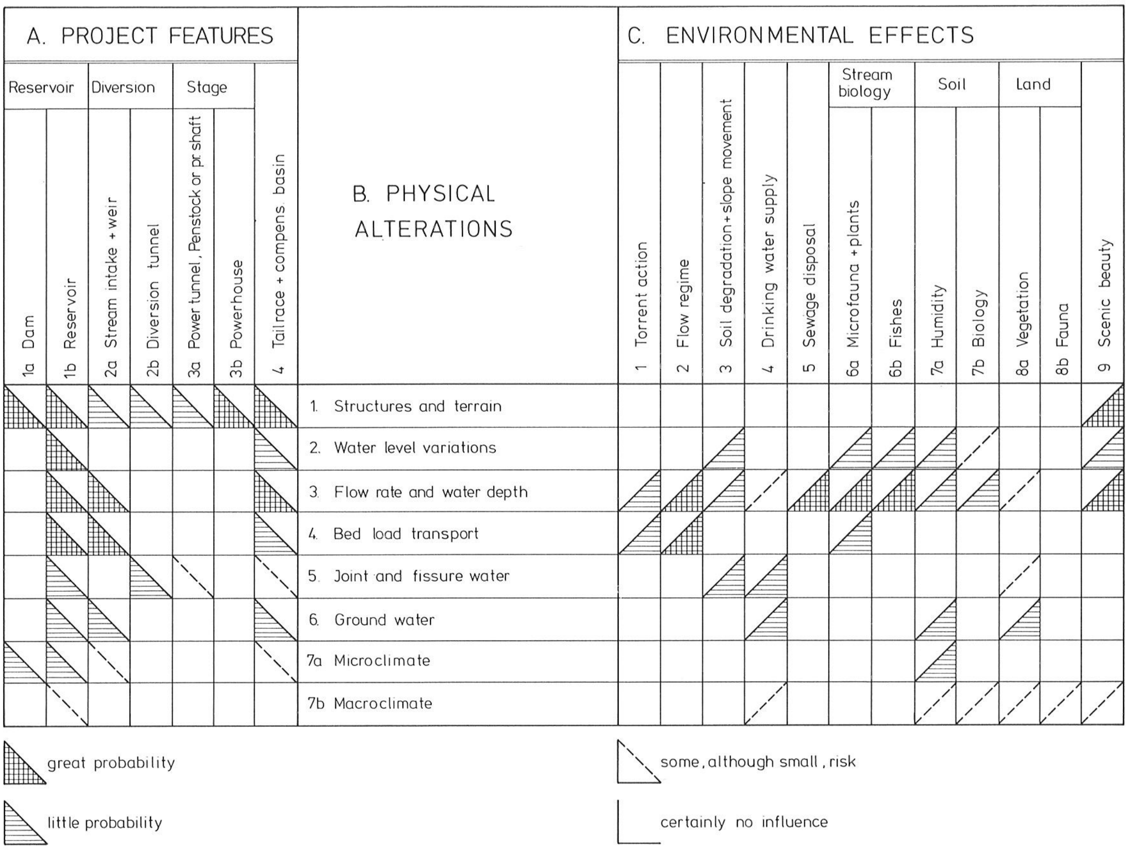


Fig. 43. Matrix for determining, in two steps, environmental effects of storage schemes

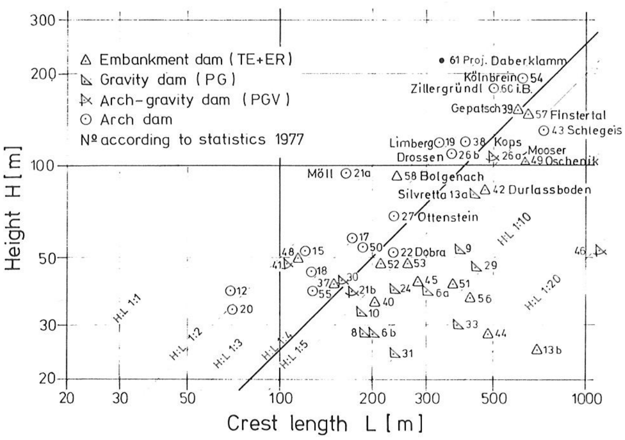


Fig. 44. Heights and crest lengths of large dams in Austria

Fig. 45. Lünersee reservoir (B2) with gravity dam

In Austria, the following dam types have mainly been used:

(a) Straight gravity dams

Examples: Silvretta dam (A1) shown in Fig. 9, Vermunt dam (A2) and Kleiner Mühldorfersee dam (L1).

(b) Gravity dams with curved alignments

Examples: Grosser Mühldorfersee dam (L1), Lünersee dam (B2) as shown in Fig. 45, new Tauernmoossee dam (J2) as shown in Fig. 31.

(c) Constant-curvature massive gravity dams

Examples: Mooser dam (H2) as shown in Fig. 28 as well as the highest part of the new Tauernmoos dam as shown in Fig. 31.

(d) True arch dams

Examples: Limberg dam (H3) as shown in Fig. 28, Kops dam (A3) as shown in Fig. 46, Schlegeis dam (F1) as shown in Fig. 22, Kölnbrein dam (M1) as shown in Fig. 40.

(e) Earthfill dams with grassy downstream faces

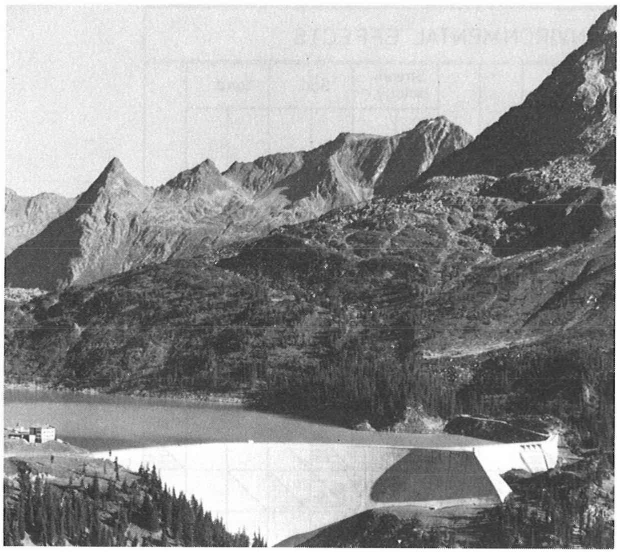


Fig. 46. Kops (A3) — arch dam with thrust block and lateral gravity dam

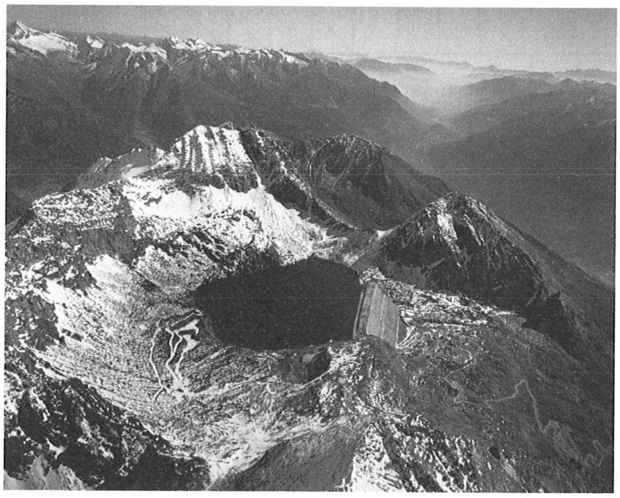


Fig. 47. Oscheniksee reservoir (K4) with rockfill dam with asphalt facing (released for publication by the BMfLV under Zl. 13080/254 — 1. 6./79)

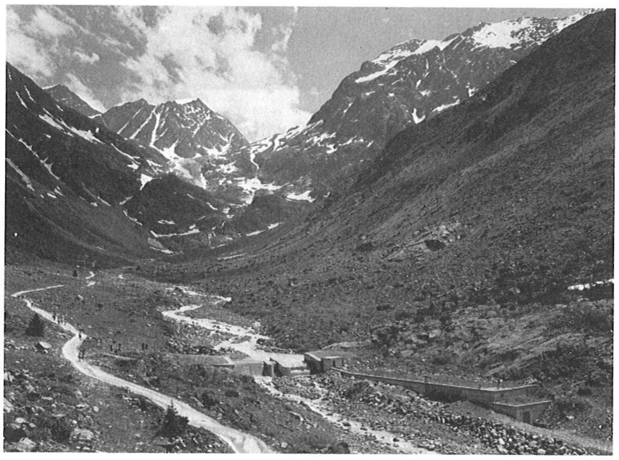


Fig. 48. Pitzbach stream intake (C) with horizontal coarse rack

Examples: Biel dam (A1) as shown in Fig. 9, with reinforced-concrete core wall,
Längental dam (D2) as shown in Fig. 17, with upstream asphalt facing,
Durlassboden dam (G1) as shown in Fig. 25, with earth core,
Galgenbichl dam (M2) as shown in Fig. 40, with upstream asphalt facing.

(f) Rockfill dams with machine-placed boulders as slope protection on downstream faces

Examples: Gepatsch dam (C) as shown in Fig. 13, with earth core,
Oscheniksee dam (K4), as shown in Fig. 47, with upstream asphalt facing,
Finstertal dam (D1), as shown on Figs. 17 and 63, with asphaltic-concrete core.

There will be no objective answer to the question which dam type blends better with the surrounding landscape. The probability is, however, that a high concrete dam will attract more attention as an engineering feat than a fill dam of the same height would, whose geometric slope shapes, although giving it away as a man-made structure as well, do so less conspicuously.

As our large dams have to withstand the highest loadings among the engineering structures—the Kölnbrein dam must sustain a load from water pressure of almost 4 million t at top water level—, selection of dam type will mainly be governed by enginering and economic appraisal of site topography and geology and availability of local construction materials.

Among the factors considered is the ratio of crest length to height as a characteristic of the valley cross section, as shown in Fig. 44 for Austria's major dams. Whereas arch dams predominate to the left of the bold line, i. e. for crest lengths less than four times the dam height, gravity and embankment dams are preferred for crest lenghts greater than four times the dam height. As demonstrated by various examples in Austria and abroad, embankments are increasingly used also for sites at narrow valley sections.

Diversions

The only visible component of a stream diversion is usually the intake, which will in general be an inconspicuous structure. Fig. 48 shows a design preferably used at high-lying sites, with a low submerged weir and with water being taken in through a horizontal coarse rack. The sand trap following downstream is either built against the slope and covered with earth (Fig. 48) or located in the adjacent tunnel. The latter is usually provided where steeply sloping tributary streams are present, so that intakes must mainly be constructed from the tunnels, so as to need no separate access road. In special cases, small concrete dams (Fig. 49) or gated weirs may be built as are often used for low-lying intakes with major catchments.

Diversion conduits usually consist of free-flow tunnels or buried pipelines with the result that the portals and potential piles of tunnel spoil are the only visible features that remain. Arguments that these piles may do harm to the scenery have been proved unfounded by experience. If enough care is used, it is always possible to make dumps of excavation materials blend with the surrounding landscape by adequate shaping and planting.

This is facilitated by improved tunnelling techniques and an increased use of tunnel boring machines, as the higher excavation rates involved allow longer tunnel sections—of 10 km or more—to be excavated from one heading. Thus, for a given length of a tunnel fewer points of attack are required for which it is easier to find suitable dump sites, unless the excavated material is used anyway for embankments and land fill.
This is confirmed by many photographs of project features, which hardly show any visible traces of the large amount of material that had to be moved during construction. An example is Fig. 16, showing the Kühtai area of the Sellrain-Silz group of power schemes (D). Concentrated in a relatively limited area were the sites for two large fill dams, the upper stage between them, involving major excavation volumes for the pressure shaft and the shaft-type power station, two major free-flow tunnels and two diversion pipelines. No dumps, borrow areas or other damage to the landscape are seen.

High-head stages

The above remarks are also true of the power tunnels and surge tanks, which rarely appear at the surface, so that little change to the landscape results.
The impact on the landscape of the steeply descending part of a power conduit between the surge tank, or reservoir, and the turbines will depend on whether this is a pressure shaft, a buried pipeline or above-ground penstock, or a combination of these possibilities.
As can be seen from the plant data listed in Tables I to X and from Fig. 50, which compares longitudinal profiles, pressure shafts and penstocks have been used in approximately equal amounts on the Austrian seasonal storage projects.

Fig. 49. Taschachbach stream intake (C) with concrete dam and frontal inlet

In particularly difficult ground, the excavation of a pressure shaft will have to be preceded by geological and geotechnical investigations extending to major depth to obtain information on in-situ rock mass, although in fact even large-scale preliminary studies do not preclude the possibility of surprises during construction. For example, the highly loaded pressure shaft above the Prutz power station of the Kaunertal scheme (C) had to be driven through rock of extremely poor mechanical properties. It was due to years of preliminary work that it was possible to complete the shaft in time. Fig. 51 is a photograph of the pressure shaft slope. In spite of the adit that had to be provided in this steep area prone to

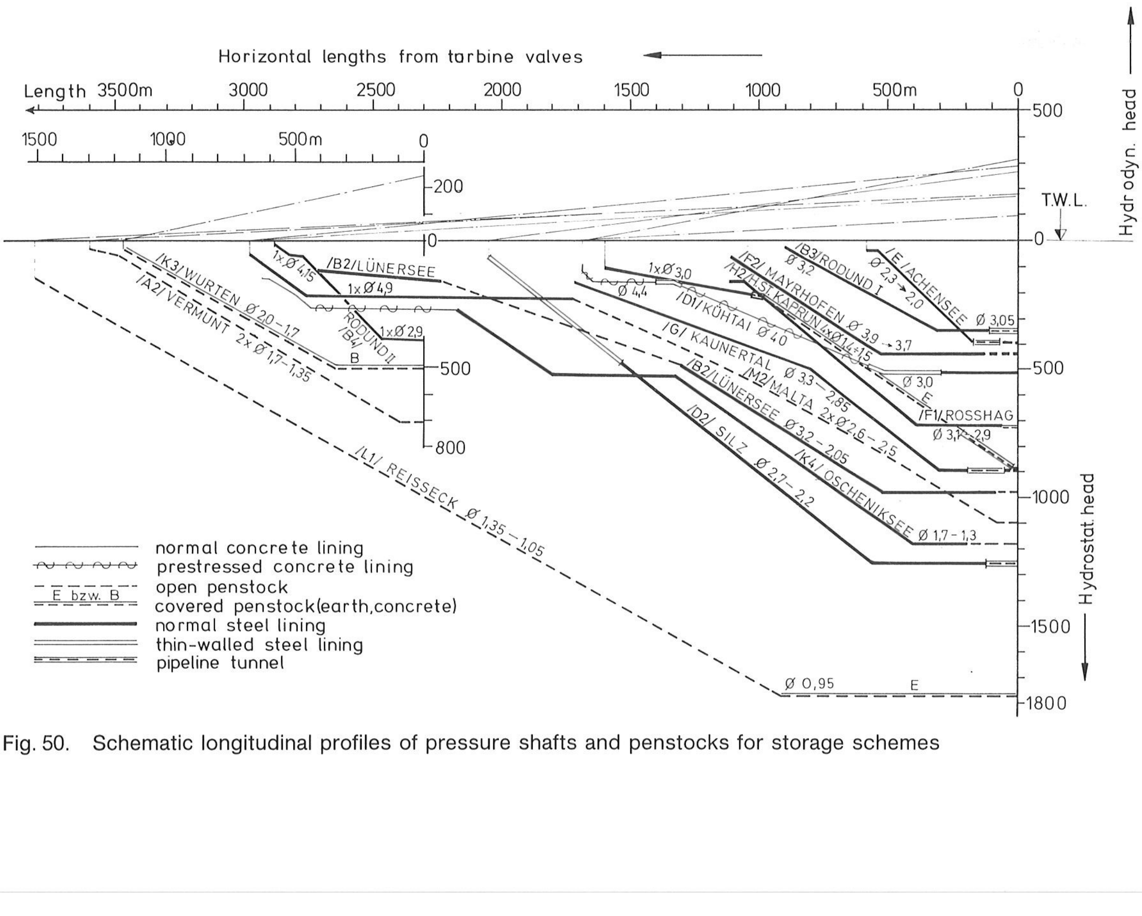


Fig. 50. Schematic longitudinal profiles of pressure shafts and penstocks for storage schemes

Fig. 51. Power shaft slope of Kaunertal scheme (C) with Prutz power station

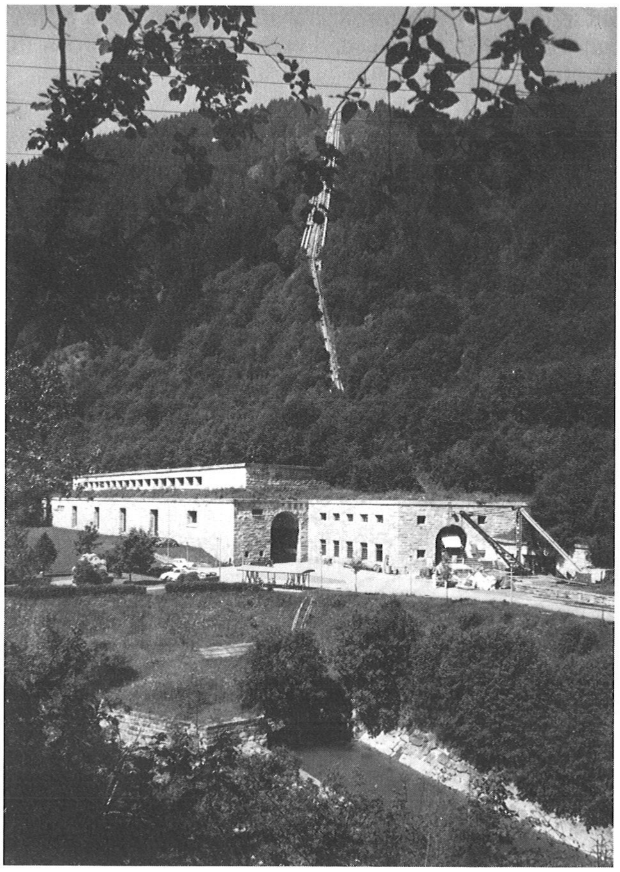


Fig. 52. Penstock and power station of Kaprun main stage (H3)

slides, the former construction sites and their access roads branching off the clearly visible public road to Fendels are hardly recognised.

Above-ground penstocks are bound to create rather conspicuous landmarks, especially where several pipes with a permanent inclined hoist form a straight track. At the Kaprun main stage (H3), even four pipes were laid along the hoist (two on either side), as shown in Fig. 52, with the lower one-third being covered by an arch structure and earth fill. The original plan was to cover the pipes with earth between the thrust blocks provided with the concrete caps then in use. This idea was abandoned in view of the problems of corrosion protection involved. The penstocks of the two Reisseck stages (L1 and L2), designed to resist maximum pressures of about 180 bar and 80 bar, respectively (Fig. 37, left), are of the conventional type, except that their lowest sections, crossing a flat talus fan, were laid as buried pipeline without intermediate thrust blocks and expansion joints.

Further development led to the omission of the concrete caps on the thrust blocks, as for instance on the Lünersee project (B2). The penstock sections of the power conduit were firmly embedded in the concrete of the thrust blocks by means of supporting rings and struts (see Fig. 53). At the Ausserfragant stage (K6), a simplified method was applied, providing for the longitudinal forces to be transferred through web plates with head bolt anchors welded to the underside of the pipe. A similar technique was used for the two penstocks of the Malta main stage (M2) (Fig. 37, right). With a diameter of 2.5 m each and designed to resist a pressure of 127 bar, these pipes represent superlatives in Austria. The end block (Fig. 55), situated 70 m above the valley floor, called for a special design with heavy steel struts and deep rock anchors to withstand the enormous forces acting upon it.

For the Wurten stage (K3) of the Fragant group of power schemes a construction method without actual thrust blocks was developed. The penstock was concrete-embedded over major lengths in a trench cut in the rock (Fig. 54). This facilitated the adaptation of the penstock alignment to the terrain. Depressions were bridged by above-ground pipe sections mounted on socketed steel columns.

Selection of the type of power conduit for the steep section descending to the turbines will mainly be determined by topographical and geological factors. Insufficient subsoil information may be a reason for precluding the pressure shaft method from consideration.

Power stations, usually located at lower levels, may be of the following types, apart from differences in the location of the main transformers, which can be read off Tables I to X.

1. Detached powerhouses,
   the most frequently used type, which may be subdivided according to manifold arrangement as follows:
   (a) with open manifold
       examples: Vermunt (A2),
       Achensee (E),
       Mayrhofen station (F2) of Zemm-Ziller scheme,
       Rottau power station of Malta main stage (M2) as seen in Fig. 55.

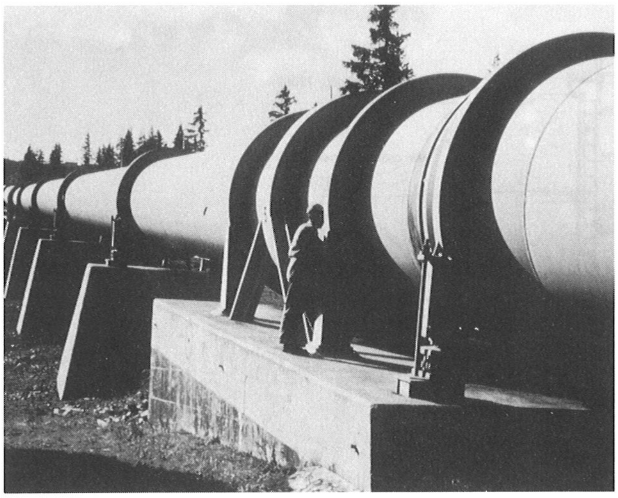


Fig. 53. Penstock thrust block without concrete cap, Lünersee scheme (B 2)

(b) with covered manifold
examples: Lünersee (B2) and
Rodund I (B3) as seen in Fig. 10,
Prutz power station of Kaunertal scheme (C) as seen in Fig. 51,
Silz lower stage (D2) of Sellrain-Silz scheme as seen in Fig. 59

2. Powerhouses built against the slope or covered with fill, mainly adopted where little space is available and as a precaution against alpine risks.
   Examples: Kaprun main stage (H3) as seen in Fig. 52,
   Rosshag power station of the Zemm upper stage (F1) as seen in Fig. 56,
   Innerfragant power station (K3 and K4) as seen in Fig. 34.
3. Shaft-type power stations, which are selected for schemes with pump-turbines requiring a high supply pressure.
   Examples: Rodund II (B4) with crane hall and
   Kühtai upper stage (D1) of the Sellrain-Silz scheme with open-air gantry crane as seen in Fig. 57.
4. Underground power stations, of which type only a few have been built for seasonal storage schemes.
   Examples: Kops (A3) as seen in Fig. 58,
   Möll pumping station (H1).
   (The underground power stations of Langenegg [VKW, 74 MW] and Braz [ÖBB, 30 MW] are not for seasonal storage, but also in the high head range.)

Although the above power station types are listed approximately in order of decreasing environmental impact, other factors are much more important in determining the degree of interference with nature resulting from a project. This concerns above all the control buildings, workshops, stores, garages, etc., which are likely to be larger than the powerhouse itself. Then the latter plays a subordinate role in the general appearance.
Inevitable facilities are high-voltage switching facilities, which are particularly large in extent where they form a node of the system. In such cases, outdoor switchyards

Fig. 54. Penstock of Wurten stage (K3) — Reinforced-concrete encased steel pipe without thrust blocks

Fig. 55. Rottau power station of Malta main stage (M2)

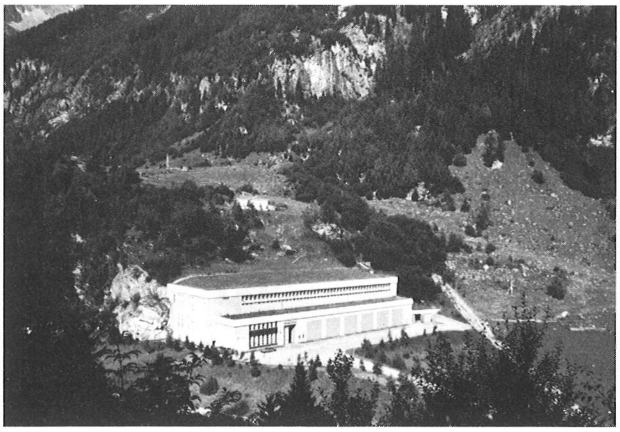


Fig. 56. Rosshag power station of Zemm upper stage (F1)

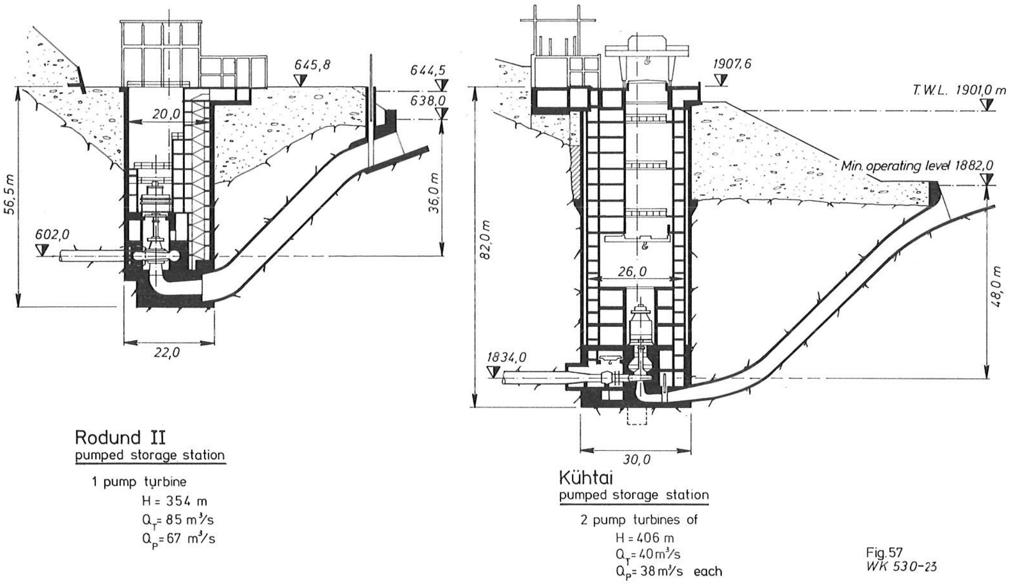


Fig. 57. Rodund II (B4) and Kühtai (D1) shaft power stations

will continue to be necessary. But they can only be located on wide valley floors anyway, where they are not exceedingly disturbing, as demonstrated by many examples (Figs. 37, 51 and 59). As the number of outgoing lines is usually small, indoor switching facilities are provided at power station locations in narrow valleys, especially where there is a potential risk of avalanches and rockfall. Examples of indoor switchgears are the Kaprun upper stage (H2) and the Innerfragant power station (K2 and K3), which are equipped with conventional 110 kV facilities, whereas SF_6 indoor installations for a voltage of 220 kV were provided at the Rosshag (F1) and Kühtai (D1) power stations.

Power stages may include tailraces and compensation or surge reservoirs. Where a wide valley floor calls for a long tailrace, a winding alignment (Fig. 59) and construction details designed to suggest a natural water course, for instance coarse gravel as bank protection and planting with local vegetation, may help to avoid the appearance of an artificial channel.

Greater repercussions may indeed result from the operation of the schemes than from the structures themselves. This particularly applies to the hydrological aspect.

B2. Water Level Variations in Storage and Compensation Reservoirs

It is certainly an uncontested fact that full or nearly full reservoirs are an asset to the landscape as compared with the original condition. Criticism is however aimed at the large water level variations, which are inevitable in seasonal storage reservoirs and which may reach as much as 100 m or more. This undeniable disadvantage is

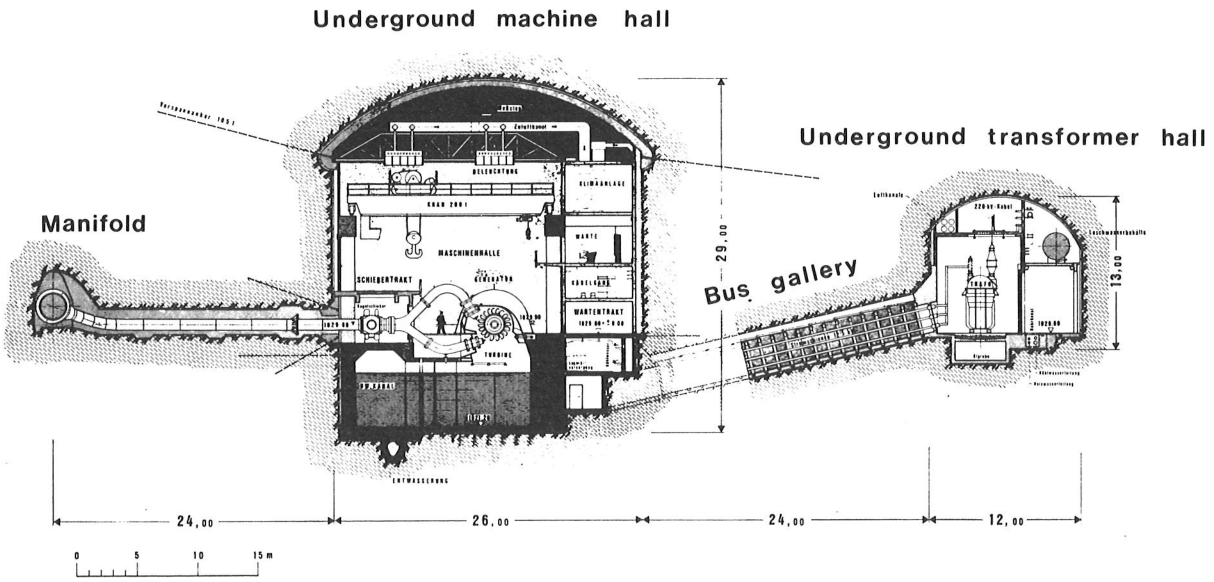


Fig. 58. Underground power station of Kops scheme (A3) [based on E. Stefko, ÖZE, 23. Jg. (1970), H. 7]

mitigated by the fact that filling proceeds rapidly in the lower reservoir portion, where the surface area is small, and that water level drawdown by some 20 m or 30 m against a background of towering peaks is less badly felt than would be in flat country.

The appearance of a reservoir is determined not so much by the amount of stored water as a percentage of active storage, as given in the statistics, as by the actual height of the water surface. Correct appraisal should be based on water level curves. Fig. 60 is a graph showing annual water level curves at Gepatsch (C) for a 10-year period. This demonstrates that the reservoir surface level is very likely to be sufficiently high from mid-July to the end of November, that is, during the main and after-seasons of tourism, whereas in winter and spring the dry reservoir slopes are covered with snow and ice anyway. Moreover, the upper slope portions of large reservoirs are usually too steep to retain mud depositions, and flat shores are lacking altogether or are limited to the upstream end of a reservoir.

Reservoir filling is faster if more flow is supplied. Any reduction in inflow, for instance by reducing the catchment or increasing the minimum release requirements, slows down the filling process and increases the probability of unsatisfactory conditions occurring, although only temporarily.

In compensation reservoirs, where water level variations are much smaller, a medium level is usually maintained for operational reasons, so that the visible strip of shore does not exceed very much the range of natural water level variations as occur for instance in cirque lakes.

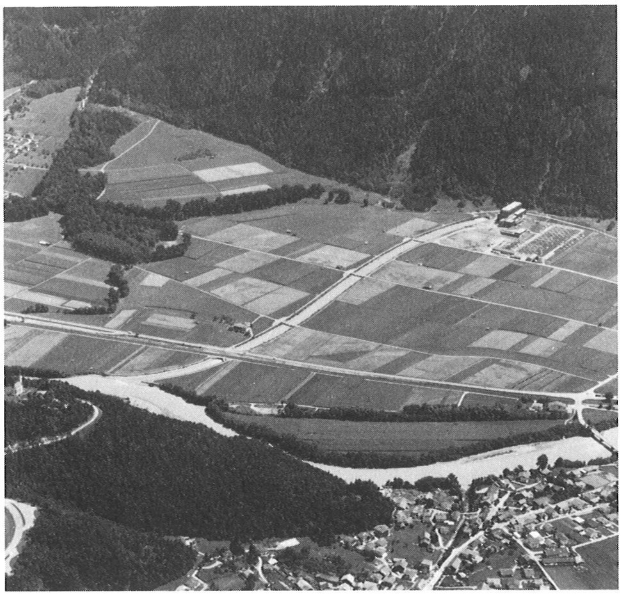


Fig. 59. Tailrace and power station of the Silz lower stage (D2)

B3. Flow and Water Level Changes in the Affected Streams

Development of the hydro potential by Alpine storage schemes is not possible without stream diversions. This implies that stream flow and, hence, water level downstream of dams and water intakes are affected. Indicating change in flow, or remaining flow, as a percentage of unaffected flow, or flow in terms of cubic metres per second, is misleading, as it is primarily the water level, or the change in water level, that forms the basis for assessing the effects. Without consulting measuring instruments, the observer will only perceive major water level changes. Therefore, the effects of changes in flow if expressed as percentages tend to be overestimated. The data furnished by the Plangeross gauging station (see Fig. 11) in the Pitz stream, a few kilometres downstream of the diversions for the Kaunertal scheme (C), have been used as a basis for studying the effect of water abstraction on water level. It has been found out

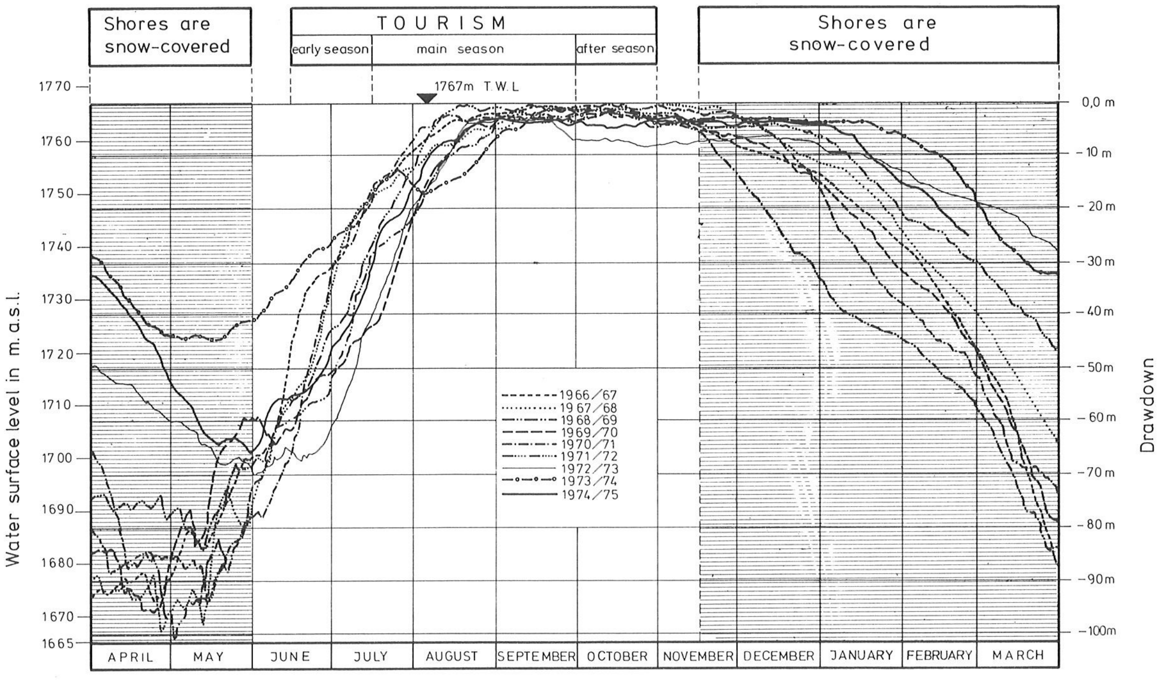


Fig. 60. Water level curves for Gepatsch reservoir (C), 1966 to 1975

Fig. 61. The Pitz stream near the Plangeross gauge during the low-flow period, with its catchment reduced to 15 per cent by flow abstraction for the benefit of the Kaunertal scheme (C)

that, as a result of flow reduction to about 15 per cent, water depth decreases to half in summer and to two-thirds in winter. At the St. Leonhard gauge further downstream, where flow amounts to about 48 per cent of the original value, the remaining water depth ranges between 80 per cent and 90 per cent. Fig. 61 is a photograph showing the Pitz stream at the Plangeross gauge during the low flow period. Although reduced to about one-seventh, streamflow is large enough to cover the whole streambed, so that there is no question of complete drainage.

Even if the entire streamflow is diverted, the severe effects are limited to a short reach downstream of a dam or intake, as tributaries combined with potential underseepage lead to a relatively rapid increase in remaining flow. Where diversions are limited to the preferred height range between elevations of about 1700 m and 2000 m above sea-level, the severely affected reaches are situated somewhere between the virtually virgin high-mountain region and the permanently inhabited settlements. During the winter months, these reaches will hardly be accessible and will practically be invisible under the snow.

Ecological effects of water abstraction from Alpine streams are limited to the streambed proper and its fauna, whereas the utilised catchment as well as the regions furnishing what streamflow remains are completely unaffected. There is certainly no potential risk to landscape ecology beyond the beds of the affected streams as for instance in the form of large-scale drainage or karst.

Detailed investigations have shown that diversion of the cold glacier water from V-shaped valleys tends to be beneficial to tree growth on the banks. Substantial abstraction of flow from the upper course of the Möll has not affected the vegetation on its banks of alders as are common in flat valley floors. Actually vegetation has spread into the streambed, now less claimed by the water.

The impact on the landscape of a reduced streamflow is largely dependent on the local conditions and defies objective appraisal. There is no doubt that unharnessed streams are a very important factor in an Alpine landscape. But the question whether or to which extent reduction in flow is permissible without impairing the landscape and its quality as a recreational resource is controversial. Criteria for assessing this question are furnished by the seasonal and weather-induced flow variations in natural streams. Actually, the season preferred by many mountaineers, Alpine painters and photographers is the autumn, although flows have substantially decreased and glacier streams can hardly be distinguished from ordinary streams at that time of the year. This renders doubtful any attempt at an academic assessment based on arbitrary assumptions or more or less suggestive inquiries among tourists. Better results will be obtained from site reconnaissance at different flows, and photographic documentation like that shown in Fig. 17, which allow realistic appraisal of the regime of remaining flows. In addition, the eleven groups of storage schemes with more than 20 seasonal storage reservoirs and more than 30 major high-head stages afford ample opportunity to find, for any special problem, comparable conditions, where longstanding experience gathered during operation facilitates realistic appraisal of the effects of hydro power development on the landscape and tourist trade.

B4. Effects on Bed Load Transport

We should distinguish between two different cases. Large reservoirs retain the entire amount of bed load so that the reduced downstream flow is matched by a reduced bed load transport. Downstream of stream intakes, however, bed load production remains unchanged in spite of the reduced flow. According to the classical bed load theory, assuming bed load production and transport capacity to be in balance, disturbance of this natural equilibrium would have to lead to large-scale sedimentation. In actual fact, in the great number of stream diversions that have been in operation for decades, nothing of that kind has happened. Sedimentation if any has remained insignificant.

Ever since R. Müller conducted his fundamental studies on this subject (1955), it has been known that many Alpine streams are in a state of "latent erosion", where bed load transport is much smaller than transport capacity, a theory that used to be difficult to prove in the individual case.

Evaluation of the automatic sand trap flushings carried on for many years on the stream intakes of the Kaunertal scheme (C) has rendered possible for the first time routine measurement of bed load transport in mountain streams and comparison of these measurements with the calculated transport capacity. In the case of the Pitz stream, transport capacity has been found to be ten times as large as the measured bed load production. Main valley stream reaches in a state of latent erosion are largely insensitive to diversion. This also explains why it has been possible to keep bed load production under control by means of occasional cleaning in streams affected by storage schemes. Streams in a state of latent erosion are characterised by very coarse-grained bed load material which is hardly moved even by major floods. This is believed to apply to the greater part of Alpine streams, as is also demonstrated by Fig. 61.

B5 and B6. Effects on Underground Water Conditions

Water contained in joints and fissures of the rock mass may be affected by the excavation of tunnels and shafts, which are likely to cause a drainage effect so as to lower the water table in places. However, groundwater in the Central Alps is a negligible factor, as it emerges, if at all, in deeply incised ravines only and is otherwise substantially below ground level, so that vegetation cannot possibly be influenced by changes in the water table.
Whereas groundwater conditions may assume great importance in backwater areas of run-of-river stations, they do so rarely in storage schemes in the Alps. There is usually no connexion between the ground water in the heterogeneous valley fills of tributary ravines and the main stream, so that water level variations, except for floods, hardly influence the ground water. Vegetation on the valley bottoms is in most cases independent of the ground water. Perceptible effects may be felt around outlet works in stream stretches with an insufficient gradient, but these are easy to control, and have practically caused no impairment.

B7. Effects on the Climate

For affecting the macroclimate, Austria's storage reservoirs would have to be by two or three decimals larger in magnitude.
As to the effects on the local microclimate, it is mainly feared that mist may form above intermediate and compensation reservoirs, most of which are situated near villages. As, however, long records of meteorological observations have shown mist to form preferably above land rather than water, and as there is enough movement of air in the tributary valleys of the Alps, such fears have in most cases proved unfounded.

B8. Benefits to Downstream Regions

(a) Flood protection

Flood storage in the large reservoirs is an important flood-risk reducing factor in the valley concerned. The

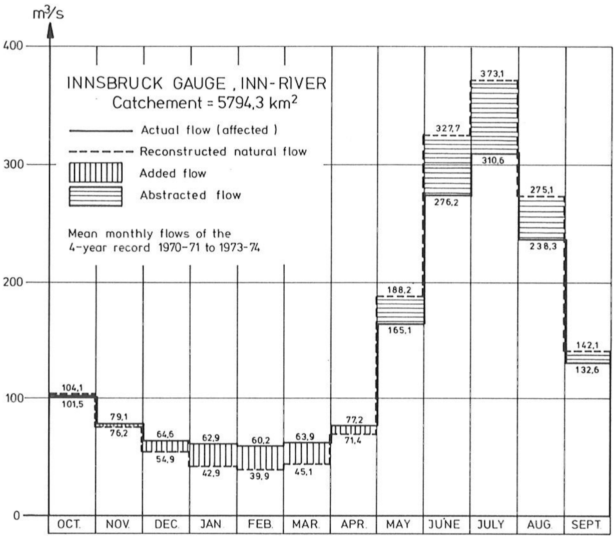


Fig. 62. Effects of storage schemes on the flow of the Inn near the Innsbruck gauge

fact that spillways are practically never in action is evidence that flood frequency downstream of large dams is substantially reduced.
The effect on downstream areas depends on power station operation, which may be inevitable to ensure power supply to the region attained by the flood. As long as the reservoir surface is rising, a favourable effect is produced downstream of the outlet works, although this effect decreases in the downstream direction.

(b) Additional flow during low-flow periods

Additional flow from reservoir operation during low-flow periods benefits even remote downstream areas. Fig. 62 is a graph showing the effect of storage schemes on the flow of the river Inn at Innsbruck. Despite the diversions towards the province of Vorarlberg (A3), low flow during the winter months is appreciably improved. The contribution from reservoir releases amounts to as much as half the natural flow in mid-winter, which is certainly beneficial to water quality, whereas flow retention during the period of abundant flows in the summer months has hardly any adverse effects.

6. Conclusions

The above analysis of main environmental effects from storage schemes confirms and explains the mainly favourable experience gathered during many decades of operation.
This allows any risk of a profound impact on the ecology to be precluded, as both the developed catchment and undeveloped catchments supplying the remaining streamflow escape the effects except for some insignificant marginal areas. Ecological alterations, if any, are limited to the storage reservoirs and the stream stretches affected by the diversions and do not extend beyond the streambeds and stream biology, whereas no harm is in general caused to the vegetation on the banks. What perceptible effects on nature and landscape are produced will in general be restricted to the transition zone between the permanently inhabited villages and the high mountain regions proper, the latter even remaining virtually unaffected and unaltered except for a few high-lying cirque lakes.
Most of the regions affected by the storage schemes are in fact no virgin country, but cultivated areas that have long been under the influence of man. In accordance with the respective climatic and economic conditions, and constantly fighting the forces of nature, man has constantly modified these areas for centuries by utilising them as alpine pastures and for forestry and other purposes. This includes intensive mining and metallurgical activities in former times, which have left traces extending to the highest mountain regions, especially in the Hohe Tauern range.

Fig. 63. Finstertal reservoir and embankment dam (D1) in the Kühtai winter sports region

Apart from the engineering structures and storage reservoirs, effects on the landscape mainly concern stream reaches affected to a major extent by the diversions. Storage schemes are in a favourable position as compared with other industrial plants in promising constancy in respect of product, process and output. This allows careful construction, maintenance and landscape preservation with a view to a long service life. Modern earthworks equipment and landscaping methods help to fit into the terrain large dams and stream intakes as well as the dumps for surplus excavation material, so that there is now hardly any reason for complaints.
Storage reservoirs are mainly considered as assets to a landscape, as it is only early in summer that the inevitable water level variations become a perceptible nuisance. Flow abstraction from stream beds is mainly felt over the reaches immediately downstream of dams and stream intakes. Especially at the high-lying sites, most stream beds are soon filled by natural affluents further downstream. As suggested by the large flow variations in nature, the appearance of a stream is governed by the water level rather than the actual amount of flow. In fact, the river bed must sufficiently be covered with water. This observation is also borne out by the large natural flow variations.
This is also the reason why in Austria, as in the rest of the Alps, compensation water releases have rarely been required in the case of high-lying storage schemes. The general introduction of minimum release requirements would imply that the same amount of energy production would call for the harnessing of a larger number of streams, so that in actual fact impairment would even be larger.
As to the economic effects it should be mentioned that normally relocation of local population is not necessary and that cultivated land accounts for only a very small proportion of the areas used for storage schemes. Apart from the construction period, during which the economy of the whole region receives an important impetus, large sums of duties and taxes are derived after the commissioning of the project, usually supplemented by current compensation payments and contributions or funds for financing improvement of the infrastructure.
Tourist trade, next to inevitable in mountainous regions to prevent rural exodus, is in general promoted by the new or improved roads necessary for the construction of hydro projects, as access is provided to hitherto hardly accessible points of scenic beauty and to new sights. Reductions in overnight stays as were in some cases experienced during construction were made up for in no time after completion of the project. At any rate, the fact that all the groups of power schemes described in this article are situated in or next to flourishing tourist regions is evidence that in the long run tourist trade certainly suffers no harm from hydro schemes.
As stated by D. Vischer (1975), the development of hydro power has so far been the only soft technology to be used for large-scale energy production.
Hydro schemes utilise as primary energy the water power continuously available in nature. From this the secondary energy needed by the consumer is generated with minimum conversion loss. In the case of storage schemes, this is valuable peak energy. Attempts made so far to utilise wind and sun for power generation have shown that large scale development of these sources of energy would have much greater environmental impact. The only alternatives to our storage schemes are at present gas turbines and pumped storage plants supplied from thermal base-load plants. Comparison of the environmental repercussions involved should consider not only direct effects of thermal generation, but also the effects of all the production and treatment processes including transports and temporary and final storage necessary for obtaining fuels or fuel elements and for the disposal of nuclear and other waste, which is often neglected.
We are faced almost daily with news about new damage to trees and other nuisance resulting from waste gases, increasing pollution of the oceans through mineral oil, the steadily increasing CO_2 concentration of the atmosphere and the generation of vast amounts of waste heat, with effects on fauna and flora and human health that are difficult to keep track of. Compared to this, the environmental impact from storage schemes is mainly of an esthetic nature and of such negligible magnitude that further application of this soft technology can be advocated and justified before future generations.

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ÖZE = Österreichische Zeitschrift für Elektrizitätswirtschaft
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TABLE I. THE SEASONAL STORAGE SCHEMES OF VORARLBERGER ILLWERKE AG (VIW) BREGENZ, Part A
PART 1: CATCHMENTS, RESERVOIRS AND DIVERSIONS

A1 to A4: Part 1

POWER SCHEME (OWNER)	1	A UPPER ILL SCHEME (VIW)			
Power stage (power station) District (province) Initial operation (extension)	2 3 4	A1 Obervermunt (Obervermunt) Bludenz (Vorarlberg) 1943 (1950)	A2 Vermunt (Partenen) Bludenz (Vorarlberg) 1930 (1953)	A3 Kops (Partenen) Bludenz (Vorarlberg), Landeck (Tyrol) 1969	A4 Rifa Bludenz (Vorarlberg) 1969
River basins Utilised Catchments: directly to res. diversions to stage or trans-basin diversions and upstream power stations total	5 6z 6a 6b 6c 6d 6e 6f 6g 6	Ill (Rhein) Ill 35 km2 Bieltalbach 10 km2 total 45 km2	Ill (Rhein) Ill 22 km2 Valzifenzbach 8 km2 Vergaldnerbach 13 km2 Garnerabach 11 km2 Vallülabäche 8 km2 from Obervermunt (A1) 45 km2 total 107 km2	Ill (Rhein), Trisanna, Rosanna (Inn) Zeinisbach 7 km2 Idbach 8 km2 Fimberbach 39 km2 Larainbach 17 km2 Jambach 36 km2 Kleinvermuntbach 20 km2 Rosanna + Fasulbach 34 km2 Verbellabach 9 km2 total 170 km2	Ill (Rhein) 0 km2 from Vermunt (A2) 107 km2 from Kops (A3) 170 km2 total 277 km2
Reservoir: Name Max./mean/min. water level Active storage (stored energy)	7 8 9	Silvretta reservoir 2030/2014/1986 m 38,6 hm3 (110 GWh)	Vermunt reservoir 1743/1735/1719 m 5,3 hm3 (12 GWh)	Kops reservoir 1809/1778/1720 m 44 hm3 (108 GWh)	Rifa compensation reservoir *) 1000/---/987,5 m 0,67 hm3
Dam: Name Type Height/crest length/crest level Volume Spillway: Type Capacity	10 11a 11b 12 13 14 15	Silvretta dam — Biel dam gravity — gravelfill with straight — reinf. concrete core 80/432 m/2032 m a.s.l. — 25/730 m/2033,3 m a.s.l. 407.000 m3 concrete *) — 0,375 . 10⁶ m3 fill overflow + side spillway — 18.000 m3 concrete 36 m3/s + 68 m3/s for ca. 0,9 m surcharge	Vermunt dam gravity straight, angled in plan 53/386 m/1744,7 m a.s.l. 144.000 m3 concrete overflow + side spillway 129 m3/s for 0,8 m surcharge	Kops dam Arch dam with abutment gravity dam double curvature 122/400 m - 1811 m a.s.l. - 43/214 m 485.000 m3 concrete 178.000 m3 overflow spillway in gravity dam, 30 m long 42 m3/s for 0,8 m surcharge	Rifa artificial basin 12,5 m deep, earthfill dam downstream asphaltic concrete facing 14/700 m/1001,5 m a.s.l. 0,3 . 10⁶ m3 earthfill spillway with stone ramp ca. 50 m long, crest 1001,1 m
Diversions to stages and trans-basin diversions (for abbreviations, see line 23) a) Name (catchment) Stream intake: (number) Q_r - type Waterway: type length/section b) Name (catchment) Stream intake: (number) Q_r - type Waterway: type length/section c) Name (catchment) Stream intake: (number) Q_r - type Waterway: Type length/section d) Name (catchment) Stream intake: (number) Q_r - type Waterway: type length/section e) Name (catchment) Stream intake: (number) Q_r - type Waterway: type length/section	16a 17a 18a 19a 16b 17b 18b 19b 16c 17c 18c 19c 16d 17d 18d 19d 16e 17e 18e 19e	a) Bieltalbach trans-basin div. (6a) (1) 5,0 m3/s - T free-flow tunnel 1,0 km/3 m2	a) Trans-basin div. of Ill tributaries (6a-c) (3) 1,5 + 2,5 + 2,0 m3/s - T free-flow tunnel 11,3 km/5 m2 b) Vallüla trans-basin div. (6d) (2) 1,5 m3/s pressure tunnel *) sag pipe, steel-lined 6,0 km/2,2 m Ø 0,2 km/0,7 m Ø	a) Paznaun div. to Jambach junction (6a+b+c) (3) 1,2 + 7,0 + 3,0 m3/s concrete pipe, free-flow tunnel, 2 sag pipes 2,9 km/0,7 m Ø;6,9 km/6 + 9 m2;1,1 km/1,4+1,6m Ø b) Paznaun div.: Jambach junction (6d) (1) 7,0 m3/s steel pipe 0,7 km/1,7 m Ø c) Paznaun div. from Jambach junction (6e) (1) 2,3 m3/s - T with ZP Kleinvermunt (l. 20) 1 sag pipe, free-flow tunnel 0,85 km/2,1 m Ø, 5,8 km/4 - 9 m2 d) Fasul - Rosanna trans-basin div. (6f) (2) 3,0 and 3,5 m3/s - T free-flow tunnel 10,7 km/ 7,0 m2 e) Verbella trans-basin div. (6g) (1) 2,0 m3/s - T free-flow tunnel 1,7 km/4,0 m2	none
(ZP) Feeder pumping station: Name (trans-b.diversion) Q_r/H_{gr} number of pumps x capacity	20 21 22			(ZP) Kleinvermunt (16c) 2,3 m3/s / 164 m 2 x 2,2 MW - 4,4 MW	
Footnotes *) Abbreviations in line 17: T.... Tyrolean weir with sand trap	23a 23b 23c 23d 23e 23f	re. line 13: side dam, 18.000 m3 concrete	re. line 18b: Connection with Kops res. (A3) butterfly valve 1,6 m Ø and needle valve		re. line 7: lower basin supplementing Partenen compensation reservoir (see B1: Latschau stage) as upper basin

TABLE I, PART 2: HIGH-HEAD STAGES AND GENERATION

POWER SCHEME (OWNER)	30	A UPPER ILL SCHEME (VIW)			
Power stage (power station)	31	A1 Obervermunt (obervermunt)	A2 Vermunt (Partenen)	A3 Kops (Partenen)	A4 Rifa
T ... generating mode P ... pumping mode; Mode of operation	32	generation	generation	generation	pumped storage *)
Max./mean/min. gross head	33	311/279/243 m	727/714/694 m	780/748/690 m	37,2/ - /16.1 m
Max. discharge Q_T (Q_P)	34	14 m3/s	26 m3/s	37.5 m3/s	30 m3/s (30 m3/s)
POWER CONDUIT OF STAGE: Intake gates (number) type	35	2 butterfly valves	2 fixed-wheel gates + 1 fixed-wheel gate	2 butterfly valves	1 fixed-wheel gate
Intake gates: cross section	36	2.2 m Ø	2.8 x 4.7 m 3.2 x 3.2 m	2.6 m Ø	5.4 x 4.5 m
Power tunnel: length sections/int. Ø	37	not applicable	2.5 km/2.8 m Ø	3.66 km/3.25 m Ø 0.77 km/3.25 m Ø	
Power tunnel: lining	38a		concrete	concrete with internal	not applicable
	38b			prestressing gap grouting concrete ring	
Power tunnel: total length/max. pressure	39		2.5 km/4 bar	4.8 km/13 bar	
Surge tank	40	not applicable	2-chamber, with orifice	2-chamber, with orifice	
Penstock or shaft: type	41	1 penstock, above-ground	2 penstocks, above-ground	1 pressur shaft	1 penstock, buried
Upper part: length sections/int. Ø	42	3.27 km/2.40 - 2.10 m Ø	not applicable	not applicable	550 m/3.0 m Ø
Upper part: construction	43a	steel pipe, riveted			reinforced concrete with
	43b	with expansion pieces & concrete thrust blocks			plastic foil lining
Gates: type, position	44	see line 36	butterfly valves	none	none
Gates: (number) cross section	45		(2 x 2) 1.7 m Ø		
Lower part: length sections/int. Ø	46	3270/2.40 - 2.10 m Ø	1368 m/2 x 1.77 - 1.35 m Ø	1227 m/2.6 m Ø	300 m/2.85 m Ø
Lower part: construction	47a	steel pipe, riveted	steel pipe *), water-gas welded & riveted	steel-lined	reinforced concrete with
	47b	with expansion pieces & concrete thrust blocks	with expansion pieces & concrete thrust blocks	gap grouting	steel-lining
Manifold: position	48	1 manifold, buried	above-ground with thrust blocks	concrete-embedded in pipe gallery, 6 branches	concrete-embedded & earth-covered, 2 branches
Manifold: max. pressure - stat./dyn.	49	29 / 35 bar	72 / bar	79/87 (exceptional 100) bar	38/53 bar
Tailrace	50a	short	concrete canal	free-flow tunnel concrete canal	2 concrete canals
	50b	tailrace canal	60 m/12.5 m2	200 m/34 m2 200 m/34 m2	50 m/6 m2
Discharge to	51	Vermunt reservoir (A2)	Partenen compensation reservoir (B1)	Partenen compensation reservoir (B1)	Rifa compensation reservoir (see line 7)
POWERHOUSE: Type	52	above-ground, reinforced concrete	above-ground, steel frame	underground, concrete lining	shaft powerhouse with crane hall
Dimensions (without control building)	53	30 x 12 m, total height 28 m	60 x 18 m, total height 20 m	70 x 26 m, total height 29 m	18 x 15 m, total height 25 m
Special features	54a	transformers in open bays	transformers in switchyard	transformer cavern 52x13 m, 13 m high	transformers in switchyard
and position of transformers	54b			turbine gates in machine hall	
Power units: (number) position, speed	55	(2) vertical, 600 rpm	(5) horizontal, 500 rpm	(3) horizontal, 500 rpm	(2) vertical, 200 rpm
Power units: type	56	1 Francis turbine each	Pelton turbine, 2 jets	2 Pelton turbines, 2x2 jets, each	1 Deriaz pump turbine each
Power units: upstream gates: type, int. Ø	57	1 rotary valve 0.95 m Ø each	2 rotary valves each 0.6 and 0.7 m Ø	1 rotary valve 0.9 m Ø each	1 butterfly valve 1.7 m Ø each
Power units: T rating: H/Q/N	58	291 m/7 m3/s / 18.1 MW	(4) 665 m/5 m3/s / 29.6 MW	776 m/12.4 m3/s / 84.6 MW	28 m/13.5 m3/s /3.3 MW
Power units: P rating: H/Q/N	59	---	(1) 665 m/6 m3/s / 36.8 MW	----	29 m/14 m3/s /4.4 MW
Power units: downstream gates: type, dimens.	60	stop logs	2 gates 5x3.5 m & 5x3.0 m	stop logs	stop logs
Power units: generator: capacity, cooling	61	19 MVA each, ring air cooling	(4) 30 MVA (1) 35 MVA	102 MVA each, ring air cooling	5.6 MVA each, motor generator
Transf.: (number) type, arrangement,	62	(2x3) singlephase, block-type	(5) threephase, block-type	(3) threephase, block-type	(2) threephase, block-type
capacity, voltage ratio	63	19 MVA, 6/20 kV	(4) 30 MVA, (1) 35 MVA, 6/110 kV	102 MVA, 12.5/220 kV	5.6 MVA, 6/110 kV
Switchplant	64	indoor 20 kV *)	switchyard 110 kV	switchyard 220 kV *)	switchyard 110 kV
Plant capacity of T and/or P; max.	65	T: 31 MW	T: 148 MW	T: 245 MW	T: 9 MW P: 9 MW
Annual energy without short-t.pumping (with)	66	45 GWh	260 GWh	392 GWh	(9 GWh)
Winter share %/full-load h.p.a.	67	58 % / 1450 h	37 % / 1760 h	34 % / 1600 h	short-term pumping only
Annual P energy without short t.pump. (with)	68	----	----	9 GWh	(13 GWh)
Footnotes *)	69	re. line 64: power sent out through 20 kV cable	re. line 47a: protective wrapping over lower station	re. line 64: connection through 220 kV cable	re. line 32: to supplement Partenen compensation reservoir, which serves as upper basin for Rifa (see B1)

TABLE II. THE SEASONAL STORAGE SCHEMES OF VORARLBERGER ILLWERKE AG (VIW) BREGENZ, Part B

PART 1: CATCHMENTS, RESERVOIRS AND DIVERSIONS

B1 to B4: Part 1

POWER SCHEME (OWNER)	1	B RODUND - LÜNERSEE SCHEME (VIW)			
Power stage (power station)	2	B1 Latschau	B2 Lünersee	B3 Rodund I	B4 Rodund II
District (province)	3	Bludenz (Vorarlberg)			
Initial operation (extension)	4	1950 (free-flow tunnel since 1943)	1958	1943 (1952)	1976
River basins	5	Ill (Rhein), Trisanna, Rosanna (Inn)	Alvier (Ill, Rhein)	Ill (Rhein), Trisanna, Rosanna (Inn)	
Utilised Catchments: directly to res.	6z	Ill (second intake) 22 km2	Lünersee 9 km2	0 km2	
diversions	6a	Tschambreu- and Valschavielbach 29 km2	Brandner Gletscher 3 km2		
to stage	6b	Unterer Garnera- and Vermielbach 27 km2			
or	6c	Suggadin- and Rasafeibach 72 km2			
trans-basin diversions	6d	Rellsbach 27 km2			
and	6e	from Vermunt st. (A2) 107 km2		from Latschau st. (B1) 454 km2	
upstream	6f	from Kops st. (A3) 170 km2		from Lünersee st. (B2) 12 km2	
power stations	6g				
total	6	total 454 km2	total 12 km2	total 466 km2	
Reservoir: Name	7	Partenen compensation reservoir	Lünersee reservoir	Latschau I and II reservoirs *)	
Max./mean/min. water level	8	1024,7/----/1016,1 m a.s.l.	1970/1939/1897 m a.s.l.	992,25/----/974 m a.s.l.	
Active storage (stored energy)	9	0,133 hm3	78,3 hm3 (255 GWh)	2,3 hm3 (2,5 GWh)	
Dam: Name	10	Partenen artificial basin	Lünersee dam	Artificial basin, 21 m deep	
Type	11a	8,6 m deep, downstream earthfill dam	gravity	West earth dam / East earth dam	
	11b	facing, 3 bitumen layers	several angles in plan	complete asphalt concrete facing	
Height/crest length/crest level	12	10/350 m/1026,0 m a.s.l.	30/380 m/1971,6 m a.s.l.	50/480 m - dam crest 993,7 m a.s.l. - 22/260 m	
Volume	13		41.000 m3 concrete	ca. 1,0.10[6] m3 earthfill	
Spillway: Type	14	spillway, 20 m long	side spillway, 50 m long	3 siphon spillways	
Capacity	15	48 m3/s for 1,2 m surcharge	12 m3/s for 0,25 m surcharge		
Diversions to stages and trans-basin diversions (for abbreviations, see line 23): a) Name (catchment)	16a	a) Ill - trans-basin diversion (6z)	a) Brandner Gletscher trans-basin diversion (6a)	none	
Stream intake: (number) Q_r - type	17a	(1) 7,0 m3/s rolling gate with sand trap	Intake under glacier		
Waterway: type	18a	concrete canal	drop shaft / free-flow tunnel		
length/section	19a	0,2 km/2 m2	16 m/1,8 m Ø / 1,35 km/3,6 m2		
b) Name (catchment)	16b	b) Tschambreu- & Valschavielbach diversion (6a)			
Stream intake: (number) Q_r - type	17b	(1) 1,0 m3/s - TE / (1) 5,0 m3/s - TE			
Waterway: type	18b	steel pipe / prestr. concrete pipe			
length/section	19b	0,8 km/1,2 m Ø / 0,9 km/1,2 m Ø			
c) Name (catchment)	16c	c) Garnera- & Vermielbach diversion (6b)			
Stream intake: (number) Q_r - type	17c	(1) 4,5 m3/s - TE / (1) 3,0 m3/s - TE			
Waterway: type	18c	concrete canal / pressure tunnel			
length/section	19c	0,06 km/3,5 m2 / 0,17 km/1,4 m2			
d) Name (catchment)	16d	d) Suggadin- & Rasafeibach diversion (6c)			
Stream intake: (number) Q_r - type	17d	(1) 14,0 m3/s - TE / (1) 5,0 m3/s - TE			
Waterway: type	18d	concrete canal, prestr.concr.pipe, reinf.concr.sag pipe			
length/section	19d	0,16 km/5 m2 0,38 km/1,2 m Ø 0,09 km/1,4 m2			
e) Name (catchment)	16e	e) Rellsbach diversion (6d)			
Stream intake: (number) Q_r - type	17e	(1) 5,0 m3/s - TE			
Waterway: type	18e	concrete pipe / free-flow tunnel			
length/section	19e	0,3 km/1,0 m Ø / 2,9 km/4 m2			
(ZP) Feeder pumping station: Name (trans-basin diversion)	20				
Q_r/H_{gr}	21				
number of pumps x capacity	22				
Footnotes *)	23a			re. line 7: reservoirs I & II with connection gallery,	
Abbreviations in lines 17a to e:	23b			seperating dam - crest 5,25 m below T.W.L.	
TE .... Tyrolean weir with sand trap	23c				
	23d				
	23e				
	23f				

TABLE II, PART 2: HIGH-HEAD STAGES AND GENERATION

POWER SCHEME (OWNER)	30	B RODUND - LÜNERSEE SCHEME (VIW)			
Power stage (power station) T ... generating mode P ... pumping mode	31	B1 Latschau	B2 Lünersee	B3 Rodund I	B4 Rodund II
Mode of operation	32	generation	pumped storage	pumped storage	pumped storage
Max./mean/min. gross head	33	28/---/11 m	975/944/902 m	364/353/330 m	364/354/330 m
Max. discharge Q_T (Q_P)	34	44 m3/s	32 m3/s (28 m3/s)	60 m3/s (10 m3/s)	90 m3/s (67 m3/s)
POWER CONDUIT OF STAGE (for diversions, see line 6a) — Intake gates: (number) type	35	(2) sluice gates	(2) butterfly valves	fixed wheel gate	bulkhead gates
Intake gates: cross section	36	4.0 x 3.7 m (sompens. res. l. 7)	2.5 m Ø (140 m downstream of intake)		
Power tunnel: length sections/int. Ø	37a	free flow channel	1. power tunnel Salonien sag pipe 2. power tunnel	not applicable	not applicable
	37b	0.82 km 1.15 km 0.36 km 15.7 km	3.06 km 1.34 km 2.47 km		
Power tunnel: lining	38a	covered reinf.-concr. trough free flow	3.05 m Ø 2.6 m Ø and 2.4 m Ø 3.05 m Ø		
	38b	concrete canal sag pipe bridges tunnel	concrete st.-lined shaft, st.pipe concrete *)		
Power tunnel: total length/max. pressure	39	18.74 km, Qmax increasing from 28 to 44 m3/s	6.9 km, 13 bar (sag pipe 34 bar)		
Surge tank	40	forebay *) T.W.L. 1002.9 m a.s.l.	2-chamber, with orifice	not applicable	not applicable
Penstock or shaft: type	41	2 penstocks	1 pressure shaft, 1 penstock	1 pressure shaft	1 pressure shaft
Upper part: length sections/int. Ø	42	not applicable	482 m/3.20 m Ø	not applicable	not applicable
Upper part: construction	43		inclined tunnel, steel-lined		
Gates: type, position	44	gates (downstream of forebay l. 40)	butterfly valve (valve chamber)	not applicable	not applicable
Gates: (number) cross section	45	(2) 4.0 x 3.7 m	(1) 2.50 m Ø		
Lower part: length sections/int. Ø	46	122 m/2 x 2.85 m Ø	1046 m/2.25 m Ø 916 m/2.15 m Ø 421 m/2.05 m Ø	676 m/3.20 m Ø 178 m/9.05 m Ø	122 m/5.0 m Ø 473 m/4.15 m Ø 80 m/4.15 & 2.9 m Ø
Lower part: construction	47a	64 m reinforced concrete pipe	steel pipe with steep shaft low-grade section	steep section low-grade section	inclined tunnel steep section low-grade section
	47b	58 m steel pipe	exp. pieces steel-lined steel-lined	steel-lined steel lined	concrete steel-lined steel-lined
Manifold: position	48	not applicable	hanging, in gate ch., 6 branches	hanging, in pipe duct, 6 branches	not applicable
Manifold: max. pressure - stat./dyn.	49		97 bar/111 bar (max. 126 bar)	35 bar/43 bar	39 bar/55 bar
Tailrace	50a	direct draft tube outlets	short concrete channels	direct draft tube outlets	60 m/6.6 m Ø
	50b				tunnel, concrete lining
Discharge to	51a	Latschau reservoir (B3 and B4)	T : Latschau reservoir (B3 & B4)	Rodund I basin *)	Rodund II basin *)
	51b		T*): Latschau forebay (B1, l. 40)	lll, or Wallgau station (constructing)	lll, or Wallgau station (constructing)
POWERHOUSE — Type	52	tower with outdoor gantry crane	above-ground, reinforced concrete	above-ground, reinforced concrete	shaft power station with crane hall
Dimensions (without control building)	53	17 m Ø x 25 m, total height 33 m	without gate hall, 119 x 19 m, height 45 m	80 x 26 m, total height 32 m	22 m Ø, total height 72 m
Special features (position of transf.)	54a	transformers in switch building of B2	service valves in machine hall	transformer against external wall	upstream gate in powerhouse shaft
	54b		transformer against external wall		transformer in switchyard
Power units: (number) position, speed	55	(2) vertical, 300 rpm	(6) vertical, 750 rpm	(4) horizontal, 500 rpm	(1) vertical, 375 rpm
Power units: type and arrangement	56	(1) Kaplan turbine each	(1) Pelton t., 5 jets, conv., five-stage pump each	(1) Francis t.,(1) double-flow, 2-slage pump *) each	(1) pump turbine
Power units: upstream gates: type, int. Ø	57		1 rot. valve + 1 rot. v. (T) + 1 needle v. (P) each	1 rot. valve 1.3 m Ø (T) 1 rot. valve 1.2 m Ø (P)each	(1) rotary valve 2.55 m Ø
Power units: T rating: H/Q/N	58	27 m/20 m3/s /4.3 MW	T: 875 m/5.5 m3/s /46.2 MW	T: 350 m/15 m3/s /43 MW	T: 354 m/90 m3/s /270 MW
Power units: P rating: H/Q/N	59	---	P: 972 m/4.2 m3/s /43 MW	P: 348 m/10 m3/s /40 MW	P: 346 m/75 m3/s /256 MW
Power units: downstream gates: type, dim.	60	stop logs	T: stop logs P: gates	bulkhead gates	fixed-wheel gate
Power units: generator: capacity, type	61	(1) 5 MVA synchron. generator	(1) synchr. motor generator 56 MVA each	(1) syn. motor generator 53 MVA	(1) motor generator 310 MVA
Transf.: (number) type, arrangement,	62	(2) threephase, block-type	(5) threephase, block-type	4 x 2 threephase, block type	(1) threephase, block-type
capacity, voltage ratio	63	5 MVA, 6/20 kV	56 MVA, 10.5/240 kV	26.5 MVA, 10.4/110 kV	310 MVA, 21/220 kV
Switchplant	64	20 kV indoor switchplant of B2	switchyard 240 kV	110 kV outdoor switchplant, on p.h. roof	switchyard 220 kV
Plant capacity of T and/or P; max.	65	T: 8 MW	T: 230 MW P: 220 MW	T: 173 MW P: 40 MW	T: 270 MW P: 286 MW
Annual energy without short-t.pumping (with)	66	22 GWh	170 GWh (371 GWh)	212 GWh (33.2 GWh)	311 GWh (486 GWh)
Winter share %/ full-load h.p.a.	67	34 % / 2750 h	100 %/ 740 h (78.5 % / 1615 h)	41 % / 1220 h (52 % / 1920 h)	41 % / 1150 h (52 % / 1800 h)
Annual P energy without short-t.pumping (with)	68	---	220 GWh (541 GWh)	--- (58 GWh)	--- (359 GWh)
Footnotes *)	69	re. line 40: with 60 m long side spillway and chute into Latschau reservoir (B3 and B4), at the same time pumping water channel for pumped storage operation of B2	re. line 38: of which 0.86 km prestressed internal ring lining 3.10 m Ø re. lines 51 and 59: when inflow to forebay is insufficient for pumping, three priming pumps 4.2 to 8.2 m3/s each can discharge to forebay	re. line 51a: reservoir level 633.0 ÷ 644.5 m a.s.l. re. line 56: on one unit only, installation possible on a further unit	re. line 51a: reservoir level 638.0 ÷ 644.5 m a.s.l.

TABLE III. THE SEASONAL STORAGE SCHEMES OF TIROLER WASSERKRAFTWERKE AG (TIWAG) INNSBRUCK
PART 1: CATCHMENTS, RESERVOIRS AND DIVERSIONS

C + D + E: Part 1

POWER SCHEME (OWNER)	1	C KAUNERTAL SCHEME (TIWAG)	D SELLRAIN-SILZ SCHEME (TIWAG)		E ACHENSEE SCHEME (TIWAG)
Power stage (power station)	2	C Kaunertal (Prutz)	D1 Upper stage (Kühtai)	D2 Lower stage (Silz)	E Achensee (Jenbach)
District (province)	3	Landeck (Tyrol)	Imst (Tyrol)	Imst, Ibck.-Land (Tirol)	Schwaz (Tyrol)
Initial operation (extension)	4	1964	1980	1981	1927 (1952)
River basins	5	Fagge, Pitzbach, Pfundser B. (Inn)	Ötztaler Ache (Inn)	Ruetz, Melach, Ötztaler Ache (Inn)	Isar (Inn)
Utilised Catchments: directly to res.	6z	Faggenbach 107,3 km2	Finstertaler Seen 6,0 km2	Nederbach 17,3 km2	Achensee 105,5 km2
diversions	6a	Fißladbach (diversion) 11,3 km2		Mittertalbach 5,1 km2	Dürrache 55,0 km2
to stage	6b	Kaunertal tributaries 32,2 km2		Oberer Zirmbach 31,9 km2	Kesselbach 8,0 km2
or	6c	Pitzbach, Taschachbach 87,4 km2		Obere Melach 30,0 km2	Unteraubach 9,0 km2
trans-basin diversions	6d	Pfundser Bäche 41,0 km2		Alpeinerbach 23,0 km2	Ampelsbach 28,8 km2
and	6e			Horlachbach 25,6 km2	Achenbach 11,8 km2
upstream	6f			from upper stage D1 6,0 km2	
power stations	6g				
total	6	total 279,2 km2	total 6,0 km2 *)	total 138,9 km2	total 218,1 km2
Reservoir: Name	7	Gepatsch reservoir	Finstertal reservoir	Längental reservoir	Achensee (nat. lake surface 929 m a.s.l.)
Max./mean/min. water level	8	1767,0/1733,0/1665,0 m a.s.l.	2322/2287/2220 m a.s.l.	1901/1893/1882 m a.s.l.	929,53/923,60/917,28 m a.s.l.
Active storage (stored energy)	9	138,3 . 10[6] m3 (286 GWh)	60,9 hm3 (226 GWh)	3,1 hm3 (9 GWh)	80,6 hm3 (62 GWh)
Dam: Name	10	Gepatsch dam	Finstertal dam	Längental dam	lake dam
Type	11a	rockfill with	rockfill with inclined	earthfill with asphaltic	11-bay weir with 9 stop logs
	11b	central earth core	asphaltic concrete core	concrete facing	and 2 gate leaves
Height/crest length/crest level	12	153/600 m/1772 m a.s.l.	149/650 m/2325 m a.s.l.	45/420 m/1904 m a.s.l.	0,75 m/24 m/929,53 m a.s.l.
Volume	13	7,1.10[6] m3 fill	4,5.10[6] m3 fill	0,4.10[6] m3 fill	----
Spillway: Type	14	bellmouth spillway 12,6 m ∅	side spillway 4,9 m long	bellmouth spillway 8,0 m ∅	over lake dam
Capacity	15	250 m3/s for 2,0 m surcharge	3,0 m3/s for 0,5 m surcharge	106,0 m3/s for 1,9 m surcharge	ca. 100 m3/s
Diversions to stages and trans-basin diversions (for abbreviations, see line 23): a) Name (catchment)	16a	a) Fißlad diversion (6a)	no diversions	a) Mittertalbach trans-basin diversion (6a)	a) Dürrache trans-basin diversion (6a)
Stream intake: (number) Q_r - type	17a	(1) 2,3 m3/s - TA *		(1) 0,9 m3/s - TA *	(1) 9,0 m3/s - *)
Waterway: type	18a	free-flow tunnel, drop shaft with cyclone		free-flow tunnel cast-iron pipe	free-flow Tunnel and pressure tunnel + canal
length/section	19a	0,1 km/4,2 m2 0,2 km/1,3 m ∅		0,1 km/6,5 m2 0,6 km/0,5 m ∅	8,1 km/6,5 m2 1,6 km/6,0 m2
b) Name (catchment)	16b	b) Blaichbachl trans-basin diversion (6b)		b) Stockach- (ZP) and Klammbach (6b in part)	b) Kesselbach diversion (6b)
Stream intake: (number) Q_r - type	17b	(1) 0,2 m3/s		(2) 0,5 m3/s and 0,7 m3/s - TA *	(1) 3,0 m3/s - TA *
Waterway: type	18b	concrete pipe		cast-iron pipe concrete pipe	pressure tunnel, discharges into 18a
length/section	19b	0,4 km/0,3 m ∅		3,2 km/0,5 m ∅ + 0,8 m; 0,5 km/0,9 m ∅	1,4 km/6,5 m2
c) Name (catchment)	16c	c) Kaunertal Ost (6b)		c) Melach trans-basin diversion (6b+c+d)	c) Unteraubach diversion (6c)
Stream intake: (number) Q_r - type	17c	(5) 0,8 to 2,5 m3/s - TA *		(9) 0,2 to 5,5 m3/s - TA *	(1) 4,0 m3/s - T *
Waterway: type	18c	free-flow tunnel;cast-iron pipe;free-flow t.		free-flow tunnel	canal, discharges into 18a
length/section	19c	1,7 km/4,6 m2; 0,4 km/0,5 m ∅; 8,1 km/5,8 m2		5,4 km/8,0 m2 15,1 km/9,5 m2	0,3 km/2,0 m2
d) Name (catchment)	16d	d) Pitzbach trans-basin diversion (6c)		d) Horlachbach trans-basin diversion (6e)	d) Ampelsbach trans-basin diversion (6d)
Stream intake: (number) Q_r - type	17d	(2) 5,4 m3/s - TA * 12,1 m3/s - *)		(1) 4,9 m3/s - TA *	(1) 3,6 m3/s - T *
Waterway: type	18d	free-flow tunnel		free-flow tunnel	free-flow tunnel + canal with trough bridges
length/section	19d	1,8 km/4,4 m2 9,3 km/7,4 m2		5,5 km/2,7 m ∅	2,8 km/3,0 m2 + 4,5 km/2,8 m2
e) Name (catchment)	16e	e) Radurschl trans-basin diversion (6d)			e) Achenbach trans-basin diversion (ZP) (6e)
Stream intake: (number) Q_r - type	17e	(2) 3,0 m3/s and 4,4 m3/s - TA *			(1) 2,1 m3/s
Waterway: type	18e	free-flow tunnel			riveted steel pipe, discharges into 18d
length/section	19e	2,1 km/5,0 m2 9,3 km/6,5 m2			240 m/1,30 m ∅
(ZP) Feeder pumping station: Name (trans-basin diversion)	20			(ZP) Stockachbach (16b)	(ZP) Achenkirch (16e)
Q_r/H_{gr}	21			0,5 m3/s / 80 m	2,1 m3/s / 30 m
number of pumps x capacity	22			5 x 0,2 MW = 1 MW	2 x 0,25 + 1 x 0,40 = 0,90 MW
Footnotes *)	23a	re. line 17d: Taschach arch dam H/L = 12/39 m	re. line 6: reservoir filling by		re line 17a: Bächental arch dam H/L = 34/70 m
Abbreviations:	23b	with frontal intake and 2 sand	pumping from		
T ..... Tyrolean weirs	23c	trap chambers	Längental reservoir (see D2)		
TA..... Tyrolean weirs with automatic	23d				
sand trap flushing	23e				
	23f				

TABLE III, PART 2: HIGH-HEAD STAGES AND GENERATION

C + D + E: Part 2

POWER SCHEME (OWNER)	30	C KAUNERTAL SCHEME (TIWAG)	D SELLRAIN-SILZ SCHEME (TIWAG)		E ACHENSEE SCHEME (TIWAG)
Power stage (power station) T ... generating mode P ... pumping mode	31	C Kaunertal (Prutz)	D1 Upper stage (Kühtai)	D2 Lower stage (Silz)	E Achensee (Jenbach)
Mode of operation	32	generation only	pumped storage	generation only	generation only
Max./mean/min. gross head	33	895/861/793 m	440/394/319 m	1258/1250/1239 m	396.8/390.7/384.5 m
Max. discharge Q_T (Q_P)	34	53 m3/s	80 (66) m3/s	48.3 m3/s	28 m3/s
POWER CONDUIT OF STAGE (for diversions, see line 6a) — Intake gates: type	35	butterfly valves	see lines 44 & 45	drop gates	gate
Intake gates: (number) cross section	36	(2) 3.50 m Ø		(2) 2.6 x 3.3 m	(1) 4.4 x 3.3 m (2) 2.6 x 2.6 m
Power tunnel: length sections/int. Ø	37	8.8 km/4.0 m Ø 3.4 km/4.0 m Ø 1.0 km/4.0 m Ø		4.3 km/3.3 m Ø 0.4 km/3.3 m Ø	0.13 km 4.6 km / 2.6 ÷ 2.85 m Ø
Power tunnel: lining	38a	concrete with concrete with thin steel-lining	no power tunnel	concrete concrete with foil	inlet section concrete lining
	38b	hole grouting gap grouting int. concrete ring		prestressing gap grouting	caisson reinf. shotcrete in places
Power tunnel: total length/max. pressure	39	13.2 km/15.7 bar		4.7 km/9.2 bar	4.6 km/4.5 bar
Surge tank	40	2-chamber with reverse-flow control throttle	no surge tank	2-chamber, with orifice	2-chamber, no orifice
Penstock or shaft: type	41	(1) pressure shaft	(1) pressure shaft	(1) pressure shaft	(1) pressure shaft
Upper part: length sections/int. Ø	42	970 m/3.30 - 3.10 m Ø	300 m/4.40 m Ø	600 m/2.7 m Ø	--
Upper part: construction	43a	steel-lining with	concrete lining with	steel-lining with int. concrete ring	--
	43b	gap grouting	prestressing gap grouting	gap grouting	--
Gates: type, position	44	butterfly valve downstream of surge tank	butterfly valves	none	butterfly valves downstream of surge tank
Gates: (number) cross section	45	(1) 3.30 m Ø	(2) 3.50 m Ø isolation valves	(power tunnel with reverse gradient)	(2) 2.30 m Ø isolation valves
Lower part: length sections/int. Ø	46	840 m/3.10 m Ø 100 m/2.85 m Ø	700 m/4.0 m Ø 500 m/4.0 m Ø 300 m/3.0 m Ø	1700 m/2.6 - 2.2 m Ø 100 m/2.2 m Ø	513 m/2.30 m Ø 80 m/2.0 m Ø
Lower part: construction	47a	steel-lining with penstock in	concrete with concrete with steel-lining	steel lining with penstock in	steel lining with penstock
	47b	gap grouting pipe gallery	prestr.gap grouting foil with gap grouting	gap grouting pipe gallery	hole grouting in pipe gallery
Manifold: position	48	hanging, in hall, 10 branches	concrete-embedded manifold, 2 branches	hanging, in pipe basement, 4 branches	hanging, outdoor, 9 branches
Manifold: max. pressure - stat./dyn.	49	89.5/98.6 bar	49/80 bar	126/150 bar	39.7/44 bar
Tailrace	50a	open canal	2 shafts 89 & 97 m/12.6 m2	open canal 1.2 km	open canal, 640 m
	50b	300 m long	concrete with foil and prestr. gap grouting	at the same time surge basin	concrete lining
Discharge to	51	Inn	Längental reservoir (D2)	Inn	Inn
POWERHOUSE — Type	52	above-ground, reinforced concrete	shaft powerhouse with outdoor gantry crane	above-ground, reinforced concrete	above-ground, reinforced concrete & steel
Dimensions (without control building)	53	28 x 110 m (without pipe hall)	30 m Ø, 80 m deep	36 x 70 m (without pipe basement)	22 x 90 m
Special features (pos. of transf.)	54a	transformersin outside recesses	transformers in recesses of operat. building	transformers in outside recesses	transformers in switchyard
	54b				50 HZ rotary c. (1≤ 2/3 HZ traction current s.l. 69)
Power units: (number) position, speed	55	(5) horizontal, 500 rpm	(2) vertical, 600 rpm	(2) vertical, 500 rpm	(2) horizontal, 500 rpm (3) horizontal, 500 rpm
type and arrangement	56	2 Pelton t., 2 x 2 jets, each	1 pump turbine each	1 Pelton turbine, 2x3 jets, each	2 Pelton t.each, 2x2 jets, 2 Pelton t.each, 2x2 jets
upstream gates: type, int. Ø	57	2 rotary valves, 0.85 m Ø each	1 rotary valve, 1.55 m Ø each	2 rotary valves, 1.1 m Ø, each	1 sluice valve each, 2 sluice valves and 1 rot. valve
T rating: H/Q/N	58	810 m/9.6 m3/s /84 MW	418 m/38 m3/s /140 MW	1159 m/24 m3/s /242 MW	380 m/3.5 m3/s/11.3 MW (2) 380 m/7.0 m3/s/22.8 MW
P rating: H/Q/N	59	---	319 m/34 m3/s /124 MW	---	(1) 380 m/7.1 m3/s/23.5 MW
downstream gates: type, dim.	60	bulkhead gates	1 gate, 3.6 x 1.8 m each	bulkhead gates	none none
generator: capacity, type	61	100 MVA, ring air cooling each	176 MVA, ring air cooling	352 MVA each, complete water cooling	13 MVA each, fresh-air c. (3) 25 MVA, fresh-ais c.
Transf.: (number) type, arrangement,	62	(5) threephase, block-type	(2) threephase, block-type	(2) threephase, block-type	(5) threephase, block-type
capacity, voltage ratio	63	100 MVA, 10/240 kV	176 (*) MVA, 18/250 kV	352 MVA, 17.5/250 kV	(2) 13 MVA, 5.5/110 kV (3) 25 MVA, 5.5/110 kV
Switchplant	64	switchyard	indooer 18 kV & 250 kV	switchyard 250 kV	switchyard 110 kV rot. c. 50 HZ + traction c. 16 2/3 HZ
Plant capacity of T and/or P; max./mean	65	T: 390/370 MW	T: 287/230 MW P: 247/235 MW	T: 488/484 MW	T: 80 MW
Annual energy without short-t.pumping (with)	66	620 GWh	55.5 (259.7) GWh	459 GWh	213.5 GWh
Winter share % / full-load h.p.a.	67	59 % / 1590 h	84 % / 195 h (75 %/905 h)	42 % / 940 h	53 % / 2700 h
Annual P energy without short-t.pumping (with)	68	---	64.5 (336) GWh	1,5 GWh (ZP Stockachbach)	4.1 GWh (ZP Achenkirch)
Footnotes *)	69		re. lines 62 & 63: can be overloaded to 270 MVA 2-unit service through 1 transformer is possible		re. l. 54b: 16 2/3 HZ traction current l. 55 : (3) horizontal, 500 rpm l. 56 : 1 Pelton turbine, 2 jets, each l. 57 : 1 jet valve l. 58 : 380 m/1.9 m3/s /5.9 MW l. 61 : 5 MVA each, fresh-air cooling l. 62 & 63: (1) singlephase, 15 MVA, 5.5/110 kV l. 64 : switchyard 5.5 kV and 110 kV

TABLE IV. THE SEASONAL STORAGE SCHEMES OF TAUERNKRAFTWERKE AG (TKW) SALZBURG, IN THE ZILLER VALLEY
PART 1: CATCHMENTS, RESERVOIRS AND DIVERSIONS

F + G: Part 1

POWER SCHEME (OWNER)	1	F ZEMM - ZILLER SCHEME (TKW)			G GERLOS SCHEME (TKW)	
Power stage (power station)	2	F1 Zemm upper stage (Roßhag)	F2 Main stage (Mayrhofen)	F3 Ziller upper stage (Häusling)	G1 Gerlos upper stage (Funsingau)	G2 Gerlos lower stage (Gerlos)
District (province)	3	Schwaz (Tirol)	Schwaz (Tirol)	Schwaz (Tirol)	Schwaz (Tirol)	Schwaz (Tirol)
Initial operation (extension)	4	1970	1971	1986	1967	1945 1948
River basins	5	Zamserbach, Zemmbach, Tuxbach (Ziller)	Tuxb., Zemmb., Stilluppb., Ziller (Ziller)	Ziller, Gerlos (Ziller)	Wilde Gerlos (Ziller), Salzach	Gerlosbach (Ziller)
Utilised Catchments: directly to res.	6z	Schlegeisgrund 57,8 km2	Stilluppgrund 61,0 km2	Zillergrund 29,8 km2	Wilde Gerlos 43,9 km2	Gerlosbach 99,1 km2
diversions	6a	Pitzenb. + Kesselbach (div.) 8,3 km2	Untere Zemm + Igentbach 33,9 km2			Mühlbach (div.) 6,0 km2
to stage	6b	Wesendleb. + Lapenkarb. (div.) 6,6 km2	from Zemm upper stage (F1) 123,4 km2	Sunderbach 12,1 km2	Oberste Salzach 20,4 km2	Schwarzachbach 13,3 km2
or	6c	Falschseitenb. + Alelebach 4,2 km2	Gungglbach 12,3 km2	Hundskehlbach 15,6 km2	Nadernachbach 10,3 km2	
trans-basin diversions	6d	Obere Zemm 33,2 km2	Floite 34,5 km2	Schönachbach 6,0 km2		
and	6e	Tuxbäche 13,3 km2	Untere Ziller 45,4 km2	Wimmerbach 4,0 km2		
upstream	6f		Bodenbach 11,4 km2			
power stations	6g		from Ziller upper stage (F3) 67,5 km2			from Gerlos upper st.(G1) 74,6 km2
total	6	total 123,4 km2	total 389,4 km2	total 67,5 km2	total 74,6 km2	total 193,0 km2
Reservoir: Name	7	Schlegeis reservoir	Stillupp reservoir	Zillergründl reservoir	Durlaßboden reservoir	Gmünd reservoir *)
Max./mean/min. water level	8	1782/1747,7/1680 m a.s.l.	1120/1113,9/1106 m a.s.l.	1850/1808,1/1740 m a.s.l.	1405/1388/1360 m a.s.l.	1190,2/1187/1176 m a.s.l.
Active storage (stored energy)	9	127,7 hm3 (320 GWh)	6,9 hm3 (7,4 GWh)	88,8 hm3 (240 GWh)	51,2 hm3 (82 GWh)	0,7 hm3
Dam: Name	10	Schlegeis dam	Eberlaste dam	Zillergründl dam	Durlaßboden dam	Gmünd dam
Type	11a	arch dam	gravelfill with	arch dam	gravelfill	original arch dam
	11b	(arch-gravity)	asphaltic concrete core	with elliptic arches	with central earth core	reinforced as arch gravity
Height/crest length/crest level	12	131x725 m/1783 & 1784,3 m a.s.l.	28x480 m/1124,0 m a.s.l.	186x505 m/1850,7 & 1852,0 m a.s.l.	70x470 m/1409 m a.s.l.	37x69 m/1192,4 m a.s.l. (parapet)
Volume	13	960.000 m3 concrete	$0,85.10^6$ m3 fill	ca. 1,300.000 m3 concrete	$2,52.10^6$ m3 fill	22.000 m3 concrete
Spillway: Type	14	lateral bellmouth	lateral bellmouth	side spillway	lateral bellmouth	overflow
Capacity	15	200 (324) m3/s for 1,5 (2,0) m surcharge	450 m3/s for 2,6 m surcharge	165 m3/s for 1,35 m surcharge	200 m3/s for 1,65 m surcharge	216 m3/s for 2,00 m surcharge
Diversions to stages and trans-basin diversions (for abbreviations, see line 23) a) Name (catchment)	16a	a) Pitzenbach trans-basin diversion (6a)	a) Untere Zemm and Igentbach diversion (6a)	a) South trans-basin diversion (6b+c)	a) Nadernach trans-basin div. (6c)	a) Mühlbach trans-basin diversion (6a)
Stream intake: (number) Q_r - type	17a	(2) 0,6 m3/s - TA	(2) 8,0 m3/s *) 0,8 m3/s - TA	(2) 2,5 m3/s *) and 3,2 m3/s *)	(1) 1,5 m3/s - TA	(1) 0,5 m3/s - T
Waterway: type	18a	discharges into upper chamber of line 40	free-flow t., rock shaft, dischargesinto	free-flow tunnel ZP see line 20	free-flow tunnes, discharges into	free-flow tunnel - pressure tunnel *)
length/section	19a	-	1,6 km/6,2 m2 95 m/1,4 m2 F1 1.50f	4,5 + 2,8 km/3,0 m ∅	1,9 km/4,4 m2 16b	0,14 km/4 m2, 0,21 km/2,0 m ∅
b) Name (catchment)	16b	b) Kessel-,Wesendle-,Lapenkarb. div. (6a+b)	b) Gungglbach diversion (6c)	b) North trans-basin diversion (6d+e)	b) Salzach trans-basin diversion (6b)	b) Schwarzach trans-basin div. (6b)
Stream intake: (number) Q_r - type	17b	(3) 1,1 m3/s, 0,6 m3/s, 0,9 m3/s - TA	(1) 3,0 m3/s - TA	(2) 0,8 m3/s - TA 1,2 m3/s - TA	(1) 3,0 m3/s overfall weir	(1) 1,0 m3/s overfall weir
Waterway: type	18b	one steel-lined shaft each	steel-lined shaft, discharges into F1	free-flow tunnel	free-flow tunnel	concrete canal
length/section	19b	0,2÷0,3 km/o,7 m ∅ discharges into l. 37	259 m/0,8 m ∅ 1.50f	4,9 + 1,7 km/3,0 m ∅	2,3 km/4,4 m2	0,73 km/0,54 m2
c) Name (catchment)	16c	c) Falschseitenb. + Aleleb.trans-b. div.(6c)	c) Floitenbach diversion (6d)			
Stream intake: (number) Q_r - type	17c	(2) 0.5 m3/s - TA	(1) 8,0 m3/s *)			
Waterway: type	18c	free-flow tunnel	free-flow tunnel & shaft discharges			
length/section	19c	0,7 km/4 m2 0,2 km/6 m2	148 m/1,4 m ∅;0,9 km/4 m2 into F1 1.50d			
d) Name (catchment)	16d	d) Obere Zemm trans-basin diversion (6d)	d) Bodenbach diversion (6f)			
Stream intake: (number) Q_r - type	17d	(1) 8 m3/s, fixed weir *)	(1) 2,5 m3/s - TA			
Waterway type	18d	free-flow tunnel	free-flow tunnel, discharges into F3			
length/section	19d	6,0 km/5,8 m2	74 m/7,8 m2 1. 50f			
e) Name (catchment)	16e	e) Tuxbäche trans-basin diversion (6e)	e) Untere Ziller diversion (6e)			
Stream intake: (number) Q_r - type	17e	(3) 1,6 m3/s, 0,5 m3/s, 0,5 m3/s - TA	(1) 10 m3/s, overfall weir *)			
Waterway type	18e	free-flow tunnel	free-flow tunnel, discharges into F3			
length/section	19e	0,3 + 0,1 + 6,8 km/5,8 m2	2,9 km/7,8 m2 1. 50f			
(ZP) Name (trans-basin div.)	20			(ZP) Klammbichl (6a & b)		
Feeder pumping Q_r/H_{gr}	21			9 m3/s / 70 m		
station: Nr. of pumps x capacity	22			3 x 2,7 = 8,1 MW		
Footnotes *)	23a	re. line 17d: overfall weir with lateral inlet and sand trap	re. line 17a, c & e: overfall weir with lateral inlet and sand trap	re. line 17a: overfall wei with lateral inlet and sand trap		re. line 7: bed load diversion through 0,5 km concrete pipe and 0,6 km tunnel 2,0 m ∅ re line 18a: discharges into pressure tunnel line 37
Abbreviations:	23b					
T .... Tyrolean weir	23c					
TA .... Tyrolean weir with automatic	23d					
sand trap flushing	23e					
	23f					

TABLE IV, PART 2: HIGH-HEAD STAGES AND GENERATION

F + G: Part 2

POWER SCHEME (OWNER)	30	F ZEMM - ZILLER SCHEME (TKW)			G GERLOS SCHEME (TKW)	
Power stage (power station)	31	F1 Zemm upper stage (Roßhag)	F2 Main stage (Mayrhofen)	F3 Ziller upper stage (Häusling)	G1 Gerlos upper stage (Funsingau)	G2 Gerlos lower stage (Gerlos)
T...generating mode P...pumping mode	32	pumped storage	generation only	pumped storage	generation only	generation only
Max./mean/min. gross head	33	676/634/560 m	476/470/462 m	744/694/620 m	135/118/90 m	614/611/600 m
Max. discharge Q_T (Q_P)	34	50 (36) m3/s	92 m3/s	65 (50) m3/s	25.7 m3/s	13.5 m3/s
POWER CONDUIT OF STAGE (for diversions, see line 6a ff) — Intake gates: type	35	sluice gate + fixed wheel gate	fixed wheel gate	butterfly valves	gate	gate
Intake gates: (number) cross section	36	(2) 2.7 x 2.7 m	(2) 4.5 x 3.8 m	(2) 3.9 m Ø	(1) 2.5 x 2.5 m	(1) 2.5 x 2.5 m
P tunnel: length sections/int. Ø	37	7.70 km/4.0 m Ø 0.07 km/4.0 m Ø	3.27 km/5.1 m Ø 0.09 km/4.9 m Ø	7.40 km/4.2 ÷ 4.1 m Ø 0.36 km/4.2 m Ø	2.42 km/2.9 m Ø 0.12 km/2.9 m Ø	4.85 km/2.5 m Ø 1.13 km/2.0 m Ø
P tunnel: lining	38a	concrete steel lining	concrete concrete + seal.foil	concrete concrete + seal. foil	concrete + shotcrete steel-lining	concrete steel-lining with
	38b	borehole grouting	borehole grouting	borehole grouting	prestressing borehole grouting	int. concrete ring
P tunnel: total length/max. pressure	39	7.77 km / 19 bar	3.36 km / 8 bar	7.76 km / 20 bar	2.54 km / 9 bar	5.98 km / 3.2 bar
Surge tank	40	2-chambers (rev. flow control throttle)	2-chamber (rev. flow control throttle)	2-chamber, rev. flow control throttle	2-chamber	2-chamber with overflow
Penstock or pressure shaft: design	41	(1) pressure shaft	(1) pressure shaft	(1) pressure shaft	(1) penstock	(1) pressure shaft
gates: type, psosition	44	butterfly valve downstream of s. t.	butterfly valve downstream of surge tunnel	butterfly valve downstream of surge tunnel	butterfly valve	gate
(number) cross section	45	(1) 3.1 m Ø	(1) 3.9 m Ø	(1) 3.4 m Ø	(1) 2.4 m Ø	(1) 3.0 x 3.2 m
length sections, int. Ø	46	897 m/3.1 ÷ 2.9 m Ø 339 m/2.9 m Ø	892 m/3.9 ÷ 3.7 m Ø 299 m/3.7 m Ø	60 m/4.2 ÷ 3.7 m Ø, 925 m/3.7 m Ø, 365m/3.2m Ø	175 m/2.4 ÷ 2.25 m Ø	1270 m/2.2 ÷ 1.6 m Ø 124 m/1.6 m Ø
construction	47a	high-grade section low-grade section	high-grade section low-grade section	transition high-grade sect. low-grade s.	steel pipe	high-grade section low-grade section
	47b	steel-lining	steel-lining	steel-lining steel/concr.ring steel-lining	buried	steel-lining
Manifold: position	48	concrete embedded, 2 runs, 4 branches each	hanging, outdoor, 2 runs, 6 branches each	concrete embedded, 2 runs, 2 branches each	end thrust block in p.h. foundation	(2) hanging, in pipe basement
max. pressure - stat./dyn.	49	73 / 83 bar	48 / 53 bar	80/103 bar	13.5 / 17.5 bar	61 / 65 bar
Tailrace: design, total length	50a	(1) power tunnel, 8.4 km	surge basin J = 0.035 hm3 with	(1) power tunnel, 7.7 km	forebay	open canal, 230 m long
valley-sections/int. Ø	50b	100 m/3.8 m Ø	regulating sill	252 m/4.2 m Ø		
crossing	50c	steel pipe in pipe duct		steel pipe		
gates-type, position	50d	butterfly valve		butterfly valve		
(number) cross sections	50e	(1) 3.8 m Ø		(1) 4.2 m Ø		
surge tank	50f	2-chamber with orifice *)		2-chamber with orifice		
pressure tunnel: sections/int. Ø	50g	0.4 km/6.0 m Ø, 3.3 km/15.2 m2 - 0.3 km/3.7 m Ø,	4.4 km/4.3 m Ø	0.13 km/4.4 m Ø 7.6 km/4.6 x 4.6 m		
lining	50h	concrete *) concrete steel pipe	concrete	steel-lining concrete		
	50i	in pipe duct				
Discharge to	51	Stillupp reservoir (F2)	Stillupp (Zemm, Ziller)	Stillupp reservoir (F2)	Gerlosbach (Gmünd reservoir G2)	Gerlosbach (Ziller)
POWERHOUSE — Type	52	foot of slope, earth-covered, reinf. concrete	above-ground, reinforced concrete	foot of slope, earth-covered, reinf. steel	above-ground, reinforced concrete	at foot of slope, reinforced concrete
Dimensions (without control building)	53	80 x 27 m, total height 38 m	142 x 28 m, total height 21 m	powerhouse shaft 35 m Ø, 50 m deep		45 x 13 m, total height 22 m
Special features (pos. of transf.)	54a	transformers in closed	transformer in open	transformers in indoor bays		transformers in open bays in
	54b	external-wall recesses	external-wall recesses			the switchyard
Power units: (number) position, speed	55	(4) vertical, 750 rpm	(6) horizontal, 375 rpm	(2) vertical, 600 rpm	(1) vertical, 333 1/3 rpm	(4) vertical, 600 rpm
type and arrangement	56	Francis t. + two-stage pump + converter	2 Pelton turbines, 2 x 2 jets, each	Francis turbine + two-stage pump + converter	(1) Francis turbine	(1) Pelton turbine, 2 jets
upstream gates: type, int. Ø	57	T: ror. valve 1.1 m Ø, P: rot. valve 1.0 m Ø	2 rotary valves 1.2 m Ø, each	1 rotary valve 1.7 m Ø each for T & P	(1) butterfly valve 2.25 m Ø	(1) rotary valve 0.5 m Ø
T rating: H/Q/N	58	538 m/12.5 m3/s /57.5 MW	447 m/15 m3/s /59 MW	610 m/32.5 m3/s /180 MW	111 m/25.7 m3/s /25.6 MW	(2) 578 m/3.0 m3/s /15.4 MW
P rating: H/Q/N	59	570 m/9.0 m3/s /60.0 MW	----	640 m/25 m3/s /180 MW	----	(2) 578 m/3.8 m3/s /17.7 MW
downstream gates: type, dim.	60	T: wicket 1.6 m Ø P: butterfly valve 1.6 m Ø	bulkhead gates	1 wicket 2.6 m Ø each for T, 2.4 m Ø for P	bulkhead gate	
generator: capacity, type	61	motor generator 65 MVA, ring air cooling	65 MVA each, ring air cooling	motor generator 195 MW	(1) 27 MVA, generator	(1) 22 MVA
Transf.: (number) type, arrangement	62	2x3 singlephase, block-type for 2 units each	3x3 singlephase, block-type for 2 units each	1x3 singlephase,block-arrang. for the 2 units	(1) threephase, block-type	(4) threephase, block-type
capacity, voltage ratio	63	44 MVA, 10/220 kV	44 MVA, 10/220 kV	134 MVA, 20/220 kV	27/8 MVA, 10/115/30 kV	18.5 MVA, 10/115 kV
Switchplant	64	220 kV (SF6)	switchyard 220 kV	indoor 220 kV (SF6)	switchyard 115 kV	switchyard 115 kV
Plant capacity of T and/or P; max.	65	T: 230 MW P: 240 MW	T: 345 MW	T: 360 MW P: 360 MW	T: 25 MW	T: 65 MW
Annual energy without short-t.pump.(with)	66	284 (534) GWh	613 GWh	176 GWh (684 GWh)	25 GWh	294 GWh
Winter share % / full-load h.p.a.	67	76 % /1230 h (59 % /2320 h)	51 % /1780 h	91 % /490 h (56 % /1900 h)	74 % /1000 h	45 % /4520 h
Annual P energy without short-t.pump.(with)	68	---- (362 GWh)	---	7 GWh (726 GWh)	---	---
Footnotes *)	69	re. line 50f - h: lower chamber as part of power conduit				

H: Part 1

TABLE V. THE SEASONAL STORAGE SCHEMES OF TAUERNKRAFTWERKE AG (TKW) IN THE KAPRUN VALLEY

PART 1: CATCHMENTS, RESERVOIRS AND DIVERSIONS

POWER SCHEME (OWNER)	1	H GLOCKNER - KAPRUN SCHEME (TKW)		
Power stage (power station)	2	H1 Möll trans-basin diversion (pumping station)	H2 Kaprun upper stage	H3 Kaprun lower stage
District (province)	3	Pinzgau (Salzburg), Spittal (Carinthia)	Pinzgau (Salzburg)	Pinzgau (Salzburg)
Initial operation (extension)	4	1952	1955	1944 (1951 and 1973)
River basins	5	Möll (Drau), Fuscher Ache (Salzach)	Kapruner Ache (Salzach)	Kapruner Ache, Fuscher Ache (Salzach)
Utilised Catchments: directly to res.	6z	Möll 44,4 km2	Kapruner Ache 21,8 km2	Kapruner Ache 14,5 km2
diversions	6a	Käferbäche 8,2 km2		Zeferetbach (div.) 4,4 km2
to stage	6b	Leiterbach 19,6 km2	Ebmattenbäche 2,4 km2	Grubbach (div.) 4,5 km2
or	6c		Wielingerbach 2,9 km2	Hirzbach 8,1 km2
trans-basin diversions	6d			
and	6e			
upstream	6f			
power stations	6g		from Möll diversion (H1) 72,2 km2	from upper stage (H2) 99,3 km2
total	6	total 72,2 km2	total 99,3 km2	total 130,8 km2
Reservoir: Name	7	Margaritze reservoir	Mooserboden	Wasserfallboden
Max./mean/min. water level	8	2000/1990/1980 m a.s.l.	2036/2002/1960 m a.s.l.	1672/1638/1590 m a.s.l.
Active storage (stered energy)	9	3,2 hm3	85,5 hm3 (238 GWh)	82,8 hm3 (163 GWh)
Dam: Name	10	Möll dam / Margaritze dam	Mooser dam / Drossen dam	Limberg dam
Type	11a	arch dam / gravity dam	gravity / arch	arch
	11b	on foundation block / slightly curved	with arch action	(arch-gravity dam)
Height/crest length/crest level	12	93 x 164 m - 2002 m a.s.l. - 39 x 175 m	107 x 494 m - 2037 m a.s.l. - 112 x 358 m	120/357 m/1672,5 and 1673,8 m a.s.l. *)
Volume	13	35.000 m3 - concrete - 33.000 m3	665.000 m3 - concrete - 335.000 m3	446.000 m3 concrete
Spillway: Type	14	overflow spillway on Margeritze dam	side spillway with 2 flaps 25 m long each	side spillway, 20 m long
Capacity	15	210 m3/s for 1,65 m surcharge	100 m3/s	26 m3/s for 0,80 m surcharge
Diversions to stages and trans-basin diversions (for abbreviations, see line 23): a) Name (catchment)	16a	a) Käferbach diversion (6a)	a) Ebmatten trans-basin diversion (6b)	a) Zeferetbach diversion (6a)
Stream intake: (number) Q_r - type	17a	(4) total 4,5 m3/s - T	(4) total 3,5 m3/s - T	(1) 4 m3/s
Waterway: type	18a	free-flow tunnel / inclined shaft, steel-lined	hillside canal / free-flow tunnel	inclined shaft, steel-lined
length/section	19a	0,93 km/4 m2 / 0,11 km/2,0 m Ø	0,3 km/0,5 m2 / 1,3 km/5 m2	0,12 km/1,35 m Ø
b) Name (catchment)	16b	b) Leiterbach trans-basin diversion (6b)	b) Wielinger trans-basin diversion (6c)	b) Grubbach diversion (6b)
Stream intake: (number) Q_r - type	17b	(1) 6,0 m3/s - T	(1) 2,0 m3/s - T	(1) 2,7 m3/s, fixed weir with lateral intake
Waterway: type	18b	free-flow tunnel	hillside canal / free-flow tunnel	inclined shaft, steel-lined
length/section	19b	1,7 km/4 m2	1,3 km/0,8 m2 / 0,1 km/4 m2	0,15 km/1,25 m Ø
c) Name (catchment)	16c			c) Hirzbach trans-basin diversion (6c)
Stream intake: (number) Q_r - type	17c			(1) 1,8 m3/s, fixed weir + secondary intake
Waterway: type	18c			free-flow tunnel / concrete pipe
length/section	19c			4,95 km/2,4 m Ø / 0,3 km/0,4 m Ø
d) Name (catchment)	16d			
Stream intake: (number) Q_r - type	17d			
Waterway: type	18d			
length/section	19d			
e) Name (catchment)	16e			
Stream intake: (number) Q_r - type	17e			
Waterway: type	18e			
length/section	19e			
(ZP) Feeder pumping station: Name (trans-basin diversion)	20			
Q_r/H_{gr}	21			
number of pumps x capacity	22			
Footnotes *)	23a	see Table V, Part 2, line 69		re. line 12: top of parapet
Abbreviations:	23b			
T ..... Tyrolean weir	23c			
TA ..... Tyrolean weir with automatic	23d			
sand trap flushing	23e			

TABLE V, PART 2: HIGH-HEAD STAGES AND GENERATION

POWER SCHEME (OWNER)	30	H GLOCKNER-KAPRUN SCHEME (TKW)		
Power stage (power station) T ... generating mode P ... pumping mode	31	H1 Möll trans-basin diversion (pumping station)	H2 Kaprun upper stage	H3 Kaprun lower stage
Mode of operation	32	only pumping for H2 *)	pumped storage	generation only
Max./mean/min. gross head	33	56/12/-20 m	446/364/288 m	891/857/809 m
Max. discharge Q_T (Q_P)	34	(20 m3/s)	36.0 m3/s (33.2 m3/s)	36.5 m3/s
POWER CONDUIT OF STAGE (for diversions, see line 6 and line 16) — Intake gates: (number) type	35	(2) gates	(2) butterfly valves	(2) butterfly valves
Intake gates: cross section	36	2.5 x 2.5 m (at Möll dam)	2.8 m ∅ (in pump cavern H1)	2.8 m ∅
Power tunnel: length sections/int. ∅	37	11.6 km/2.9 - 3.2 m ∅	0.4 km/3.5 m ∅ 0.07 km/2.8 m ∅ 3.92 km/3.3 m ∅	5.4 km/3.34 - 3.2 m ∅ 1.6 km/3.20 m ∅
Power tunnel: lining	38a	partly concrete, partly shotcrete only	steel pipe (or concrete) steel pipe concrete with	concrete with plaster prestressed concrete
	38b		(inlet section) (pumping st.) shotcrete	partly reinf. shotcrete *)
Power tunnel: total length/max. pressure	39	11.6 km/7 bar	4.3 km/11.4 bar	7.1 km/11.4 bar
Surge tank	40	2-chamber	2-chamber	2-chamber, differential
Penstock or shaft: type	41	not applicable	(1) pressure shaft	(1) inclined tunnel + (4) penstocks *)
Upper part: length sections/int. ∅	42		not applicable	613 m/3.0 m ∅
Upper part: lining	43a			steel-lining with
	43b			caulked joints
Gates: (number) type	44	(1) butterfly valve	(1) butterfly valve (2) rotary valves	(4) rotary valves + (4) butterfly valves
Gates: cross section (position)	45	2.8 m ∅ (in pump cavern)	2.8 m ∅ (below surge tank) 1.7 m ∅ (below low-grade section)	1.2 m ∅ 1.4 m ∅
Lower part: length sections/unt. ∅	46		460 m/2.9 - 2.7 m ∅ 180 m/2.5 m ∅ 40 m/2 x 1.70 m ∅	1,200 m (2) 1.30 - 1.15 m ∅ + (2) 1.35 - 1.25 m ∅
Lower part: lining	47a		steel lining steel lining penstock	steel pipe steel pipe
	47b		high-grade section low-grade s. in pipe gallery	with expansion pieces and concrete thrust blocks
Manifold: position	48	P inlet: above-ground with 4 branches	2 manifolds with 2 branches each in pipe basement	4 manifolds (2 branches each), concrete-embedded
Manifold: max. pressure - stat./dyn.	49	P outlet: above-ground with 2 branches	48/51 & 65 bar	89/99 bar
Tailrace	50a	pressure tunnel from H2	(2) steel pipes 2.2 m ∅	covered concrete channel
	50b	0.4 km/3.5 m ∅ to inlet	concrete-embedded in Limberg dam	
Discharge to	51	Mooserboden dam (H2)	Wasserfallboden reservoir (H3)	Kapruner Ache
POWERHOUSE — Type	52	underground, east of Drossendam (H2)	at foot of Limberg dam, reinforced concrete	at foot of slope, earth-covered, reinforced concrete
Dimensions (without control building)	53	46 x 17 m, total height 19 m	80 x 30 m, total height 30 m	94 x 35 m, total height 25 m
Special features	54a	inclined shaft for access	transformers in	transformers in indoor bays
position of transformers	54b	powersupply through 10 kV cable	undoor bays	
Power units: (number) position, speed	55	(2) horizontal, 495 rpm	(2) horizontal, 500 rpm	(4) horizontal, 500 rpm
type	56	single-stage double-flow pumps	Francis turbine + two-stage pumps	2 Pelton turbines, 2 x 1 & 2 x 2 jets, each
upstream gates: type, int. ∅	57	2 needle valves 1.4 m ∅	T: 1 rotary valve 1.4 m ∅ P: 1 needle valve 1.5 m ∅	2 rotary valves 0.7 m ∅ & 0.85 m ∅, each
T rating: H/Q/N	58	----	T: 363 m/18 m3/s /57 MW	T (2) 845 m/6 m3/s /45 MW
P rating: H/Q/N	59	69 - 30 m/5.5 - 13.9 m3/s /6.7 MW	P: 320 m/16.6 m3/s /62 MW	P (2) 845 m/9 m3/s /66 MW
downstream gates: type, dim.	60	4 rotary valves 1.1 m ∅	T: 1 rotary valve 1.5 m ∅ P: 1 needle valve 1.4 m ∅	stop logs
generator: type, capacity	61	2 asyn.-motors 16.7 MW	motor generator 63 MVA	(2) 50 MVA, (2) 70 MVA
transf.: (number) type, arrangement	62	----	(2) threephase, block-type	(4) threephase, block-type
capacity, voltage ratio	63	----	63 MVA, 10/110 kV	(2) 50 MVA, (2) 70 MVA, 10/110 kV
Switchplant	64	10 kV switchplant in upper stage powerhouse	indoor 110 kV	switchyard 110 kV and 220 kV
Plant capacity of T and/or P: max.	65	P: 13.4 MW	T: 112 MW P: 130 MW	T: 220 MW
Annual energy without short-t.pumping (with short-t.p.)	66	----	152 GWh (252 GWh)	454 GWh
Winter share % / full load h.p.q.	67	----	57 % /1360 h (58 % /2250 h)	85 % /2060 h
Annual P energy without short t. pumping (with)	68	15 GWh	(156 GWh)	----
Footnotes *)	69	re. line 32: Upper stage (H2) can alternatively be operated as power station from Margaritze reservoir and directly discharge to Wasserfallboden reservoir of main stage (H3)		re. line 38b: Rings made up of precast segments were prestressed according to a wire-wrapping method and grouted after placing. re. line 41: Covered with arches and earth over their lower portion.

TABLE VI. THE SEASONAL STORAGE SCHEMES ÖSTERREICHISCHE BUNDESBAHNEN (ÖBB) IN THE STUBACH VALLEY

PART 1: CATCHMENTS, RESERVOIRS AND DIVERSIONS

POWER SCHEME (OWNER)	1	J STUBACH SCHEME (ÖBB)			
Power stage (power station)	2	J1 Amersee - Weißsee (remote reservoir)	J2 Upper stage (I Enzingerboden)	J3 Middle stage (II Schneiderau)	J4 Lower stage (III Uttendorf)
District (province)	3	Pinzgau (Salzburg)	Pinzgau (Salzburg)	Pinzgau (Salzburg)	Pinzgau (Salzburg)
Initial operation (extension)	4	1952 (1959)	1929 (1974)	1940 (1962)	1948 (1950)
River basins	5	Stubache (Salzach)	Stubache (Salzach), Landeckbach (Isel)	Stubache (Salzach)	Stubache (Salzach)
Utilised Catchments: directly to res.	6z	Weißenbach 5,4 km2	Tauernmoosbach 22,3 km2	Stubache 3,8 km2	Stubache 12,0 km2
diversions	6a	Amerbach 2,3 km2	Landeckbach 7,5 km2	Wiegenbach 2,2 km2	Schrofenbach 1,5 km2
to stage	6b	Salzplattensee 0,5 km2	Seebach 4,3 km2	Wurfbach 3,3 km2	Ödbach 18,8 km2
or	6c	Eisbach 1,9 km2	Seetörlbach 0,3 km2		Böndelbach 0,9 km2
trans-basin diversions	6d		Schotterbach 2,0 km2		
and	6e		Wurfbach 3,6 km2		
upstream	6f			from Grünsee *) 4,7 km2	
power stations	6g		from Weißsee (J1) 10,1 km2	from upper stage (J2) 50,1 km2	from middle stage (J3) 64,1 km2
total	6	total 10,1 km2	total 50,1 km2	total 64,1 km2	total 97,3 km2
Reservoir: Name	7	Amersee res. Salzplattensee res. Weißsee res.	Tauernmoossee reservoir	Enzingerboden compensation reservoir	no reservoir
Max./mean/min. water level	8	2279,5/2247 m asl; 2298,5/2261,4 m asl;2250/2191,1 m asl	2023/2007/1984,5 m a.s.l.	1463,5/1461,5/1459 m a.s.l.	impounding admissible to 1035,7 m a.s.l.
Active storage (stored energy)	9	5,6 hm3 (13,3 GWh) 1,1 hm3 (2,6 GWh) 16,0 hm3 (38 GWh)	55,3 hm3 (131 GWh)	0,3 hm3	---
Dam: Name	10	Amersee dam Salzplatten dam Weißsee dam (side dam)	New Tauernmoos dam	Enzingerboden dam	Schneiderau weir
Type	11a	gravity gravity gravity	gravity dam with hollow space	gravity	vertical-lift gate weir with sand trap
	11b	curved straight straight	arch action in the uppermost part	straight	3 bays 4,0 m wide each
Height/crest length/crest level	12	30/162 m 16/88 m 37/235 (8/64) m	53/1100 m/2024,5 m a.s.l.	29/76 m/1465 m a.s.l.	
Volume	13	20.300 m3 5,300 m3 59.000 (700) m3	250.000 m3 concrete	11.000 m3 concrete	
Spillway: Type	14	side spillway overflow overflow/side dam	side spillway, 75 m long	lateral chute, 52 m long	see line 11
Capacity	15	15 m long 69 m long 23 m3/s for 0,7 m surcharge	108 m3/s for 1,0 m surcharge	60 m3/s for 0,6 m surcharge	
Diversions to stages and trans-basin diversions (for abbreviations, see line 23): a) Name (catchment)	16a	a) North diversion - Amersee to Eisbach (6a)	a) South diversion and power station *) (6a)	a) Wiegenbach diversion (6a)	a) Schrofenbach diversion (6a)
Stream intake: (number) Q_r - type	17a	Amersee reservoir	(1) 1,5 m3/s, concrete dam	(1) 0,7 m3/s - T	(1) ca. 0,3 m3/s
Waterway: type	18a	free-flow tunnel	cast-iron pipe	cast-iron pipe	drop shaft
length/section	19a	1,85 km/6 m2	0,4 km/0,6 m Ø	0,24 km/ 0,2 m Ø	
b) Name (catchment)	16b	b) North diversion - Salzplattensee to 18a (6b)	b) South diversion to upper Landeckbach intake(6b+c)	b) Mittlerer Wurfbach trans-basin div. (6b)	b) Ödbach trans-basin diversion (6b+c)
Stream intake: (number) Q_r - type	17b	Salzplattensee reservoir	(1) 7 m3/s - TA + sec. intakes	(1) 4 m3/s - T	(2) total 2,25 m3/s - T
Waterway: type	18b	pressure tunnel free-flow tunnel	free-flow tunnel	free-flow tunnel	concrete canal
length/section	19b	0,1 km/3,4 m2 0,4 km/3,4 m2	2,0 km/5,2 m2	1,7 km/2,9 m2	0,9 km/1,3 m2
c) Name (catchment)	16c	c) North diversion from Eisbach (6c)	c) South diversion to lower Landeckbach intake(6b)		
Stream intake: (number) Q_r - type	17c	(1) 1,5 m3/s - T	(1) 1 m3/s - TA with ZP (see line 20)		
Waterway: type	18c	free-flow tunnel	cast-iron pipe in gallery		
length/section	19c	3,8 km/6 m2	0,3 km/0,6 m Ø discharges into 18b		
d) Name (catchment)	16d		d) South div. from upper Landeckbach intake (6d)		
Stream intake: (number) Q_r - type	17d		(1) 1,25 m3/s, concrete dam		
Waterway: type	18d		free-flow tunnel		
length/section	19d		6,4 + 0,5 km/5,2 m2		
e) Name (catchment)	16e		e) Oberer Wurfbach diversion (6e)		
Stream intake: (number) Q_r - type	17e		(3) total ca. 1,2 m3/s - T		
Waterway: type	18e		free-flow tunnel		
length/section	19e		2,2 km/6,6 m2		
(ZP) Feeder pumping station: Name (trans-basin diversion)	20		(ZP) Landeckbach (s. l. 17c)		
Q_r/H_{gr}	21		1 m3/s / 80 m		
number of pumps x capacity	22		3 x 0,4 MW = 1,2 MW		
Footnotes *)	23a		re. l. 16a and 20: south power station between	re. l. 6f: Grünsee-Enzingerboden power station	
Abbreviations:	23b		Seebach and 18b	for station service supply	
T ...... Tyrolean weir	23c		(0,8 m3/s / 210 m / 1,2 MW)		
TA ...... Tyrolean weir with automatic	23d		for power supply to		
sand trap flushing	23e		(ZP) Landeckbach		

TABLE VI, PART 2: HIGH-HEAD STAGES AND GENERATION

POWER SCHEME (OWNER)	30	J STUBACH SCHEME (ÖBB)			
Power stage (power station)	31	J1 Amersee - Weißsee	J2 Upper stage (I Enzingerboden)	J3 Middle stage (II Schneiderau)	J4 Lower stage (III Uttendorf)
T ... generating mode P ... pumping mode Mode of operation	32	remote storage for J2 *)	generation	generation	generation
Max./mean/min. gross head	33		558/542/520 m	428 m	244 m
Max. discharge Q_T (Q_P)	34	6.0 m3/s	17.6 m3/s	10.5 m3/s	15.0 m3/s
POWER CONDUIT OF STAGE (for diversions, see line 6 and line 16): Intake gates: (number) type	35	(1) needle valve	(2) butterfly valves	(2) gates	gates
Intake gates: cross section	36		2.0 m Ø	2.5 x 3.0 m	
Power tunnel: length sections/int. Ø	37	0.1 km/1.5 m Ø 0.4 km/4 m2	0.8 km/3.10 m Ø	1.54 km/2.1 ÷ 2.5 m Ø	7.1 km/5.4 m2
Power tunnel: lining	38a	steel pipe in gallery free-flow tunnel	concrete with	partly concrete	free-flow tunnel
	38b	(free discharge to Tauernmoos reservoir)	prestressing gap grouting	partly shotcrete only	
Power tunnel: total length/max. pressure	39		0.8 km/6.4 bar	1.54 km/2 bar	gallery holding
Surge tank	40		2-chamber	2-chamber	30,000 m3 of water
Penstock or shaft: type	41		(1) pressure shaft	(2) penstocks	(1) penstock
Upper part: length sections/int. Ø	42		----	50 m/1.80 m Ø	----
Upper part: construction	43a		----	(1) connection tunnel	----
	43b		----	steel-lined	----
Gates: type, position	44		none	butterfly valves	rapid closing gate
Gates: (number) cross section	45		----	(2) 1.6 m Ø	(1) 4.6 x 6.3 m
Lower part: length sections/int. Ø	46		880 m/2.3 m Ø 200 m/2.3 - 1.9 m Ø	1270 m/2 x 1.7 ÷ 1.2 m Ø	650 m/1.7 m Ø
Lower part: construction	47a		high-grade section low-grade section	steel pipe with expansion pieces	steel pipe with expansion pieces
	47b		steel-lining	and concrete thrust blocks	and concrete thrust blocks
Manifold: position	48		hanging, outdoor, 6 branches	2 piping runs	1 piping run
Manifold: max. pressure - stat./dyn.	49				
Tailrace	50a		short free-flow channel	short, partly covered	covered channel
	50b			channel	
Discharge to	51	Tauernmoossee reservoir (J2)	Enzingerboden compensation reservoir (J3)	Stubache (J4)	Stubache (Salzach)
POWERHOUSE: Type	52		above-ground, reinforced concrete	above-ground, reinforced concrete	above-ground, reinforced concrete
Dimensions (without control building)	53		87 x 13 m, total height 19 m	58 x 19 m, total height 19 m	64 x 18 m, total height 18 m
Special features	54a		transformers in switchyard	transformers in switchyard	transformers in switchyard
	54b		traction current 16 2/3 Hz	traction current 16 2/3 Hz	traction current 16 2/3 Hz
Power units: (number) position, speed	55		(2) horizontal, 333 rpm (2) horizontal, 500 rpm	(2) horizontal, 500 rpm (1) horizontal, 500 rpm	(3) horizontal, 333 rpm
Power units: type and arrangement	56		1 Pelton t. w.1 jet each 2 Pelton t. w.2 jets each	2 Pelton t. w.2 jets each 1 Pelton t. w.2 jets each	2 Pelton turbines with 2 jets each
Power units: upstream gates: Type, int. Ø	57		1 rot.valve 0.6 m Ø each 2 rot.valves 0.7 m Ø each	1 needle valve 0.8 m Ø each 1 rot.valve 0.8 m Ø each	1 radial valve 0.6 m Ø each
Power units: T rating: H/Q/N	58		525 m/2.7 m3/s /13 MW 525/6 m3/s /28 MW	420 m/3.6 m3/s /12.1 MW 420 m/3.5 m3/s /11.8 MW	227 m/4.9 m3/s /9.0 MW
Power units: P rating: H/Q/N	59		--- ---		
Power units: downstream gates: type, dim.	60		valves	gate	
Power units: generator: capacity, type	61		12.5 MVA each 32 MVA each	12.5 MVA each with ring air cooling	10 MVA each with ring air cooling
Transf.: (number) type, arrangement	62				
capacity, voltage ratio	63		(2) 12.5 MVA, 9.5/110 kV (2) 32 MVA, 11/110 kV	(3) 12.5 MVA, block-type, 6.3/110 kV	(3) 10 MVA, block type, 6.6/110 kV
Switchplant	64		switchyard 110 kV	switchyard 110 kV	switchyard 110 kV
Plant capacity of T and/or P; max.	65		T: 81.2 MW	T: 35.4 MW	T: 27.0 MW
Annual energy without short-t.pumping (with)	66		120 GWh	115 GWh	75 GWh
Winter share % / full-load h.p.a.	67		79 % (1480 h)	65 % (3250 h)	53 % (2780 h)
Annual P energy without short-t.pumping (with)	68		----		
Footnotes *)	69	re. line 32: Construction of a high-head stage between Weissee and Tauernmoossee reservoirs (J2) is planned			

TABLE VII. THE SEASONAL STORAGE SCHEMES OF KELAG
PART 1: CATCHMENTS, RESERVOIRS AND DIVERSIONS

K1 to K4: Part 1

POWER SCHEME (OWNER)	1	K1 to K4 FRAGANT SCHEME, UPPER REGION WITH SEASONAL STORAGE RESERVOIRS			
Power stage (power station) District (province) Initial operation (extension)	2 3 4	K1 Zirmsee trans-basin diversion Spittal (Carinthia) 1982	K2 Zirknitz Spittal (Carinthia) 1974	K3 Wurten (Innerfragant) Spittal (Carinthia) 1969	K4 Oschenik (Innerfragant) Spittal (Carinthia) 1968/1980
River basins Utilised Catchments: directly to res. diversions to stage or trans-basin diversions and upstream power stations total	5 6z 6a 6b 6c 6d 6e 6f 6g 6	Fleißbach (Möll) Zirmsee 2,7 km2 Fleißkeesbach 2,0 km2 Brettsee 1,2 km2 total 5,9 km2	Zirknitzbach (Möll) Großsee + Hochwurten 7,3 km2 Schwarzsee 1,7 km2 Stübele + Gastrop 3,6 km2 Weißsee 0,9 km2 Kegelesee + Garnitzenbach 4,7 km2 from Zirmsee (K1) 5,9 km2 total 24,1 km2	Fleißbach, Zirknitzbach, Wurtenbach (Möll) Wurtenbach 7,7 km2 Feldsee 1,6 km2 Zirknitzbäche 18,5 km2 Fleißbäche 21,8 km2 Guttal-, Tauern- and Hoferbach 13,7 km2 from Zirknitz power stage (K2) 24,1 km2 total 87,4 km2	Fragantbach (Möll) Oscheniksee 1,7 km2 pumped storage from Wurten stage (K3) and Haselstein stage (K1) total 1,7 km2
Reservoir: Name Max./mean/min. water level Active storage (stored energy)	7 8 9	Zirmsee reservoir (interm. constr. stage) 2529,5/-----/2487,0 8,65 hm3 (32 GWh)	Großsee reservoir + Hochwurten (1. 23) 2417/2398/2330 26,7 hm3 (98 GWh)	Wurtenalm reservoir + Feldsee remote storage res. 1695/1688/1675 2217/2210/2196 2.7 hm3 (5.8 GWh) 1.6 hm3 (3.5 GWh)	Oscheniksee reservoir 2391/2348/2245 33 hm3 (82 GWh)
Dam: Name Type Height/crest length/crest level Volume Spillway: Type Capacity	10 11a 11b 12 13 14 15	Zirmsee dam rockfill with asphaltic concrete facing 44/315 m/2532,5 m a.s.l. 0,47.10^6 m3 fill trapezoidal or rectangular channel 11,7 m3/s for 1,4 m surcharge	Großsee dam / Hochwurten dam rockfill / gravelfill with asphaltic concrete facing 46/445 m + 55/260 m/2420 m a.s.l. 0,74.10^6 m3 + 0,60.10^6 m3 fill trapezoidal channel + pipe 6,7 m3/s + 21,0 m3/s for 1,4 m surcharge	Wurten dam / Feldsee dam rockfill / earthfill asphaltic concrete facing 42/282 m/1699 m a.s.l. 24/253 m/2220 m a.s.l. 0,265.10^6 m3 fill 0,065.10^6 m3 fill bellmouth spillway 11,0 m Ø trapez. channel 160 m3/s for 1,7 m surch. 25 m3/s for 1 m surcharge	Oschenik dam rockfill with asphaltic concrete facing 116/530 m/2394 m a.s.l. 2,3.10^6 m3 fill trapezoidal channel 6,4 m3/s for 1,2 m surcharge
Diversions to stages and trans-basin diversions (for abbreviations, see line 23) a) Name (catchment) Stream intake: (number) Q_r - type Waterway: type length/section b) Name (catchment) Stream intake: (number) Q_r - type Waterway: type length/section c) Name (catchment) Stream intake: (number) Q_r - type Waterway: type length/section d) Name (catchment) Stream intake: (number) Q_r - type Waterway: type length/section e) Name (catchment) Stream intake: (number) Q_r - type Waterway: type length/section	16a 17a 18a 19a 16b 17b 18b 19b 16c 17c 18c 19c 16d 17d 18d 19d 16e 17e 18e 19e	a) Fleißkeesbach diversion (6a) (1) 1,5 m3/s - concrete dam pressure tunnel, discharges into 37 0,77 km/9,6 m2 b) Brettsee diversion (6b) tapping of lake discharges into 37 0,37 km/9,6 m2	a) Schwarzsee trans-basin div. (6a) ZP to 16c (1) 0,26 m3/s - concrete dam plastic pipe, concrete-encased 0,75 km/0,4 m Ø b) Stübele trans-basin diversion (6b) ZP to 16c (6) total 0,6 m3/s - T plastic pipe, concrete-encased 0,85 km/0,5 ÷ 0,7 m Ø c) Weißsee trans-basin div. (6c+6a+b) ZP to 7 (1) 1,04 m3/s - fill dam plastic pipe, concrete-encased 0,4 km/0,4 m Ø d) Kegelesee trans-basin diversion (6d) ZP to 46 (1) 0,5 m3/s - concrete dam plastic pipe, concrete-encased 0,5 km/0,6 m Ø	a) Zirknitzbäche trans-basin div. + K2 (6b + e) (2) 1,4 m3/s and 1,1 m3/s - TA free-flow tunnel 8,62 km/6,71 m2 b) Fleißbäche trans-basin diversion (6c) to 16a (2) 1,6 m3/s and 1,2 m3/s - TA free-flow tunnel plastic pipe 5,5 km/6,71 m2 0,1 km/0,5 m2 c) Guttalbach trans-basin diversion (6d) to 16b (3) 0,15 to 0,75 m3/s - TA plastic pipe free-flow tunnel 7,74 km/0,5 m2 0,5 km/4,5 m2	none
(ZP) Feeder pumping station: Name (trans-basin diversion) Q_r/H_{gr} number of pumps x capacity	20 21 22		ZP Schwarzsee (16a): 0,26 m3/s /41 m, (1) 0,13 MW ZP Stübele (16b): 0,6 m3/s /157 m, (1) 1,2 MW ZP Weißsee (16c): 1,04 m3/s /40 m, (2) 0,6 MW ZP Kegelesee (16d): 0,5 m3/s /252 m, (1) 1,5 MW		
Footnotes *) Abbreviation in line 17a to e: T .... Tyrolean weir TA .... Tyrolean weir with automatic sand trap flushing	23a 23b 23c 23d 23e		reservoir connected in parallel, connection tunnel 1,8 km/6,5 m2		

TABLE VII, PART 2: HIGH-HEAD STAGES AND GENERATION

K1 to K4: Part 2

POWER SCHEME (OWNER)		30	K1 to K4 FRAGANT SCHEME (KELAG), UPPER REGION WITH SEASONAL STORAGE RESERVOIRS			
	Power stage (power station) T ... generating mode P ... pumping mode	31	K1 Zirmsee trans-basin diversion	K2 Zirknitz (Zirknitz)	K3 Wurten (Innerfragant)	K4 Oschenik (Innerfragant)
	Mode of operation	32	remote storage for K2 (see l. 69)	generation only	generation only (see l. 69)	pumped storage (see l. 69)
	Max./mean/min. gross head	33		689/670/602 m	490/483/470 m	1186/1143/1040 m
	Max. discharge Q_T (Q_P)	34		11.4 m3/s	16 m3/s	10 m3/s (13 m3/s)
POWER CONDUIT OF STAGE (for diversions, see line 6a)	Intake gates: type	35	stop logs			see l. 44/45
	Intake gates: (number) cross section	36	(2) 2.2 x 2.0 m			
	Power tunnel: length sections/int. Ø	37	7.0 km/7.7 m2	0.62 km/6.5 m2	1.2 km/4.5 m2	not applicable
	Power tunnel: lining	38a	shotcrete in places	concrete	concrete	
		38b				
	Power tunnel: total length/max. pressure	39	7.0 km, partly free-flow tunnel	0.62 km/10 bar	1.2 km/10 bar	
	Surge tank	40	with free discharge	2-chamber	2-chamber	not applicable
	Penstock or shaft: type	41	not applicable at present	(1) penstock	(1) penstock	(1) pressure shaft
	Upper part: length sections/int. Ø	42			----	0.5 km/4.0 m2 0.15 km/1.9 m Ø
	Upper part: construction	43a				concrete steel lining
		43b				prestressing gap grouting
	Gates: type, position	44		butterfly valves	butterfly valves	butterfly valve
	Gates: (number) cross section	45		(2) 1.20 m Ø	(2) 1.80 m Ø	(1) 1.60 m Ø
	Lower part: length sections/int. Ø	46		3.1 km/1.20 ÷ 0.8 m Ø	1.2 km/2.0 ÷ 1.7 m Ø	2.1 km/1.70 m Ø, 0.3 km/1.45 m Ø, 0.1 km/1.30 m Ø
	Lower part: construction	47a		steel pipe, concrete-encased	steel pipe, partly concrete-encased	steel-lining (see also line 69) penstock
		47b		without thrust blocks & expansion pieces	or on socketed steel columns, no thrust blocks	drainage and gap grouting
	Manifold: position	48		concrete-embedded, 2 branches	in pipe hall, partly concrete-embedded, 6 branches	hanging, in pipe hall, 6 branches
	Manifold: max. pressure - stat./dyn.	49		69/79 bar	49/62 (exception 75) bar	120/148 bar
	Tailrace	50a		free-flow tunnel	concrete canal, discharges into 37 of K6	concrete canal, discharges into 37 of K6
		50b			0.3 km/7.3 m2	0.3 km/7.3 m2
	Discharge to	51	Großsee reservoir (K2)	Zirknitzbach trans-basin diversion (16a of K3)	stage K2, or Innerfragant reservoir	stage K2, or Innerfragant reservoir
POWERHOUSE	Type	52		above-ground, reinforced concrete	above-ground, reinforced concrete	
	Dimensions (without control building)	53		32 x 14 m	116 x 26 m in common with K4	as K3
	Special features	54a			transformers against external wall	
		54b				
	Power units: (number) position, speed	55		(2) horizontal, 600 rpm	(2) horizontal, 500 rpm	(3) horizontal, 750 rpm
	Power units: type and arrangement	56		1 Pelton turbine, 2 jets, each	2 Pelton turbines, 2 x 2 jets, each	1 pelton turbine, 2 jets, each + 1 storage pump
	Power units: upstream gates: type, int. Ø	57		1 rotary valve 0.6 m Ø each	2 rotary valves 0.8 m Ø each	1 T rot. valve 0.7 m Ø each + 1 P rotary valve
	Power units: T rating: H/Q/N	58		667 m/2.84 m3/s /16 MW	485 m/7.0 + 8.8 m3/s /36 + 40 MW	1143 m/2 x 3.0 + 1 x 4.2 m3/s / 2 x 33 + 1 x 42 MW
	Power units: P rating: H/Q/N	59		---	----	see line 69
	Power units: downstream gates: type, dim.	60		stop logs	stop logs	T - stop logs P - rotary valve 1.0 m Ø
	Power units: generator: type, capacity	61		1 synchr. generator 16 MVA each	1 synchr. generator each 32 & 40 MVA	1 motor generator 2 x 33 + 1 x 42 MVA, each
	Transf.: (number) type, arrangement	62		(2) three-phase	(2) three-phase, block-type	(3) three-phase, block-type
	capacity, voltage ratio	63		(1) 55 MVA, 10.5/115 kV (1) 16 MVA, 10.5/21 kV	40 MVA, 10.5/115 kV	1 x 33 MVA 1 x 40 MVA 1 x 42 MVA
	Switchplant	64		10.5, 21 and 115 kV (SFG) - indoor	115 kV indoor	115 kV indoor
	Plant capacity of T and/or P: max.	65		T: 32 MW ZP (see 22) 3.4 MW	T: 66 MW	T: 108 MW P: 94 MW
	Annual energy without short-t. pumping (with)	66		55.2 GWh	99 GWh	82 GWh (no inf.)
	Winter share % / full-load h.p.a.	67		91 % / 1720 h	57 % / 1500 h	100 % / 758 h
	Annual P energy without short-t.pumping (with)	68		für ZP 10.3 GWh	---	72 GWh (no inf.)
	Footnotes *)	69	re. line 32: Construction of a high-head stage, Zirmsee (Zirknitz), with separate penstock parallelling penstock of K2 is planned		water abstraction for pumped storage in Oschenik stage (K4)	re. line 47a: (1) rotary valve 1.3 m Ø at downstream end of pressure shaft re. line 59: storage pump rating 1 x from K3: 670 m/4.3 m3/s /28 MW 1 x from K5: 870 m/3.3 m3/s /29 MW 1 x from K3: 670 m/5.6 m3/s /37 MW

TABLE VIII. THE SEASONAL STORAGE SCHEMES OF KELAG

PART 1: CATCHMENTS, RESERVOIRS AND DIVERSIONS

POWER SCHEME (OWNER)	1	K5 to K7 FRAGANT SCHEME (KELAG), MIDDLE AND LOWER REGION		
Power stage (power station)	2	K5 Haselstein (Innerfragant)	K6 Ausserfragant	K7 Wölla upper stage (Wölla)
District (province)	3	Spittal (Carinthia)	Spittal (Carinthia)	Spittal (Carinthia)
Initial operation (extension)	4	1968	1968 (1982)	1982/1984
River basins	5	Fragantbach (Möll)	Fragantbach, tributaries (Möll and Drau)	Wölla, tributaries (Möll and Drau)
Utilised Catchments: directly to res.	6z	0 km2	0 km2	
diversions	6a	Großfragant (diversion) 13,0 km2	Oschenik (rest) + Wollnitzenbach (diversion) 9,8 km2	Draßnitzbach (Drau) 22,8 km2
to stage	6b	Kleinfragant 8,5 km2	Wurtenbach (rest) 4,3 km2	Lamnitzbach (Möll) 10,3 km2
or	6c		from Wurten stage (K3) 87,4 km2	Wölla 12,7 km2
trans-basin diversions	6d	pumped storage	from Oschenik stage (K4) 1,7 km2	
and	6e	from Ausserfragant (K6)	from Haselstein stage (K5) 21,5 km2	
upstream	6f		from Wölla upper stage (K7) 45,8 km2	
power stations	6g		Wölla-, Gron- and Klonbach (diversion) 13,4 km2	
total	6	total 21,5 km2	total 183,9 km2	total 45,8 km2
Reservoir: Name	7	Haselstein reservoir	Innerfragant reservoir	Wölla reservoir
Max./mean/min. water level	8	1470,5/1465/1458 m a.s.l.	1201/1198/1193 m a.s.l.	1542/1539,5/1534,5 m a.s.l.
Active storage (stored energy)	9	0,04.10⁶ m3	0,175 hm3	0,01 hm3 (+ 0,08 hm3 in tunnel)
Dam: Name	10	artificial basin, 12,5 m deep	artificial basin, 8,0 m deep	artificial basin
Type	11a	talus material dam downstream	talus material dam downstream	tunnel debris fill
	11b	asphalt concrete membrane	asphalt concrete membrane	asphalt concrete membrane
Height/crest length/crest level	12			
Volume	13	0,05.10⁶ m3 material movement	0,185.10⁶ m3 material movement	0,10.10⁶ m3 material movement
Spillway: Type	14	spillway	bellmouth spillway	concrete channel
Capacity	15	2,8 m3/s	26,0 m3/s	10,0 m3/s for 0,82 m surcharge
Diversions to stages and trans-basin diversions (for abbreviations, see line 23): a) Name (catchment)	16a	a) Großfragant diversion (6a)	a) Oschenik- and Wollnitzenbach diversion (6a)	a) Draßnitzbach trans-basin diversion (6a)
Stream intake: (number) Q_r - type	17a	(1) 1,5 m3/s - TA	(2) 0,5 m3/s and 1,0 m3/s - TA	(2) 1,5 m3/s, 2,5 m3/s - TA
Waterway: type	18a	steel pipe, connected to 41	1 free-flow tunnel each, discharge into 37	buried pipeline, free-flow tunnel
length/section	19a	2,8 km/1,0 m Ø	0,08 km/6,7 m2 0,53 km/4,2 m2	2,0 km/0,6 and 1,2 m Ø, 7,0 km/3,5 m Ø
b) Name (catchment)	16b	b) Kleinfragant trans-basin diversion (6b)	b) Wurtenbach trans-basin diversion (6b)	b) Lamnitzbach trans-basin diversion (6b)
Stream intake: (number) Q_r - type	17b	(1) 1,25 m3/s - TA	(1) 4,1 m3/s - TA	(2) 1,0 m3/s and 1,5 m3/s - TA
Waterway: type	18b	steel pipe	concrete canal	buried pipeline, free-flow tunnel
length/section	19b	0,15 km/0,7 m Ø	0,25 km/5,1 m2	1,9 km/0,5 - 0,9 m Ø, 4,1 km/3,5 m Ø
c) Name (catchment)	16c		c) Wölla diversion with K7 (6f+g)	c) Wölla trans-basin diversion (6c)
Stream intake: (number) Q_r - type	17c		(1) 4,0 m3/s - TA bzw. 6,0 m3/s from K7	(1) 2,5 m3/s - TA
Waterway: type	18c		concrete canal, free-flow tunnel, pressure pipe *)	buried pipeline
length/section	19c		0,2 km/6,7 m2; 6,5 km/3,5 m Ø; 1,7 km/1,5 - 1,4 m Ø	0,3 km/0,9 m Ø
d) Name (catchment)	16d		d) Gron- and Klonbach diversion (6g)	
Stream intake: (number) Q_r - type	17d		(2) 0,7 m3/s - TA	
Waterway type	18d		free-flow tunnel	
length/section	19d		0,2 km/3,5 m2 discharges into 18c	
e) Name (catchment)	16e			
Stream intake: (number) Q_r - type	17e			
Waterway: type	18e			
length/section	19e			
(ZP) Feeder pumping station: Name (trans-basin diversion)	20			
Q_r/H_{gr}	21			
number of pumps x capacity	22			
Footnotes *)	23a		re. line 18c: concrete-encased, discharges into line 48,	
Abbreviations:	23b		2 butterfly valves, 1,6 m Ø, upstream	
T .... Tyrolean weir	23c			
TA .... Tyrolean weir with automatic	23d			
sand trap flushing	23e			

TABLE VIII, PART 2: HIGH-HEAD STAGES AND GENERATION

POWER SCHEME (OWNER)	30	K5 to K7 FRAGANT SCHEME (KELAG), MIDDLE AND LOWER REGION		
Power stage (power station) T ... generating mode P ... pumping mode	31	K5 Haselstein (Innerfragant)	K6 Ausserfragant	K7 Wölla upper stage
Mode of operation	32	pumped storage *)	generation only *)	generation only
Max./mean/min. gross head	33	276/266/256 m	488/485/480 m	326/324/319 m
Max. discharge Q_T (Q_P)	34	1.74 m3/s (+ 1.72 m3/s)	23 m3/s	6.0 m3/s
POWER CONDUIT OF STAGE (for diversions, see line 6a): Intake gates – type	35			see lines 44 & 45
Intake gates – (number) cross section	36			
Power tunnel – length sections/int. Ø	37		0.5 km/5.8 and 7.3 m2 5.0 km/6.0 m2 0.1 km/2.6 m Ø	
Power tunnel – lining	38a		concrete canal tunnel steel lining	
	38b			
Power tunnel – total length/max. pressure	39		5.1 km/6 bar	
Surge tank	40		2-chamber, partly steel pipe, concrete-encased	
Penstock or shaft: type	41	1 penstock	2 penstocks	1 penstock
Upper part – length sections/int. Ø	42	45 m/1.80 m Ø		
Upper part – construction	43a	concrete pipe		
	43b	buried		
Gates – type, position	44	(1) butterfly valve	(2) x (2) butterfly valves	(2) butterfly valves
Gates – (number) cross section	45	1.40 m Ø	1.80 m Ø	1.5 m Ø
Lower part – length sections/int. Ø	46	333 m/1.50 m Ø 630 m/1.10 m Ø	1.48 km/2 x 1.8 ÷ 1.5 m Ø	2.06 km/1.5 ÷ 1.4 m Ø
Lower part – construction	47a	steel pipe steel pipe	steel pipes with expansion pieces	steel pipe
	47b	partly concrete-embedded buried	thrust blocks without concrete caps	concrete-embedded
Manifold – position	48		1 pipe run with 6 branches, partly concrete-embedded	
Manifold – max. pressure - stat./dyn.	49		49/56 bar	
Tailrace	50a	directly to 37 of K6	open canal	concrete canal
	50b		concrete lining	
Discharge to	51	K2 stage, or Innerfragant reservoir	Möll	Wölla diversion 16c of K6
POWERHOUSE: Type	52	above-ground, reinforced concrete	above-ground, reinforced concrete	above-ground, reinforced concrete
Dimensions (without control building)	53	18 x 10 m	17 x 54 m	
Special features	54a		transformers against external wall	
	54b			
Power units: (number) position, speed	55	(1) horizontal, 1007 rpm	(3) horizontal, 500 rpm	(1) vertical, 1000 rpm
type and arrangement	56	two-stage pump turbine	2 Pelton turbines, 2 x 2 jets, each	Francis turbine
upstream gates: type, int. Ø	57	1 rotary valve 0.6 m Ø	2 rotary valves 0.8 m Ø each	
T rating: H/Q/N	58	266 m/1.74 m3/s /4.0 MW	464 m/2 x 7.0 + 9.0 m3/s /2 x 30 + 36 MW	326 m/6.0 m3/s /17 MW
P rating: H/Q/N	59	266 m/1.72 m3/s /5.0 MW	----	
downstream gates: type, dim.	60	1 follower-type gate valve 0.9 m Ø	stop logs	stop logs
generator: type, capacity	61	1 asyn. motor generator 6 MVA	1 synchr. generator each 2 x 32 + 40 MVA	synchron. generator 20 MVA
Transf.: (number) type, arrangement,	62	10.5 kV cable connection	(3) 3-phase, block-type	(1) 3-phase, block-type
capacity, voltage ratio	63	to Innerfragant power station (K3 and K4)	2 x 32 + 40 MVA, 10.5/115 kV	20 MVA, 6.3/115 kV
Switchplant	64		115 kV switchyard	115 kV indoor
Plant capacity of T and/or P: max./mean	65	T: 4.0 MW P: 5.0 MW	T: 96 MW	T: 17 MW
Annual energy without short-t. pumping (with)	66	8.9 GWh (K. A)	236 GWh	40.3 GWh
Winter share % / full-load h.p.a.	67	33 % / 2250 h	49 % / 2460 h	25 % / 2370 h
Annual P energy without short-t. pumping (with)	68	allowed for in K4	(after commissioning of K7)	
Footnotes *)	69	water abstraction for pumping in Oschenik stage (K4)	water abstraction for pumping in Haselstein stage (K5)	

TABLE IX. THE SEASONAL STORAGE SCHEMES OF ÖDK - REISSECK-KREUZECK GROUP

PART 1: CATCHMENTS, RESERVOIRS AND DIVERSIONS

POWER SCHEME (OWNER)	1	L REISSECK - KREUZECK SCHEME (ÖDK)		
Power stage (power station)	2	L1 Reißeck storage scheme (Kolbnitz) with Hattelberg pumping station	L2 Reißeck run-of-river scheme (Kolbnitz)	L3 Kreuzeck run-of-river scheme (Kolbnitz)
District (province)	3	Spittal an der Drau (Carinthia)	Spittal an der Drau (Carinthia)	Spittal an der Drau (Carinthia)
Initial operation (extension)	4	1957/60	1950/52	1958/60
River basins	5	Tributaries (Möll)	Tributaries (Möll)	Tributaries (Möll and Drau)
Utilised Catchments: directly to res.	6z	Großer Mühldorfer See *) 1,1 km2	Zwenberger Bach (diversion) 13,1 km2	Teuchlbach 42,5 km2
diversions	6a	Kleiner Mühldorfer See *) 1,4 km2	Riekenbach (diversion) 17,7 km2	Niklaibach 22,1 km2
to stage	6b	Hochalmsee (diversion) 1,5 km2	Mühldorfer Bach 11,8 km2	Grabach 21,4 km2
or	6c	Radlsee (diversion) 1,7 km2		Gnoppnitzbach 28,7 km2
trans-basin diversions	6d	total reservoirs 5,7 km2		(with tributaries)
and	6e	Kessele- and Quarzsee 1,9 km2		
upstream	6f			
power stations	6g			
total	6	total 7,6 km2	total 42,6 km2	total 114,7 km2 (of which Niklai intermediate p. st. 64,2 km2)
Reservoir: Name	7	A. Großer Mühldorfer See; B. Kleiner Mühldorfer See; C. Hochalmsee; D. Radlsee	Gondelwiese daily storage reservoir	Roßwiese daily storage reservoir
Max./mean/min. water level	8	A. 2319/2255 m a.s.l.; B. 2379/2335 m a.s.l.; C. 2379/2330 m a.s.l.; D. 2399/2354 m a.s.l.	1288,5/1280,5 m a.s.l.	1194/1180 m a.s.l.
Active storage (stored energy)	9	A. 7,8 hm3 (30,5 GWh); B. 2,8 hm3 (11,3 GWh); C. 4,1 hm3 (16,4 GWh); D. 2,5 hm3 (10,1 GWh); (total 17,2 hm3 and 68,3 GWh)	0,04 hm3	0,20 hm3
Dam: Name (see line 7)	10	A. concrete dam; B. concrete dam; C. concrete dam & fill dam; D. concrete dam	artificial basin, 12 m deep	artificial basin, 19 m deep
Type	11a	A. gravity with hollow space; C. gravity with; D. rockfill with	concrete-lined upstream slope and bottom	completely lined with asphaltic concrete
	11b	precast panel facing; C. hollow space; D. concrete core wall	downstream buttress dam	downstream earthfill dam
Height/crest length/crest level	12	A. 47/433 m; B. 41/159 m; C. 25/237 m, 9/120 m; D. 16/212 m	12,5/120 m/1289,5 m a.s.l.	19,5/350 m/1196 m a.s.l.
Volume	13	A. 153.000 m3; B. 60.000 m3; C. 29.000 m3, 4.000 m3; D. 20.000 m3		130.000 m3 fill
Spillway: Type	14	A. overflow spillw.; B. overflow spillw.; C. overflow spillw.; D. side spillway	side weir in supply tunnel 18b	side weir in supply tunnel 18b
Capacity	15	A. 13 m3/s (0,74 m); B. 14,6 m3/s (0,82 m); C. 13,5 m3/s (0,69 m); D. 19,8 m3/s (0,88 m)	at Mühldorfer Bach	at Lünitzbach, 14 m3/s (1,32 m)
Diversions to stages and trans-basin diversions (for abbreviations, see line 23): a) Name (catchment)	16a	a) Hochalmsee diversion (6b) to Radlsee connection	a) Zwenberg- and Riekenbach diversion (6a and b)	a) Teuchlbach trans-basin diversion (6a)
Stream intake: (number) Q_r - type	17a	(1) tapping of lake (2 butterfly valves)	(2) 1,5 and 3,0 m3/s - TE	(2) 1,5 to 5,0 m3/s - TE + secondary diversions
Waterway: type	18a	pressure tunnel; steel pipe in gallery; buried steel pipe; steel pipe in tunnel	free-flow tunnel; buried steel pipe; st.pipe in gall.	concrete pipe; free-flow tunnel
length/section	19a	0,1 km/1,7 m ∅; 0,3 km/0,65 m ∅; 1,2 km/0,65 m ∅; 1,2 km/0,69 m ∅	3,8 km/5,5 m2; 1,5 km/0,9 m ∅; 2,1 km/1,2 m ∅	1 km/1,4 m ∅; 6,9 km/6 m2; 1,3 km/10,6 - 12,9 m2
b) Name (catchment)	16b	b) Kesseleseen and Quarzsee diversion (6e) in 16a	b) Mühldorfer trans-basin diversion (6c)	b) Gnoppnitz & Grabach trans-b.div.(6b+c+d) to Niklai p.st.
Stream intake: (number) Q_r - type	17b	(2) lake intakes	(1) 1,5 m3/s - TE + secondary diversions	(3) 2,8, 2,0 and 1,2 m3/s - TE + secondary div.
Waterway: type	18b	spur conduit to 18a	free-flow tunnel	free-flow tunnel; steel pressure pipe
length/section	19b		1,0 km/4,5 m2	9,3 km/6,0 m2; 0,3 km/1,20 m ∅
c) Name (catchment)	16c	c) Radlsee diversion (6c) to junction with connection to reservoir B outlet (l. 37) *)		c) Niklai trans-b.div. from Niklai p. st. (6b+c+d)
Stream intake: (number) Q_r - type	17c	(1) tapping of lake (1 butterfly valve)		sec. diversions of Niklai tributaries
Waterway: type	18c	pressure tunnel; steel pipe in gallery		free-flow tunnel
length/section	19c	0,1 km/1,7 m ∅; 1,2 km/0,55 m ∅; 1,3 km/0,96 m ∅ (with 16a and b)		4,2 km/6,0 m2
d) Name (catchment)	16d			
Stream intake: (number) Q_r - type	17d			
Waterway: type	18d			
length/section	19d			
e) Name (catchment)	16e			
Stream intake: (number) Q_r - type	17e			
Waterway: type	18e			
length/section	19e			
(ZP) Feeder pumping station: Name (trans-basin diversion)	20	Hattelberg pumping station 1113 m a.s.l. with 3 eight-stage pumps		Niklai intermediate power station
Q_r/H_{gr}	21	supply from penstock L2 1,35 m3/s / 1030 to 1110 m		3,6 m3/s / 57 m (between 16b and 16c)
number of pumps x capacity	22	discharge to penstock L 1 3 x 6 MW = 18 MW		(2) 0,5 + 1,1 MW = 1,6 MW
Footnotes *)	23a	re. l. 6z & 6a: Power conduits from reservoir A (Großer Mühldorfer See)	Water release	
Abbreviations to l. 17:	23b	and reservoir B (Kleiner Mühldorfer See), see stage (lines 35 to 40)	to stage L1	
TE .... Tyrolean weir with sand trap	23c			
	23d			
	23e			

TABLE IX, PART 2: HIGH-HEAD STAGES AND GENERATION

L: Part 2

POWER SCHEME (OWNER)	30	L REISSECK - KREUZECK SCHEME (ÖDK)		
Power stage (power station) T ... generating mode P ... pumping mode	31	L1 Reißeck storage scheme (Kolbnitz) (Hattelberg pumping station for pumping from L2, see 1. 20 to 22)	L2 Reißeck run-of-river scheme (Kolbnitz)	L3 Kreuzeck run-of-river scheme (Kolbnitz)
Mode of operation	32	generation alternatively from reservoirs A and B	generation - daily storage	generation - daily storage
Max./min. gross head	33	1772.5/1648.5 m	678.5 m	587.5 m
Max. discharge Q_T (Q_P)	34	4.5 m3/s	5.0 m3/s	9.0 m3/s
POWER CONDUIT OF STAGE (for diversions, see line 16)		from reservoir A (Großer Mühldorfer See) / from reservoir B (Kleiner Mühldorfer See)		
Gates to surge tank: (number) type	35	1 butterfly valve 1.1 m Ø 1 needle valve / 1 butterfly v., 1 butterfly v. + 1 needle v.	1 butterfly valve / 1 needle valve	not applicable
position	36	lake tapping point Reißeck valve chamber / lake tapping point Reißeck valve chamber	downstr. of Gondelwiese res. / upstream of surge tank	
Waterway from reservoir to surge tank: length section	37	0.1 km, 0.3 km, 0.6 km, 2.7 km / 0.1 km 0.4 km 0.2 km	0.3 km / 1.5 km	
cross section (int.Ø or area)	38a	1.9 m Ø, 1.1 m Ø steel p., 1.35 m Ø steel p. / 1.9 m Ø 1.10 m Ø steel pipe	Ø 0.9 m steel pipe	not applicable
design	38b	press.t., pipe gall., buried, in pipe gall. / press.tunnel buried in pipe gallery	buried / in pipe gallery	
total length, max.press.	39	3.7 km (3.2 km from Reißeck valve ch.) - 16 bar - 3.9 km (0.7 km + 3.2 km from Reißeck valve ch.)	1.8 km	
Surge tank	40	2-chamber, lower chamber & shaft: buried steel pipe, upper chamber: concrete tank	inclined shaft with upper chamber gallery	not applicable
Penstock/shaft: (runs) design	41	(1) penstock	(1) penstock	(1) penstock
Upper part: length sections/int. Ø	42	30 m/1.35 m Ø		bellmouth inlet
construction	43			concrete
Gates: (number) type	44	1 butterfly valve	2 butterfly valves	1 butterfly valve
int. Ø (position)	45	1.4 m Ø (Schoberboden valve chamber)	1.4 m Ø (downstream of surge tank)	1.8 m Ø (at inlet)
Lower part: length sections/int. Ø	46	1286 m/1.35 - 1.15 m Ø / 2120 m/1.15 - 0.95 m Ø / 730 m/0.95 m Ø	1150 m/1.35 - 1.0 m Ø / 730 m/1.0 m Ø	1546 m/1.8 - 1.35 m Ø
construction	47a	smooth steel pipe / wrapped steel pipe / smooth steel pipe	steel pipe with / steel pipe	steel pipe
	47b	with expansion pieces & thrust blocks / buried, no thrust blocks	exp. pieces & concr. thr. bl. / buried, no thr.bl.	with expansion pieces & concrete thrust blocks
Manifold: position	48	hanging, in valve hall, 3 branches	hanging, in pipe basement, 2 branches *)	hanging, in pipe basement, 2 branches *)
max.pressure - stat./dyn.	49	177/196 bar	68/75 bar	59/65 bar
Tailrace	50a	closed concrete canal along powerhouse	as L1	as L1
	50b	then open canal (in common with L2 and L3)		
Discharge to	51	Möll	Möll	Möll
POWERHOUSE: Type	52	above-ground, reinforced concrete (in common with L2 & L3)		
Dimensions (without control building)	53	100 x 25 m, total hieght 19 m (not incl. roof)	as L1	as L1
Special features	54a	transformers in switchyard		
	54b			
Power units: (number) position, speed	55	(3) horizontal, 750 rpm	(2) horizontal, 500 & 750 rpm	(2) horizontal, 500 rpm
type and arrangement	56	1 Pelton turbine with 1 jet, each	1 Pelton turbine, 2 jets, each	1 Pelton turbine, 2 jets, each
upstream gates: type, int. Ø	57	1 needle valve + 1 rotary valve 0.5 m each	1 rotary valve 0.8 m Ø, each	1 rotary valve 0.8 m Ø each
T rating: H/Q/N	58	1765 m/1.5 m3/s /23 MW	T (1) 620 m/3.8 m3/s /20 MW	584 m/4.6 m3/s /23.3 MW
P rating: H/Q/N	59	---	T (1) 625 m/1.5 m3/s /8 MW	---
downstream gates: type, dim.	60	stop logs	stop logs	stop logs
generator: type, capacity	61	1 synchron generator 28 MVA, ring air cooling	1 synchron generator each, 20 MVA & 9 MVA	1 synchron generator 25 MVA each
Transf.: (number) type, arrangement	62	(3) 3-phase, block-type	(1) 3-phase, block-type; (2) variable voltage transf.	(1) 3-phase, block-type
capacity, voltage ratio	63	25 MVA, 10.5/115 kV	20 MVA, 10.5/115 kV 20 & 25 MVA	25 MVA, 10.5/115 kV
Switchplant	64	115 kV switchyard, 10 kV & 20 kV indoor	115 kV switchyard over 10.5 kV switchplant	115 kV outdoor 10 kV indoor
Plant capacity of T and/or P: max./mean	65	T: 67.5 MW	T: 23 MW	T: 45 MW
Annual energy without short-t. pumping (with)	66	73 GWh (no short-term pumping)	62 GWh (no short-term pumping)	163 GWh (no short-term pumping)
Winter share % / full-load h.p.a.	67	100 % / 1070 h	27 % / 2700 h	27 % / 3600 h
Annual P energy without short-t.pumping (with)	68	26 GWh (Hattelberg pump station, see 1. 20 to 22)	0	0
Footnotes *)	69		re. line 48: connection to L3 through 2 needle valves 0.7 m Ø	re. line 48: connection to L 2 through 2 needle valves 0.7 m Ø

TABLE X. THE SEASONAL STORAGE SCHEMES OF ÖDK - MALTA SCHEME

PART 1: CATCHMENTS, RESERVOIRS AND DIVERSIONS

M: Part 1

POWER SCHEME (OWNER)	1	M MALTA SCHEME (ÖDK)		
Power stage (power station)	2	M1 Malta upper stage (Galgenbichl)	M2 Malta main stage (Rottau)	M3 Malta lower stage (Möllbrücke)
District (province	3	Spittal an der Drau (Carinthia)	Spittal an der Drau (Carinthia)	Spittal an der Drau (Carinthia)
Initial operation (extension)	4	1978	1978	1978
River basins	5	Malta and Lieser (Drau)	Malta and Lieser (Drau)	Möll, Malta and Lieser (Drau)
Utilised Catchments: directly to res.	6z	Malta, Kölnbreinbach 51,3 km2	Malta (remaining catchment) 6,6 km2	Möll 1081,3 km2
diversions	6a		Gößkar 10,6 km2	
to stage	6b		Göß south tributaries 11,0 km2	
or	6c		Göß north tributaries 2,4 km2	
trans-basin diversions	6d		Malta south tributaries 18,2 km2	
and	6e		Malta north tributaries (see l. 23) 17,5 km2	
upstream	6f		Lieser 11,0 km2	
power stations	6g		from upper stage M1 51,3 km2	from main stage 128,6 km2
total	6	total 51,3 km2	total 128,6 km2	total 1209,9 km2
Reservoir: Name	7	Kölnbrein reservoir	A. Galgenbichl reservoir / B. Gößkar reservoir	Rottau compensation reservoir
Max./mean/min. water level	8	1902/1854,2/1730 m a.s.l.	1704/1695,6/1680 m a.s.l.	598/597,3/596,5 m a.s.l.
Active storage (stored energy)	9	200 hm3 (577 GWh)	A: 4,4 hm3 (11,2 GWh) / B: 1,8 hm3 (4,6 GWh)	0,5 hm3
Dam: Name	10	Kölnbrein dam	Galgenbichl dam / Gößkar dam	Rottau weir & power station (see line 20)
Type	11a	arch	gravelfill dams with asphaltic concrete facing	vertical lift gate weir
	11b			with 2 bays 15 m wide each
Height/crest length/crest level	12	200/626 m/1902,7 (1904 *) m a.s.l.	50/115 m/1706,9 m a.s.l. / 55/270 m/1707,4 m a.s.l.	25/46 m/600,5 m a.s.l.
Volume	13	1,58.10[6] m3 concrete	6700 m3 concrete 0,165.10[6] m3 fill / 0,531.10[6] m3 fill	26.000 m3 concrete
Spillway: Type	14	side spillway, 30 m long	side dam, 40 m overflow / bellmouth spillway, 9,5 m Ø	2 radial gates with flaps, 15 x 13,7 m
Capacity	15	138 m3/s for 1,9 m surcharge	196 m3/s for 1,7 m surcharge / 96 m3/s for 1,3 m surcharge	930 m3/s with full gate opening
Diversions to stages and trans-basin diversions (for abbreviations, see line 23): a) Name (catchment)	16a	none	a) Göß south diversion to 7 B	none
Stream intake: (number) Q_r - type	17a		(3) 1,0 - 1,5 m3/s - TA	
Waterway: type	18a		free-flow tunnel	
length/section	19a		4,1 km/8,0 m2	
b) Name (catchment)	16b		b) Göß north diversion to 7 B	
Stream intake: (number) Q_r - type	17b		(1) 0,75 m3/s - TA	
Waterway: type	18b		steel pipe	
length/section	19b		1,1 km/0,5 m Ø	
c) Name (catchment)	16c		c) Malta south trans-basin diversion to 7 A	
Stream intake: (number) Q_r - type	17c		(5) 0,5 - 6,0 m3/s - TA	
Waterway: type	18c		free-flow tunnel	
length/section	19c		6,6 km/9,0 m2	
d) Name (catchment)	16d		d) Malta north trans-basin diversion to 7 A	
Stream intake: (number) Q_r - type	17d		(5) 0,6 - 1,5 m3/s - TA (see line 23)	
Waterway: type	18d		free-flow tunnel	
length/section	19d		10,2 km/9,0 m2	
e) Name (catchment)	16e		e) Lieser trans-basin diversion to 16d	
Stream intake: (number) Q_r - type	17e		(1) 5,0 m3/s - TA	
Waterway: type	18e		free-flow tunnel	
length/section	19e		3,7 km/9,0 m2	
(ZP) Feeder pumping station: Name (trans-basin diversion)	20	none	none	Rottau weir power station
Q_r/H_{gr}	21			5 m3/s / 14 m
number of pumps x capacity	22			1 x 0,6 MW
Footnotes *7	23a	re. line 12: top of parapet	re. lines 6e and 17d: minimum release of 140 l/s	
Abbreviations:	23b		required at certain times for	
T .... Tyrolean weir	23c		Melnikbach stream intake	
TA .... Tyrolean weir with automatic	23d		(catchment = 6,1 km2)	
sand trap flushing	23e			

TABLE X, PART 2: HIGH-HEAD STAGES AND GENERATION

M: Part 2

POWER SCHEME (OWNER)	30	M MALTA SCHEME (ÖDK)		
Power stage (power station) T ... generating mode P ... pumping mode	31	M1 Malta upper stage (Galgenbichl)	M2 Malta main stage (Rottau)	M3 Malta lower stage (Möllbrücke)
Mode of operation	32	pumped storage	pumped storage	generation only
Max./mean/min. gross head	33	222/158.6/46 m	1102.5/1093.4/1078.5 m	45/44.3/43.5 m
Max. discharge Q_T (Q_P)	34	44 to 70 (32 to 76) m3/s	80 (23.2) m3/s	110 m3/s
POWER CONDUIT OF STAGE — Intake gates: type	35	butterfly valves	A. Galgenbichl reservoir: butterfly valve; B. Gößkar reservoir: butterfly valves *)	bulkhead (emergency weir) gates
Intake gates: (number) cross section	36	(2) 3.80 m Ø	A: (1) 4.00 m Ø; B: (2) 4.00 m Ø	15 x 13 m
Power tunnel: length sections/int. Ø	37	2.0 km/4.70 m Ø 0.3 km/4.70 m Ø 0.3 km/4.40 m Ø	A: 9.5 km/4.9 m Ø 0.4 km/4.0 m Ø; B: 8.8 km/4.9 m Ø, 0.8 km/4.7 m Ø, 0.1 km/4.4 m Ø	2.5 km headrace 79 m2
Power tunnel: lining	38a	concrete sealing foil steel-lining	A: concrete with steel-lining; B: concrete & bore hole grouting subsegment steel-lining steel-lining	asphaltic concrete
	38b			
Power tunnel: total length/max. pressure	39	2.6 km/24 bar	19.6 km/13.5 bar	
Surge tank	40	none	2-chamber with reverse-flow control throttle	none
Penstock or shaft: type (for diversions, see line 6a)	41	see line 37 to 40	(1) pressure shaft - (2) penstocks	power tunnel
Upper part: length sections/int. Ø	42		1.3 km/4.0 m Ø	1.61 km/6.6 m Ø 0.1 km/6.0 m Ø
Upper part: construction	43a		steel-lining	concrete steel-lining
	43b			
Gates: type, position	44		at end of manifold butterfly valves downstream of manifold	
Gates: (number) cross section	45		(1) + (1) 2.60 m Ø	
Lower part: length sections/int. Ø	46		1.8 km/2 x (2.6 - 2.5) m Ø	
Lower part: construction	47a		steel pipe with expansion pieces	
	47b		thrust blocks without concrete caps	
Manifold: position	48	concrete-embedded in gallery, 2 branches	(2) hanging, above-ground, 3 branches each	1 steel manifold, concrete-encased
Manifold: max. pressure - stat./dyn.	49	25/32 bar	110.3/127 bar	5/6.5 bar
Tailrace	50a	pressure tunnel 0.15 km/5 m Ø	T - (4) concrete canals, 40 m long	open canal, 82 m long
	50b	concrete, end section is steel-lined	P - (2) steel pipes, 50 m/2.8 m Ø	
Discharge to	51	Galgenbichl reservoir (M2 A)	forebay of Rottau compensation reservoir	Drau
POWERHOUSE — Type	52	abovegr., reinf. concrete, deep powerhouse basement	aboveground, reinforced concrete, with deep powerhouse basement	aboveground, reinforced concrete
Dimensions (without control building)	53	25 x 46 m, total height 40 m	21 x 89 m, total height 59.5 m	20 x 30 m, total height 33 m
Special features	54a	transformers in building	transformers along external wall	transformers in switchyard
	54b			
Power units: (number) position, speed	55	(2) vertical, alternatively 375 & 500 rpm	(2) only T, (2) T + P, vertical, 500 rpm	(2) vertical, 300 rpm
type and arrangement	56	1 Isogyre pump turbine each	(4) Pelton turbines, 6 jets (2) single-flow pumps, 4 stages	1 Kaplan turbine, 7 vanes, each
upstream gates: type, int. Ø	57	1 rot. valve 2.3 m Ø + 2 cylinder valves in turbine	1 rotary valve 1.4 m Ø each 1 rotary valve 1.2 m Ø each	1 butterfly valve 3.6 m Ø each
T rating: H/Q/N	58	50 - 200 m/22 - 35 m3/s /max. 63 MW	1030 m/20 m3/s /182.5 MW	42.9 m/55 m3/s /21.5 MW
P rating: H/Q/N	59	50 - 200 m/16 - 38 m3/s /21 - 58 MW	1100 m/11.6 m3/s /145 MW	
downstream gates: type, dim.	60	T 1 rot.v. 2.3 m Ø P 1 butterfly v. 2.3 m Ø, each	stop logs gates	bulkhead gates
generator: type, capacity	61	1 synchron motor generator each, 42.5 & 70 MVA	(2) generators 220 MVA *) (2) motor generators 220 MVA *)	1 synchron generator 27 MVA
Transf.: (number) type, arrangement,	62	(2) 3-phase, block-type	(4) 3-phase, block-type	(2) 3-phase transformers
capacity, voltage ratio	63	70 MVA, 8.8/112.5 kV	220 MVA, 13.8/235 kV	27 MVA, 10.5/115 kV
Switchplant	64	indoor 110 kV	220 and 110 kV outdoor with coupling transformer, 200/200/30 MVA, 220/110/10 kV	outdoor 110 kV
Plant capacity of T and/or P; max.	65	T: 120 MW P: 116 MW	T: 730 MW P: 290 MW	T: 41 MW + 0.6 MW weir power station
Annual energy without short-t. pumping (with)	66	76 GWh	715 GWh (1155 GWh)	114 GWh
Winter share % / full-load h.p.a.	67	94 % / 630 h	83 % /980 h	45 % / 2780 h
Annual P energy without short-t. pumping (with)	68	52.4 GWh	138 GWh (740 GWh)	----
Footnotes *)	69		re. line 35: (1) butterfly valve between power tunnel sections under A & B in line 37 re. line 61: 2/3 direct water cooling, 1/3 ring air cooling	

Run-of-River Plant in Austria

By **R. Fenz***

The purpose of this report is to present a description of run-of-river plants existing at the turn of the year 1984—85, and to demonstrate the importance of this type of power station for Austria's electricity supply. While, for the sake of clearness, the scope of plant discussed here will be limited in terms of power station capacity (i. e. stations with a maximum capacity less than 10 MW will be precluded from consideration), the series of power stations on Austria's main rivers will be described in greater detail to make due allowance for their importance in the overall generating system. In this respect, this report is largely based on an inventory of run-of-river plants, made up under the title of "Flußstauwerke in Österreich" (R. Fenz, Österr. Wasserwirtschaft, Jahrgang 29, Heft 9/10) in 1977, and should be regarded as an updated version of this inventory.

The importance of hydro power for electricity generation is very much a function of the geographical, hydrological and topographical conditions of a country and, hence, varies considerably. The hydraulic share of total electricity production is for instance 12 per cent in the U. S. A., 68 per cent in Canada, 19 per cent (mean value) in Europe. In Austria the contribution of hydro towards total electricity production, about 50 per cent in 1918, increased to more than 80 per cent in the years 1932 to 1938 and then decreased to less than 60 per cent by the years 1971 and 1972. At present, the percentage of hydro varies between 68 per cent and 72 per cent. Even in dry years, hydro accounts for almost two-thirds of total generation. In Europe, larger hydro shares are found only in Norway (99.7 %) and Iceland, whereas Austria and Switzerland can be regarded as almost equally entitled to the attribute of "hydro power country". Although these two countries, both situated in the Alps, are similar in many respects, there are some important differences. Austria's developable hydro potential is 53700 GWh and, thus, some 50 per cent larger than that of Switzerland. The resulting hydro resources per inhabitant are 25 per cent larger. Still, related to the area of national territory, Austria's "hydro density" is 25 per cent lower than that of Switzerland (Table 1). This implies that the area percentage required for the higher per capita share of hydro energy in Austria is in fact lower than that of Switzerland. Further comparison with neighbouring Switzerland, the classical and traditional Alpine hydro power country, reveals that Austria owes her high hydro potential mainly to her run-of-river plant — existing and planned — as this accounts for some two-thirds of the total potential, whereas in Switzerland high-level storage plant predominates. The developed share of the developable potential is at present 93 per cent in Switzerland and approximately 60 per cent in Austria.

In 1983, total electricity generation was about 42.6 TWh (i. e. 42000 GWh), of which 30.6 TWh (or 71.8 per cent) came from hydro stations and 12.0 TWh (28.2 per cent) from thermal stations. The above 30.6 TWh of hydro generation falls into 21.3 TWh from run-of-river stations and 9.3 TWh from storage schemes. The 21.3 TWh of run-of-river energy thus accounted for 50 per cent of the total generation (hydro and thermal) of 42.6 TWh. For the sake of completeness, 4.4 TWh of imported electricity must be added, which brings the total energy to 47 TWh, of which 7.9 TWh was exported and 39.1 TWh was used for domestic consumption.

Table 1. Comparison of Alpine hydro power countries Switzerland–Austria

	I Inhabitants (10^6)	A Area 10^3 km²	I/A	P Hydro-potential GWh/a	Spec. potential P/I kWh/a/I	Spec. potential P/A GWh/a/km²
Switzerland (CH)	6.1	41	149	35100	5760	0.86
Austria (A)	7.5	84	90	53700	7160	0.64
Comparison (A/CH)	+23%	+105%	−40%	+53%	+25%	−25%

Out of the total of 21.3 TWh of run-of-river energy, 19.7 TWh, or 92.5 per cent, was generated by the seven series of power stations on the rivers Danube, Drau, Enns, Inn, Mur, Salzach and Traun, and 1.6 TWh, or 7.5 per cent, by other run-of-river stations.

Austria's dense population, especially in the wide river valleys, and the topographical and civilisational conditions in this country allow practically no major impoundment, because the resulting flooding of river banks would involve considerable relocations and loss in cultivated land and cultural assets. The commonest type of run-of-river power station works under a limited head of between 8 and 16 m and, in reaches of very favourable topography, under heads of up to 20 or 25 m. A few power stations are of the diversion type with long tunnels, representing in fact a transitional type between run-of-river station and alpine high-head station. Apart from their primary activity of energy generation, many run-of-river projects in Austria carry out a number of subsidiary activities. This is particularly true of the development of the Danube as a high-capacity waterway. But other run-of-river projects, too, may be called multi-purpose, especially with respect to flood protection for the banks, prevention of natural river bed degradation, and measures for handling sewage problems so as to contribute towards water pollution control and, as a consequence, to the creation of recreational resources.

It has already been mentioned that the greater part of run-of-river power comes from series of power stations. Although in many cases isolated projects were initially planned, it was soon realised that continuous series of power projects were desirable for reasons of power economy and river morphology. The individual river ba-

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sins with their series of power projects will be described in the following. Except for a few cases, which will be mentioned, practically all the run-of-river schemes are situated in the river and some provide storage. In very few cases, power stations were constructed on diversions in the form of tunnels or channels.

Table 2. Austria's series of run-of-river stations, 1985 (power stations of more than 10 MW capacity)

River	AAE Energy GWh/a	MC Max. capacity MW	Number of p. st. incl. boundary st.
Danube	11696	1924	8+½
Drau	2474	504	8
Enns	2373	518	14
Inn	1959	333	2+5×½+¼
Mur	803	147	10
Salzach	660	156	3
Traun	526	103	4
	(655)	(121)	(6)*
	20491	3685	49+7=56

* see 7. Traun

Table 2 is a list of the seven river basins mentioned above, arranged in order of average annual energy in terms of gigawatt-hours p. a. (AAE). Also shown in the table is maximum capacity (MC) in terms of megawatts. Both values refer to the year 1985 (in respect of commissioning). For the rivers Inn and Danube, only Austria's share of the output produced by boundary stations has been allowed for. The following description of individual river basins will be in the same order as shown in the table.

1. Danube (see Table: Danube)

The Danube, Europe's largest river, crossing eight countries along its path from West to East, has not only been a factor of great historical and cultural consequence, but has for many centuries been a boundary and oftener still a link for Europe. Above all, however, the Danube has always been a traffic route and will in a few years constitute an essential part of the Rhine-Main-Danube trans-European waterway. Along its course through Austria, the Danube is characterised both by a considerable gradient and by an abundance of water, resulting from the substantial flows contributed by the river Inn at Passau. Whereas the reach immediately upstream, in Germany, has a gradient of only 0.2‰, and the almost 1900 km-long reach east of Austria down to the Black Sea drops at about 0.06‰, except for the gorge developed by the Djerdap power station (Iron Gate), the Austrian reach, more than 350 km in length, has a gradient of 0.4‰. This involves not only a high energy potential for this country, but also a small channel depth due to the high flow velocities, especially during low flows. A multi-purpose plant on the Danube thus provides the required improvement of navigation as well as valuable and clean domestic energy production.
The great diversity of contributing catchments (Central Alps, foothills) ensures a most favourable distribution of river flow, so that the ratio of winter production to summer production by the Austrian power stations on the Danube is about 43 per cent to 57 per cent. In wet years (for instance in 1981), this may even be 49 per cent to 51 per cent. All the power stations on the Austrian Danube are multi-purpose installations which, although planned, designed and constructed by an electricity-supply company, constitute an essential factor in the improvement of the waterway. This implies that allowance is made for navigation requirements by providing locking facilities, and that on the other hand the government authorities responsible for the waterway pay a share of the total cost (20 to 25 per cent).
Development of the Austrian Danube was commenced when the demand was consistent with the large energy potential available, which actually was not the case until the period after the Second World War. Only some preliminary studies and isolated projects had been prepared before that time. This led to the most welcome result that, prior to the construction of the first power project at Jochenstein, a master plan covering the whole Austrian reach of the Danube was available. Although this was subsequently modified in some respects to allow for the progress of technology — in particular, the number of planned power stations was reduced from fifteen to twelve by combining projects for reasons of economy — the Danube Master Plan continues to be used as a general guide. Its stage-wise implementation has been in progress ever since 1953, i. e. for 30 years, and has been characterised by an almost perfect continuity with respect to both time and especially staff. Concentration of planning and design, construction supervision, operation and administration in a single company and the continuity that has partly been accomplished in the execution of construction items and supplies have allowed extraordinary cost savings and reduction in construction time.
Among the power projects shown on the Master Plan (Fig. 1), the first (viewed in the direction of flow of the Danube) is Jochenstein, jointly owned by Austria and the Federal Republic of Germany, its output being shared between the two countries. The remaining eleven power projects are owned, or planned to be constructed, by Österreichische Donaukraftwerke AG (DoKW) in Vienna.
The power stations (including half of Jochenstein) shown on the Master Plan, which covers a river length of 350 km and a head of approximately 150 m, are capable of a total power of 2574 MW and a total energy of 15478 GWh p. a. As can be seen from the graph on Fig. 1, the power stations at Jochenstein, Aschach, Ottensheim-Wilhering, Abwinden-Asten, Wallsee-Mitterkirchen, Ybbs-Persenbeug and Melk as well as at Altenwörth and Greifenstein are completed, whereas construction of Hainburg is planned to be started in 1985. The energy at present supplied by the Danube in Austria is 11696 GWh p. a. (1924 MW) and meets as much as about 29 per cent of an estimated domestic consumption of about 41000 GWh in 1985.
Whereas Jochenstein, Aschach and Ybbs-Persenbeug are situated at narrow valley sections which the Danube has cut through the granitic gneisses of the Bohemian Massif, all the other stations, that is, from Ottensheim down to Greifenstein and Hainburg, are situated in flat lowlands, where it was possible and expedient in each

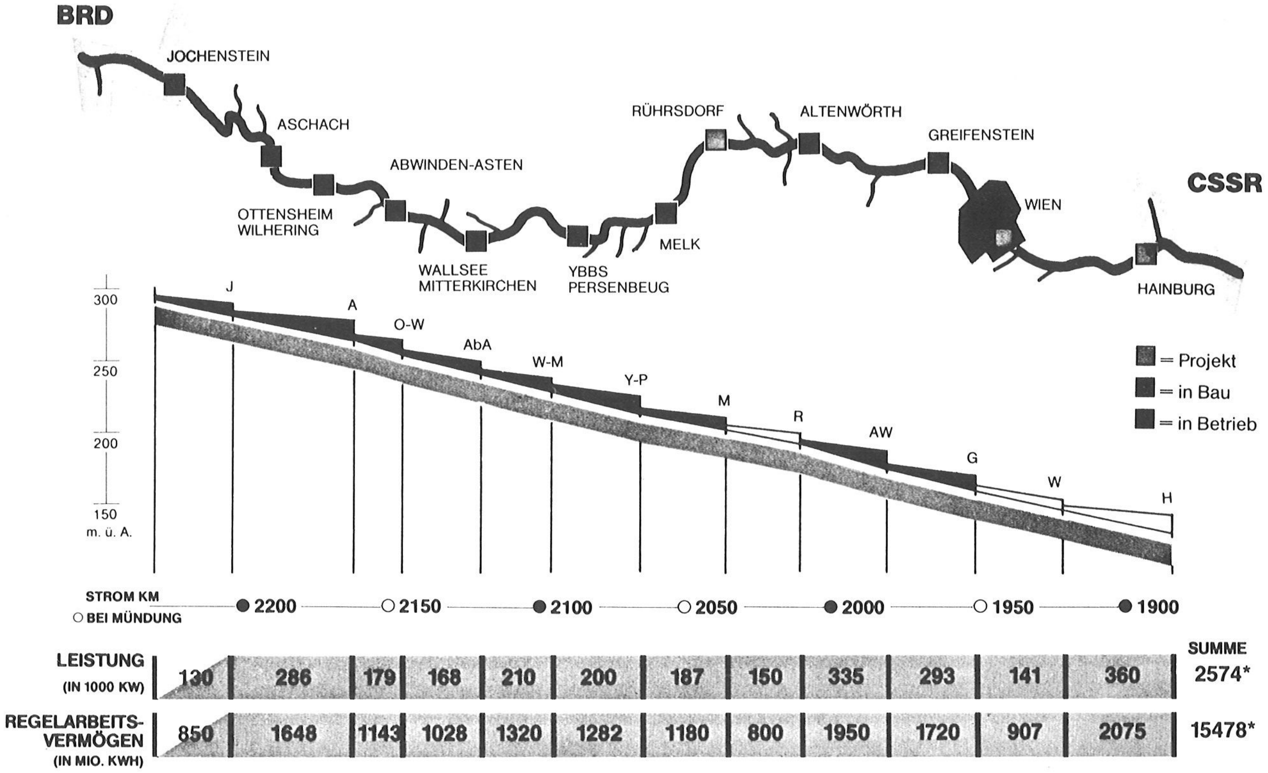


Fig. 1. Masterplan for Danube-powerstation, 1984 (by Österreichische Donaukraftwerke AG)

* MIT 1/2 ANTEIL VON JOCHENSTEIN

case to locate the main structure lateral to the natural river channel. The advantage of such an arrangement is that the whole project, consisting of powerhouse, spillway and lock, is constructed speedily in a single pit, safe from floods and interference from navigation, obviating the need for provisions to handle floods during construction. In the case of the former group of power projects, the narrowness of the sites allowed only stagewise construction in several successive construction pits. The resulting increase in flood water depth during construction was tolerable there.

Construction sites in the lowlands, with the main structure located besides the natural river channel, compared very favourably in terms of construction time and cost with the sites at the narrow valley sections. Another essential difference concerns the effect of floods in the backwater areas. Whereas between the high banks the entire flows remain within the river channel even during floods, large-scale flooding ist an essential characteristic of the riverine lowlands. In order to maintain this for ecological reasons, and for its flood retarding effect on downstream reaches as well as for economic reasons, overflow sections were provided at all the lowland stations except for Melk. For this purpose, some of the flanking embankments were constructed lower and designed so as to allow floods in excess of a given magnitude to flow out into the areas that used to be attained by the floods prior to development of the river. This prevents aggravation of the flood situation in downstream reaches. During an extreme flood wave, as much as 20 per cent of the total flow may pass over the overflow sections, and as this drains off in the areas outside the dykes to return to the main river downstream of the power station, spillway design can be limited to 80 per cent of the maximum flood.

A fundamental difference between high-bank and lowland power stations on the Danube lies in the geological conditions. Whereas Jochenstein, Aschach and Ybbs-Persenbeug are founded on granitic gneiss, the lowland stations had to be built mainly on sediments, mostly "schlier", a local variety of shale, covered by alluvial material about 10 to 14 m in thickness. Special foundation measures were required in places to prevent slope caving and to transfer horizontal forces safely into the schlier. At Melk, the structure was founded on densely packed sands, requiring a continuous cutoff, whereas Greifenstein had to be built on flysch of varying mechanical properties.

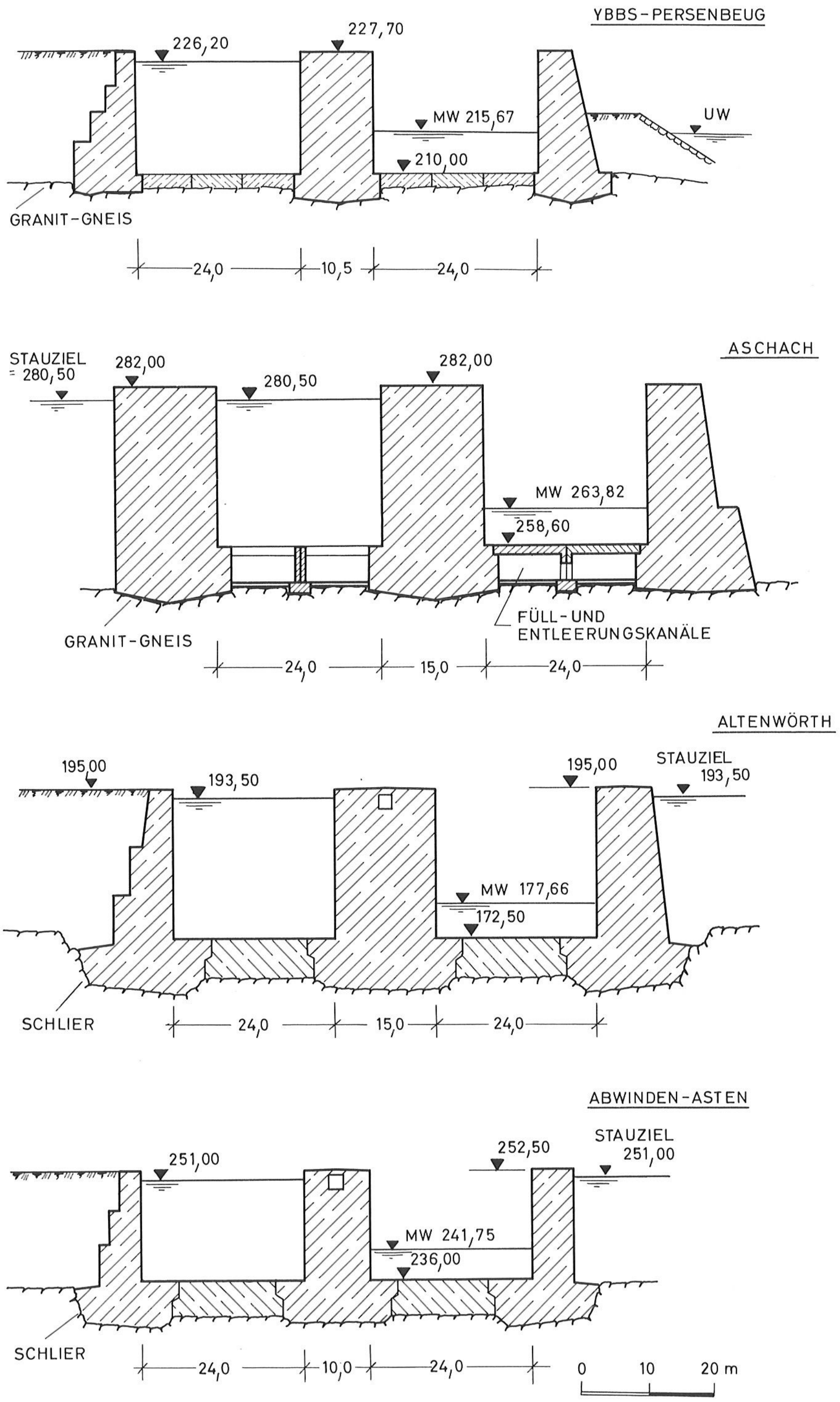
In the following paragraphs, some special design characteristics of the main features (lock, spillway, powerhouse and dykes) will be discussed in greater detail.

1.1 Locks

The dimensions of the locks to be provided to allow shipping on the river have been laid down by the International Danube Convention. This provides that twin locks 24 m in width and 230 m in effective length be built within the Austrian reach of the Danube.

In order to allow major trains of barges as are planned in the Eastern countries to go up to Vienna (and to the Korneuburg shipyard), one of the two lock chambers will be 34 m wide and 275 m in effective length at Hainburg and probably also at Vienna.

In spite of the different heads (between 9 and 16 m), depending on the respective river topography, and the resulting differences in lock filling flow, it is considered desirable that all the locks be designed for a uniform filling time of approximately 15 minutes so as to accomplish a uniform capacity of about 40 million t of annual navigation for each scheme on the river. It is only at Jochenstein and Ybbs that locks are filled from the upper approaches and emptied to the lower approaches, through the lock gates. Since the construction of Aschach in 1962, locks have been filled from the impounded headwater and emptied to the tailwater, but outside the approaches, so as to afford greatly improved navigation conditions. The locks including training and quay walls along the approaches cover a length of more than 1000 m in the direction of flow and account for 50 or 60 per cent of the total concrete volume needed for a power project. Lock chamber walls (Fig. 2) are comparable to concrete dams as to their statical function, with vertical side walls being a requirement and with the two faces of the middle wall alternatively acting as "upstream" and "downstream" faces in terms of statics. Crest height (in general, 2 m above water level) from lowest foundation is 30 m and 30.5 m, respectively, at Aschach and Altenwörth. Wall thicknesses vary between 10.5 m and 15 m. As the gravel present in the riverbed is



Stauziel: *storage-level*

Füll- und Entleerungskanäle: *filling and emptying system*

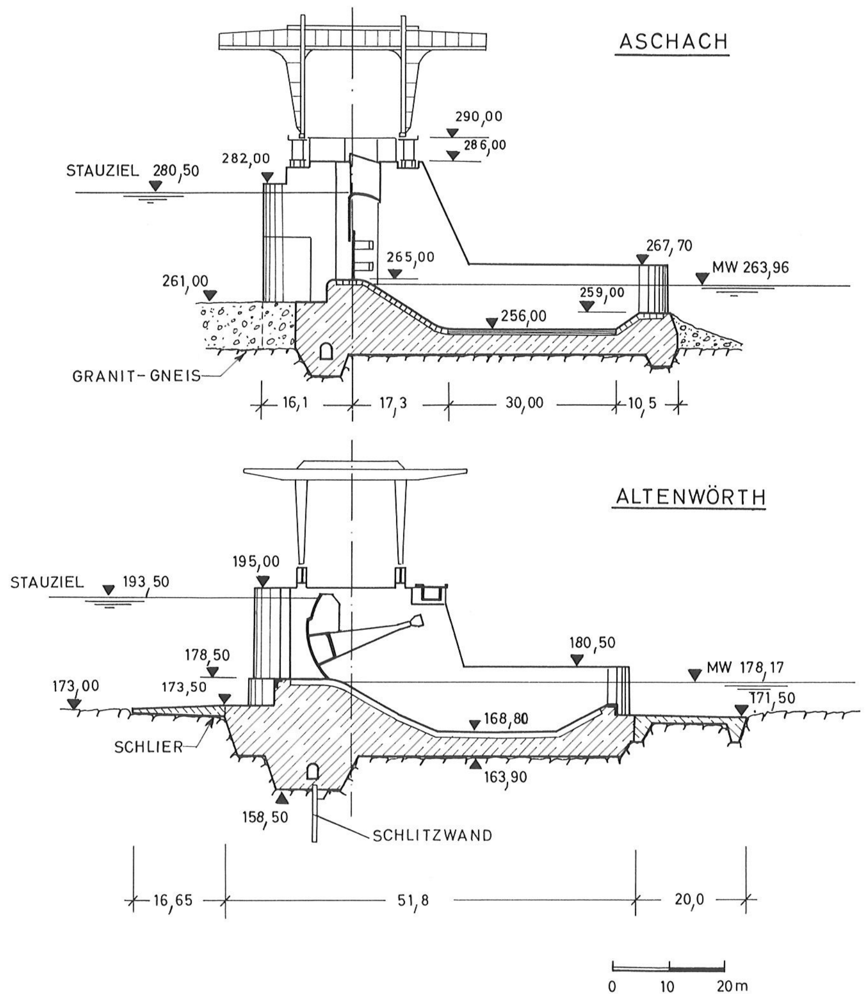
Fig. 2. Danube: Locks

an excellent concrete aggregate, attempts to replace the gravity type by a different design have given no economical results. Rationalisation efforts have been aimed at using a cement-saving concrete by careful mix design and by allowing for the moisture contens of all the aggregate components to minimise the water-cement factor.
Lock walls founded on rock are statically independent of the chamber floors and are designed to resist unilateral water or earth pressure and ice pressure (maximum pressure, 5 t/m). For structures founded on the schlier (lowlands), the whole lock cross section (three walls, two floors) is regarded as an articulated chain, so as to include the chamber floors as supporting elements and above all to ensure safety against sliding with the chamber empty or partly empty. For this purpose, joints are grouted after the end of the setting process, as is practised in high concrete dams.
Similarly, the extremely high pressures from the mitre gates are absorbed not only by the abutment blocks but also by the adjoining lock wall elements, which are bonded by joint grouting to form a statical unit. In addition, components subjected to major horizontal loadings (such as water pressure), as for instance the upper gate blocks, are tightly keyed in the schlier foundation by means of a kind of concrete studs so as to be safe from shear, as in situ shear tests had shown the schlier to have only a limited capability of withstanding horizontal forces along the foundation contact.

Another important statical factor is the location of the main structural axis relative to the lock, which passes across the upper gate at Jochenstein and Ybbs and across the lower gate at all the other power stations on the Danube.
The walls of lock located in the tailwater (Jochenstein or Ybbs) will be pushed outwards during chamber filling, whereas the walls of a lock situated in the headwater will be pushed inwards when the chamber is empty. Concrete is better suited to meet the requirements of the latter design, which also allows the chamber floor to be included as a supporting element, which is especially desirable where the foundation is prone to sliding.
The overall concept of the power schemes on the Danube provides for the locks to be used besides the spillways for the passage of catastrophic floods, as navigation is stopped anyway in the case of large flows for reasons of flow velocity, clearance under bridges etc. The additional cost incurred for the lock, especially for the steel hydraulics gates, is only a small proportion of what additional spillway bays would cost.

1.2 Spillways

The spillway is intended to handle flows in excess of the maximum turbine flow. Overflow over the lowered gates occurs rarely and than will at first be of a small magnitude. It is only in extreme cases that the spillway bays are used more or less for the discharge of floods. Up to 1974, all the spillways on the Danube (Fig. 3) were



Schlitzwand: *cutoff (concrete)*

Fig. 3. Danube: Wears

equipped with mechanically driven hook-type double leaf gates. Oil hydraulic driven tainter gates with flaps on top have been used since the construction of Altenwörth. All the spillways have a uniform bay width of 24 m, i. e. the same as the lock chambers. An exception is Ybbs with a bay width of 30 m. The uniform width of 24 m allows the application of stop logs both in locks and spillways and exchange among the power stations. Maximum hydraulic loading is highest at Aschach, equal to $11\,000/7 \times 24 = 66$ m³/s/m, or $11\,000/6 \times 24 = 77$ m³/s/m, depending on whether the maximum design flood is assumed to be handled by (n) or (n−1) spillway bays. Piers, especially those founded on bedrock, are designed as single structures. Measures are taken in the spillway floors to ensure uplift relief in the case of unwatering for maintenance and repair. At the lowland stations founded on the schlier, spillway bays and piers are either combined to form frames or designed as drop-in girders. A massive concrete key under the weir sill of each station accomodates an inspection gallery which also serves for potential subsequent grouting, as an instrument gallery and for relief and observation of pore pressures, especially at the foundation contact. At Altenwörth, the key connects to a concrete trench cutoff 10 m deep to prevent seepage. Similar provisions had to be made at Melk. In the longitudinal direction, piers are shaped as stepped blocks with subsequently grouted joints. At the piers equipped with tainter gates, pivot bearing forces are transmitted to the upstream through prestressing elements.

Cut granite stone facings were first applied over the whole spillway bays (stilling basins) and piers, but were then reduced from project to project. At present, hard-aggregate or high-quality concrete facing is used almost exclusively. End sills are steel-lined. Due to the fairly continuous development of the Danube and main tributaries (Inn and Enns) by series of power stations, bed load transport through the spillways is expected to occur only under extreme conditions.

Apart from Jochenstein, whose spillway is curved in plan and not equipped with a crane runway, all the dams on the Danube are provided with a 120 to 220 t capacity gantry crane running across powerhouse, spillway and locks. This serves for erection and for lowering stop logs upstream of the spillway. Crane girders, first of the steel box type, have been of reinforced concrete since Wallsee. The same is true of the intra-plant roadway bridges taken across the pier tops.

The piers, up to 41 m high above lowest foundation and only 6.0 to 7.5 m wide, are outstanding features requiring solid keying in the bedrock, or by studs in the "schlier" to resist the substantial water load. In addition, they have to withstand high linear loads where hook-type double leaf gates are present, and concentrated loads in the case of tainter gates, with prestressing anchorage fixtures being used in the latter case.

1.3 Powerhouse

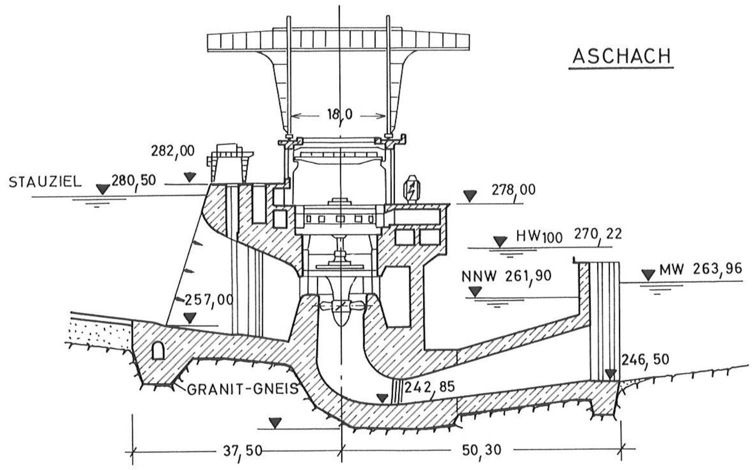
Power station design on the Danube has undergone changes in two respects, although the nine projects have been constructed in relatively rapid succession, between 1952 and 1984. One essential change relates to the selection of the type and number of turbines; these are in chronological order: five at Jochenstein, six at Ybbs, four at Aschach, six at Wallsee, all vertical-shaft Kaplan turbines; since 1970 (commencement of work at Ottensheim), nine horizontal-shaft Kaplan turbines (bulb turbines) each. It should be pointed out right away that, despite this variety and the very different heads involved, it has been possible to maintain a largely uniform inlet and outlet width so as to ensure universal use of stop logs. The single-part inlets and outlets of the stations equipped with horizontal-shaft turbines are of a width corresponding to half the width of the inlets and outlets (divided into two) of the stations equipped with vertical-shaft Kaplan turbines, as for instance Ybbs, Aschach, Wallsee.

Partly due to the choice of turbines as described above — governed by economic aspects, especially in the structural sector — and partly as a result of the basic projekt idea, a second development took place in the form of a substantial reduction in powerhouse height (Fig. 4) above the impounded water level. Whereas this is as much as 22.40 m at Jochenstein, the only plant with a crane provided in the powerhouse hall, powerhouse height ist only 10.50 m at Aschach, 9.30 m at Ybbs and as little as 5.00 m at Wallsee, which does not even exceed the height of powerhouses equipped with horizontal-shaft turbines. It should be pointed out in this context that the level of the powerhouse roof, which serves as a runway for the universal gantry crane described in connexion with the spillway, ist dependent to a high degree on the position of the main axis of the power station relative to the lock. Where the main structural axis crosses the lock at the upper gate, as at Jochenstein and Ybbs, the required clear height of 8.00 m above the impounded water level will have an important bearing on the choice of the roof level. At all the other stations, the lock is crossed at the lower gates, where the water level is lower. This also avoids the unfavourable visual effect of a lock wall towering over the tailwater level in its full height. The statical aspect of the lock structure in this respect has been discussed above.

Naturally, powerhouse statics is largely a function of the foundation conditions. As a feature common to all the power stations, there is a structural unit, separated from the adjoining blocks by joints, for each power unit; in this context, reduction of block width from a maximum of 32 m (Aschach) to a value between 17 m and 18 m for the bulb turbines has not only been a great advantage in terms of statics, but has helped to overcome construction problems and avoid cracking. In some cases, the joint separating the power unit blocks is deliberately connected to the adjacent water pressure.

Viewed in the direction of flow, powerhouses equipped with verticalshaft units show a structural division into inlet, middle block and outlet, mainly to answer the geometrical requirements of spiral casing and draft tube bend. Mutual statical support between the three powerhouse elements is ensured. In the powerhouses equipped with bulb turbines, the inlet structure, much shorter in this case, directly passes into the middle part, which houses the power units.

This is an essential advantage of this arrangement. Only the outlet structure is constructed as a separate element but then made to form a statical unit with the whole powerhouse cross section by means of joint grouting. It should finally be mentioned that it has lately been made a rule to place gravel fill on the draft tube for



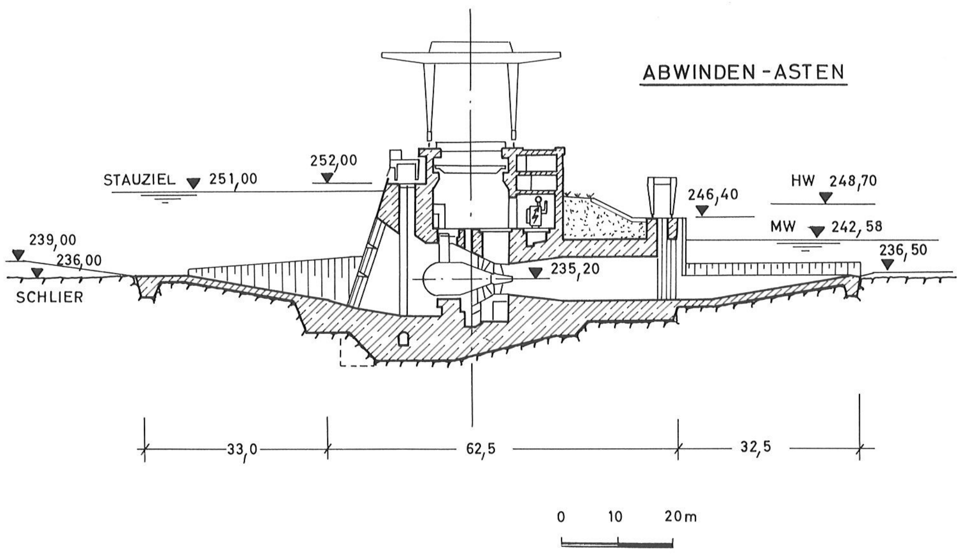


Fig. 4. Danube: Powerstations

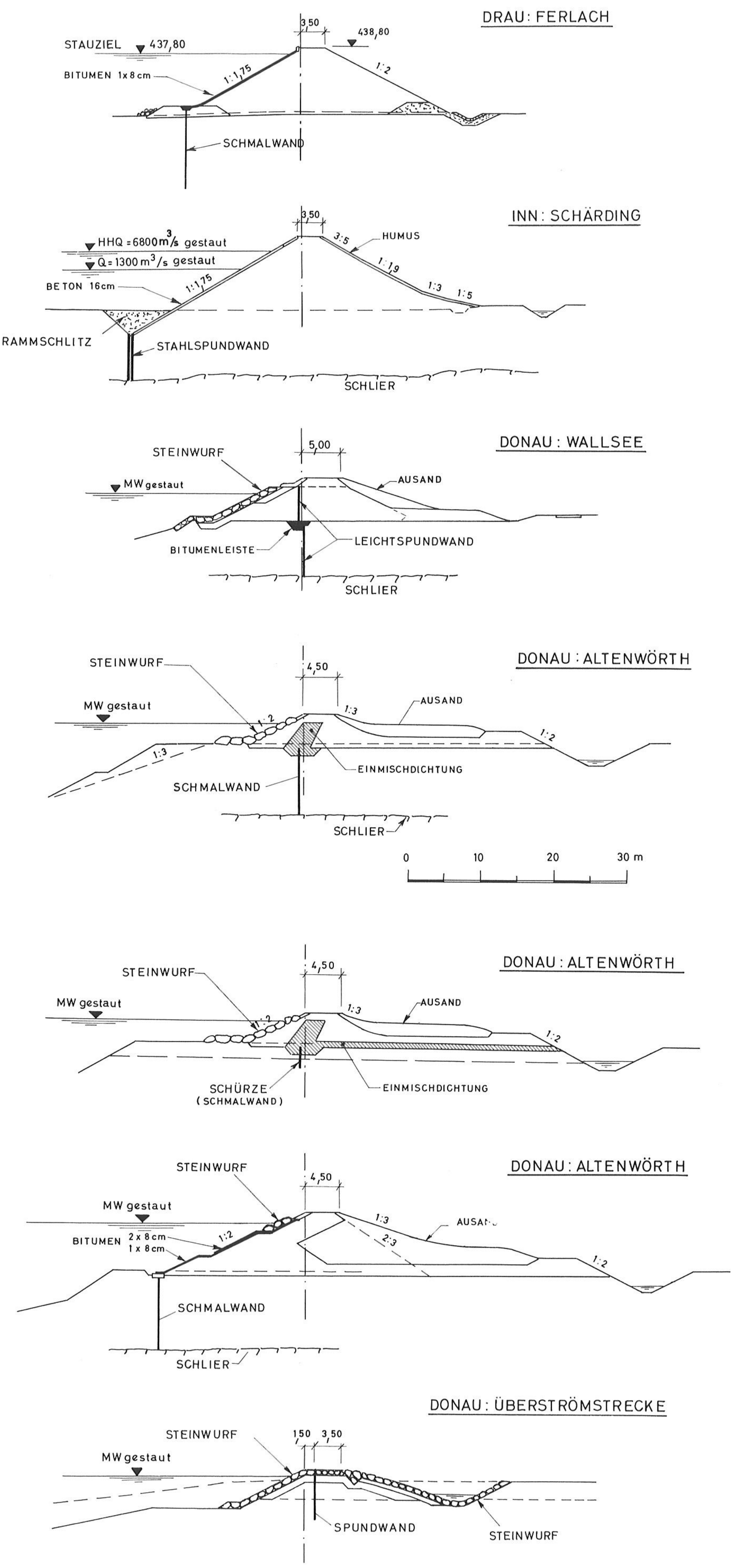
ballast. At the power stations founded on the schlier, deep excavations (Wallsee) first presented some difficulties from slides; this gave rise to the development of keying structures in the form of concrete-filled wells acting as "studs" projecting downwards from the base of the structure. In addition, large-area excavation, especially in the powerhouse area, called for special precautions to protect the schlier, which tends to heave when exposed and later settles again when covered.

By way of summary, one may say that structural design has gradually been simplified, especially in respect of erection bay and auxiliary room requirements and, around the time of constructing the Ottensheim project (1970), developed into what may be called the "Danube construction method". Its outstanding feature is the gantry crane installation that extends over the whole plant, servicing the powerhouse, the spillway and the lower gates of the locks. Another characteristic ist the systematic transition to bulb turbines. This allows the construction of low buildings, which are felt to blend well with the surrounding riverine lowlands.

1.4 Dykes

It would be very much beyond the scope of this report to mention even the most important problems, their solution and the structural measures taken in the backwater areas above the power stations on the Danube. Therefore, discussion will be limited to the embankments in the backwater areas on the Danube. Whereas very few dykes were provided at the high-bank power sites, Jochenstein, Aschach and Ybbs, they constituted a very important structural and cost item at the power stations in the lowlands.

Having to retain the impounded water so as to protect low-level country behind (riverine lowlands or cultivated land), dykes have to answer high stability standards and must ensure watertightness both within the structure and more or less also in the foundation. In addition, waterside facings of new dykes must meet the requirements of a navigable river as well as the requirements resulting from ice formation, water level variations and ecological and biological needs. A special case are the overflow sections mentioned earlier in this report.



Schmalwand:
thin diaphragm

Raumschlitz:
piling channel

Spundwand:
sheet pile

Leichtspundwand:
light-weight sheet

Bitumenleiste:
bitumen strip

Steinwurf:
riprap

Einmischdichtung:
mix of gravel and sand

Ausand
riverside sand

Überströmstrecke:
„overflow"-embankment

Fig. 5. Cross-sections of dykes

The development of dyke cross sections (Fig. 5) reflects technological and economic progress made in recent construction methods. A decisive feature is obviously dam height above ground level. Fill volumes at lowland power stations vary between 5.0 and 12.0 million m^3 and may well compete with large dam projects in terms of volume of earth moved.

At the first lowland power station, Wallsee, imperviousness was achieved by two light-weight sheet walls (35 to 40 kg/m^2). The lower one was vibrated into position from ground level down to the impervious schlier. Then a strip of bitumen was placed at the head of the sheet wall and the dam fill deposited on top. The second sheet wall was then carefully sunk by vibration through the dam fill and into the bitumen strip. In some very low dykes, impervious cores consist of a special mix of sandy gravel and riverside sand. Bank protection is by riprap everywhere on the Danube.

In the construction years 1970 to 1973, more economical methods were developed for the Ottensheim project. These included the use of thin diaphragm cutoffs, which will be described in connection with the development of the river Drau. In addition, bituminous concerete was used for the first time on the Danube for sealing a waterside slope. This was however limited to a bank length of 5.6 km, where site conditions allowed a gently sloping fill of natural gravel to be placed in front, which saved riprap and accomplished a flat bank of great biological value. For the rest, the development of impervious core material (gravel/sand mix) from natural sources, its processing and continuous test measurement during construction were systematically pushed ahead.

At Altenwörth, involving the largest amount of dyke fill, the above-mentioned 12 million m^3, thin diaphragms were the only foundation cutoffs used. For low embankment heights, the diaphragm was connected to an impervious core. Where major fill heights were concerned, reaching a maximum of 12 m above ground level at Altenwörth, the thin diaphragm was arranged at the waterside toe and connected to a bituminous slope facing carried to a level above the top water level. This facing, serving as a sealing and bank protection element, was applied in a single 8 cm layer and, in the area of potential berthing impacts, in two 8 cm layers. Upwards from a berm provided on the bitumen facing below top water level, the facing was covered with riprap as a protection against wave action from navigation and potential damage from ice, as well as to allow man and animals to climb up and down, and above all to answer the requirements of stream biology in the important uppermost, light-filled, water layer; the latter is an important factor enhancing the self-purifying capacity of the dammed-up river.

From the economic point of view, the above mentioned bituminous slope facing was not acceptable for fill heights less than 8 or 10 m. Another important economic criterion is the availability within easy haul distance of quarries for the large riprap stone requirements. At Altenwörth, almost 1.8 million t of stones were placed in the main structure and in the backwater area, within a period of about two years.

Foundation cutoffs are carried down to the impervious schlier (some 10 to 14 m below ground level) only where the impounded water level is at least 3 or 4 m above ground level, or near towns and villages. Otherwise a short cutoff extending into the gravel foundation is sufficient to prevent seepage flow from reaching unacceptable magnitudes. An important element in dyke structures is the landside drainage channel (bottom some 1.0 m below mean water level, original condition), serving to maintain the inland water table at the original level or to control it as desired; special water release structures (inlets to convey stored water to riverside plains) are provided for this purpose.

A special design is required in the so-called overflow sections of the flanking embankments. Whereas all the other dykes at the power stations on the Danube are not overflown even during maximum floods and have unpaved landside slopes sown with grass seed, overflow sections allow part of flood water to flow out into the hinterland. For this reason, the heavy riprap protection is not limited to the waterside slope, but covers the crest, the landside slope and a widened channel along its toe, serving as a stilling basin. A lightweight sheet wall in the middle of the dyke, extending from the crest down to the gravel foundation or below the channel bottom prevents scouring within and below the riprap. Dyke cross section and stone size were tested and determined on hydraulic scale models.

As overflow sections are rarely in action (approximately every two or three years) and, if so, practically never over their whole lengths, landside riprap-protected slopes are covered with riverside sand and seeded. Otherwise they would look barren and ugly. It has even been found out that this grass serves as an additional slope and crest stabilisation. The risk of potential destruction during floods is accepted.

By way of winding up, it should be mentioned that in special cases plastic foil has lately been used as a sealing element in permanent embankments on the Danube. This development was spurred by the excellent experience made with sealing of construction-pits up to 1.4 km^2 in area by providing thin diaphragm cutoffs in the foundation and plastic foil in the fill. This method has completely replaced the former steel sheet piling, which took long to construct and was high in cost, and has contributed a great deal towards accelerating and rationalising the construction process.

2. **Drau** (see Table: Drau)

The river Drau, flowing through East Tyrol and Carinthia in an easterly direction, collects the greater part of the run-off from the southern flank of the main ridge of the Alps and from the Southern Calcareous Alps. With a catchment area of 11 000 km^2 and a mean flow of 275 m^3/s, it leaves Austrian territory near Lavamünd. Its adjoining reach in Yougoslavia is also developed for electricity production. Development completed to date on the Austrian Drau encompasses an about 105 km-long reach between the town of Villach and the national border, with a head of 144 m. Development of the fairly flat reach upstream of Villach, up to Möllbrücke (outlet of Malta lower stage) near Spittal an der Drau is in process, with the Villach station in operation, Kellerberg under construction and three further projects in the design stage. This Upper Drau section is about 50 km long and develops a head of 67.5 m.

Independently of these reaches of the Drau in Carinthia, construction of a run-of-river scheme at Strassen-Amlach was started in 1984, in East Tyrol. This will be a diversion-type power station (22 km tunnel) utilising a high-grade reach with a head of 370 m between Tassenbach and Lienz. With a capacity of 60 MW, Strassen-Amlach will generate an energy of 233 GWh p. a.
For chronological reasons, the description of power stations given in the following paragraphs will be against the direction of flow, proceeding in an upstream direction from the Austro-Yougoslav border. The series of developments on the lower and middle Drau (Lavamünd to Rosegg) comprises seven power stations with a total capacity of 480 MW and generating 2367 GWh p. a. Addition of the Villach station on the upper Drau brings the total installed capacity to 504 MW and the annual energy to 2474 GWh, which make this the second largest series of run-of-river stations in a river basin in Austria.
Five power stations are barrages, with spillway and powerhouse forming a single structure. The uppermost station, Rosegg—St. Jakob, has a separate weir structure, a headrace 3.4 km long capable of a discharge of 430 m³/s, and a powerhouse located on the river bank. The most downstream station, Lavamünd, was constructed as a pierhead power station (Grengg-Lauffer) in 1942. This is equipped with one 8.3 MW-capacity vertical-shaft Kaplan turbine in each of the three weir piers. The same design was applied for power stations following downstream, on the Yougoslav reach (as for instance Dravograd and Maribor).
Heads attain a maximum of 26 m, which implies that the water level is raised substantially. This calls for dykes up to 24 m high along the backwater reaches. Recent dykes are almost uniformly of the gravelfill type with bitumen facings (concrete at Edling) on the waterside slope (inclined at 1 : 1.75) and with thin diaphragm and cast in situ walls as cutoffs in the foundation as impervious elements (Fig. 5). Construction of a thin diaphragm consists of vibrating an I-beam some 20 m deep into alluvial material (gravel/sand) with a cement-flour-bentonite mix being injected as the beams are gradually withdrawn, so as to form an impervious diaphragm several centimetres in thickness.
Weir piers and powerhouse structure (Fig. 6), designed in accordance with the surface level of the impounded water, attain heights of 40 m. Some of the power stations are founded on rock and those situated in flat valley reaches on conglomerates, which called for deep cutoffs, Annabrücke on sand-gravel layers, for instance a grid of thin diaphragms. At almost all the stations, there are inspection galleries in the weir sill and below the turbine inlet, rendering possible subsequent grouting.
Whereas Lavamünd and Schwabegg were constructed during the war, between 1939 and 1944, development was continued from 1959 and terminated with the completion of Annabrücke in 1981. It may be worth mentioning that the first two stations are equipped with hook-type double-leaf gates and all the following stations with tainter gates on the spillway structures and that concrete volumes in general vary between 130 000 m³ and 170 000 m³ for heads of between 20.5 m and 24.0 m. It is only the Lavamünd pierhead power station, with a head of 9.0 m, which required not more than 52 000 m³ of concrete.

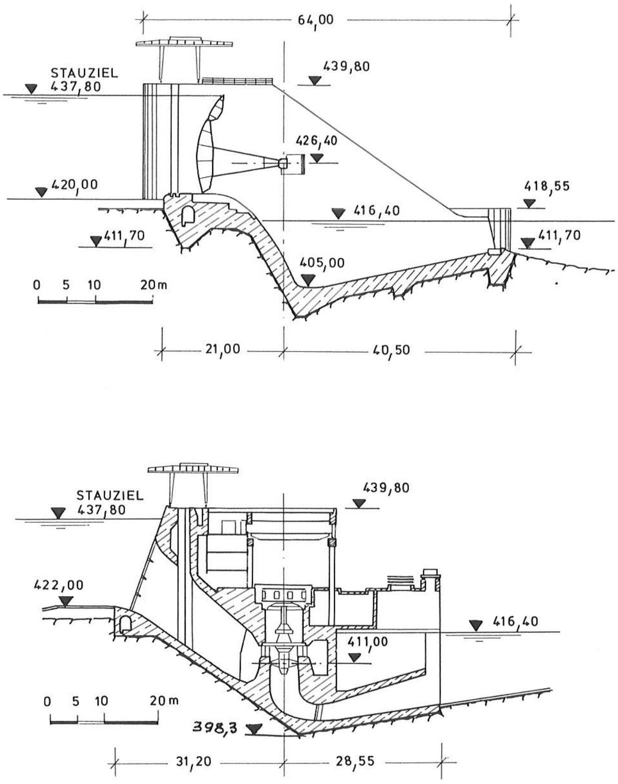


Fig. 6. Drau: Weir and powerstations at Ferlach

The above mentioned dykes on the banks of the backwater reaches along the Drau, 6 m to 24 m in maximum height, have fill volumes of between 0.4 and 5.0 million m³, depending on the topography.
Following extensive study of different project possibilities and problems of regional planning, construction was started on the Upper Drau series of power stations in 1981. This includes 5 power stations. Proceeding in an upstream direction, these are Villach, Kellerberg, Paternion, Mauthbrücken and Spittal, the latter two having heads of 18 or 19 m, the former three of about 10 m.
The series of power stations will have an istalled capacity of 3 × 24 MW and 2 × 49 MW, that is a total of 170 MW, and will generate 675 GWh p. a. Villach has been in operation since 1984. Kellerberg is scheduled for completion and initial operation in 1985/86. Further development is planned to continue in an upstream direction, to be finished between 1992 and 1995.
The Villach, Kellerberg and Paternion stations are pierhead power stations with two power unit piers and three spillway bays each, whereas the two stations with higher heads, Spittal and Mauthbrücken, are planned to be built in an artificial widening of the river bed. Except for the Villach station, which is located on a ridge of rock, the remaining four stations have to be founded on fine-grained, little consolidated post-glacial lake deposits, so that here too the main structures have to be placed on foundation grids of thin diaphragms as a precaution against potential earthquake risks.
Backwatering along this series of power stations has to be confined to the original width of the river, as the valley floor in this area is intensively cultivated. Except for the Villach station, whose backwater area is situated between high banks, continuous dykes have to be built

on both banks almost everywhere. They will even be continued as flood protection dams beyond the upstream ends of the backwater areas so as to connect to a ground, natural or artificial, that is high enough to be safe from floods. Dykes are mainly of gravelfill. Imperviousness is accomplished by thin diaphragms in the foundation and stone-covered asphaltic concrete facings on the embankments. Flood protection afforded by the power projects is evidence of the multi-purpose character of these stations.

All the power stations of the above two series in Carinthia are operated by Österreichische Draukraftwerke AG (ÖDK) in Klagenfurt. Except for Schwabegg and Lavamünd, they were also designed and constructed by this company. The existing stations are operated on a pondage basis in accordance with the demand. The flow regime during the winter months is greatly enhanced by valuable contributions from upstream storage schemes (Reisseck, Fragant, Malta), so that winter energy accounts for 37 per cent and summer energy for 63 per cent of total annual generation.

The above mentioned Strassen-Amlach station on the Drau is situated in the most upstream reach of the Drau, in East Tyrol, and is being constructed by Tiroler Wasserkraftwerke AG (TIWAG) in Innsbruck. The Drau will be diverted near the Austro-Italian border by a two-bay weir and a daily storage basin, from which a power tunnel some 22 km in length (design cross section ranging from 3.20 to 3.40 m) will lead to a surge tank, pressure shaft and above-ground powerhouse in the vicinity of Amlach near Lienz. With a rated discharge of 20 m^3/s and working under a head of 370 m, the station will have a capacity of 60 MW and produce an annual energy of 233 GWh (67 per cent in summer and 33 per cent in winter). This station is planned to be placed into service in 1988. The 60 km reach of the Drau between the outlet works near Amlach and the upstream end of the Spittal backwater reach is the subject of general development studies. It should finally be mentioned that the Malta lower stage, also to be considered as a run-of-river scheme (41 MW and 114 GWh), joins the Drau as a tributary at the upstream end of the Spittal backwater reach.

3. **Enns** (see Table: Enns)

Rising in the northern part of the Alps (Niedere Tauern), the Enns is the only major river (catchment area is 6100 km^2 and mean flow is 220 m^3/s) to flow on Austrian territory over its whole length. The main part of this river, that is its middle and lower course about 130 km in length and with a substantial fall, down to its mouth in the Danube, is developed by a continuous series of power stations. It is only near the town of Steyr that a reach about 3 km long has remained unaffected. In this manner, a total gross head of 324 m is utilised by fourteen power stations with a total capacity of 518 MW and generating 2373 GWh p. a. This also includes the most upstream Hieflau, a diversion-type power station with an about 6 km-long tunnel and a combined surge tank and daily storage reservoir at Waag, developing the steep gradient of a gorge named Gesäuse.

This pilot power station is followed by stations at Landl, Krippau and Altenmarkt. These have weirs equipped with small turbines for water release to the reach from which flow is abstracted, as well as power tunnels and power stations (of which two are underground) equipped with one power unit each. This group of four power stations, situated along the Styrian reach of the river Enns, were placed into operation between 1955 and 1967 by Steirische Wasserkraft und Elektrizitäts AG (Steweag) in Graz. All the stations are located within a narrow valley the Enns has cut through limestone and dolomite formations. No unusual foundation problems were encountered, except for foundation treatment in the weir areas to ensure imperviousness.

Downstream follow ten power stations with different layouts to suit local conditions. Schönau, Losenstein, Ternberg, Rosenau, Staning and Mühlrading show the usual side-by-side arrangement of spillway and powerhouse, with 3 to 5 spillway bays and 2 to 4 turbines. Narrowness of valley section at Weyer and additional difficulties from the presence of a railway line and a road called for a concept with 2 spillway bays and a power unit pier in between and with a second power unit located at the end of a short tunnel in the river bank about 1 km downstream of the weir site. At Grossraming, a symmetrical arrangement was adopted with a two-bay spillway in the middle and one power unit on each bank. At Garsten, the power station was built in a cut across a river bend, with a small turbine catering for water delivery to the dead branch. St. Pantaleon is a diversion-type power station with a 9 km-long asphalt-lined headrace, a powerhouse equipped with two power units and a downstream tailrace canal ending in the Danube. A remarkable feature of the two vertical-shaft Kaplan turbines in the St. Pantaleon powerhouse is the so-called spiral casing outlet. This consists of a gate device provided in the rear wall of the spiral casing. The gate opens when the unit is stopped, so as to prevent surge from developing in the long headrace. A remarkable feature is the fact that one Kaplan unit each at Weyer and St. Pantaleon is designed for 16 ⅔ HZ traction current. These ten power stations of the Enns are operated by Ennskraftwerke AG (EKW) in Steyr.

Development of the river Enns was Started in 1941 and terminated in 1972. The characteristics of river course, geology, population pattern and traffic routes led to a multitude of interesting solutions. Many of the experiences gathered in this way have subsequently been used in other run-of-river developments. It should be mentioned in this context that the middle reach of the river Enns was the subject of discussions that went on for years. Besides the multi-stage project finally realised, an alternative was considered which provided for a single-stage scheme with a dam about 100 m high. The advantage of a large energy reserve, which would also benefit downstream power stations, conflicted with adverse effects on inhabited areas, railway lines and roads. In fact, almost 30 years ago, the problems created by a large reservoir with fluctuating water levels in an inhabited region in the foothills of the Alps (about 400 m a. s. l.) were already felt, perhaps even subconsciously, and the decision then taken appears to have been the right one in the light of our present consciousness of environmental impact.

The power and energy of the continuous series of power stations on the Enns, i. e.

Steweag	140 MW,	681 GWh
EKW	378 MW,	1692 GWh
total	518 MW,	2373 GWh

has been available to the Austrian electricity supply since 1972, that is for more than 12 years. Nearness of these power stations to the Upper Austrian and Styrian industrial area affords considerable advantages, additional benefit resulting from pondage operation carefully scheduled to meet the requirements as they arise during the day. This past decade has also shown that nature and man have willingly accepted the inevitable changes involved. The scenic appearance of the backwater areas along the river is anything but that of destroyed nature. The river Enns is a very good example of how wrong it would be to assess environmental effects on the basis of the planning and design stage. It should also be mentioned in this context that hydro development was accompanied by the construction of roads and sewage treatment plants and the provision of recreation and sports facilities. In the long abstraction reach downstream of the weir diverting flow to the headrace of St. Pantaleon, a separate weir was constructed only to maintain the water level in the river bed.

4. Inn (see Table: Inn)

Apart from the Danube, the Inn is the largest river in Austria. Its uppermost catchment area lies in south-eastern Switzerland. Then it flows through Austria over a length of 220 km, from the Tyrolean-Swiss boundary near Pfunds (Hochfinstermünz) to the boundary with Germany (Federal Republic) near Kufstein. It is only after a further length of 150 km in Germany that, from its junction with the Salzach coming from the central Alpine region in Austria, it forms the Austro-German boundary and then, near Passau, discharges in the Danube, which at this point is divided between Germany and Austria. Catchments and mean flows at the above mentioned points along the Austrian boundary are as follows:

Boundary	Catchment	Q_m
(a) Switzerland/Austria	2700 km²	75 m³/s
(b) Austria/Germany	9400 km²	320m³/s
(c) Germany/Austria (incl. Salzach)	22900 km²	700 m³/s
(d) Germany/Austria (Passau) .	26000 km²	750 m³/s

The 220 km-long upper course of the Inn (Tyrolean Inn) is at present utilised for energy production by not more than two power stations, Prutz-Imst and Kirchbichl. Both are isolated power stations owned by Tiroler Wasserkraftwerke AG (Tiwag), Innsbruck, described later in this report.

In the German reach of the river Inn, systematic development was carried on, with some interruptions, ever since construction of a diversion-type power station was started at Töging as far back as 1919, and was finally completed with the commissioning of Nussdorf in 1982. This developed reach comprises 10 power stations — one diversion-type power station and nine stations in the river bed — of which the youngest and most upstream station, Nussdorf, is situated entirely on German territory (Bavaria), whereas backwatering partly extends into the right-hand bank area, which is Austrian, so that Austria's share of this station's output accounts for 23.5 per cent. Upstream of Nussdorf follows the site of the Oberaudorf project, also jointly owned (one half each) by Germany and Austria, with the powerhouse and backwater area being situated along the Upper Boundary Inn, which extends as far as Kufstein. Commencement of construction of this project is envisaged for 1986.

In the boundary section ("Grenz-Inn"), covering a length of 70 km between the mouth of the tributary Salzach and the junction with the Danube, development as a continuous series of power stations was started in 1939 and completed in 1965. Five power stations with heads of between 9.70 m and 11.60 m were constructed. A fairly uniform general concept was maintained, in particular on the projects realised between 1951 and 1965, Braunau-Simbach, Schärding-Neuhaus and Passau-Ingling. Together with the Ering-Frauenstein and Egglfing-Obernberg power stations, constructed in the years of war 1939 to 1944, this group develops about 80 km of river length with a head of about 53 m, with a generating capacity of 435 MW and an annual energy of 2470 GWh made available in equal shares to the Federal Republic of Germany and Austria.

The joint development of the Boundary Inn can be regarded as the very example of successful intergovernmental cooperation in the field of hydro development and power economy as well as in solving the technical, administrative and financial problems arising in planning, design, construction and operation.

The importance of the Inn in terms of water resources and energy potential is illustrated by the following characteristic values of the Inn at its junction with the Danube near Passau, where it substantially exceeds the Danube in flow:

	Inn	Danube
Catchment area	26100 km²	48200 km²
Annual volume of flow	23×10^9 m³	21×10^9 m³
Q_{min}	195 m³/s	165 m³/s
Q_m	750 m³/s	630 m³/s
Q_{max}	7400 m³/s	3700 m³/s

All the power stations along the Boundary Inn are equipped with vertical-shaft Kaplan turbines (14 to 24 MW each) and show a completely uniform design for reasons of economy. The same applies to the spillways, which consist of five bays of 23 m width and 6 m-wide piers, all closed by hook-type double-leaf gates, at four power stations alike (Fig. 7). Only Ering has six 18 m-wide spillway bays and 5 m-wide piers. All the stations are founded on schlier localy called "flinz", except for Passau-Ingling, which is founded on granitic gneiss. The flinz present in the Inn basin is a very stable, impervious and ultra-fine grained sediment perfectly capable of withstanding the structural loads involved. The statical system of the spillways consists partly of a continuous slab with piers placed on top and partly of independent spillway bays and piers (on the granite at Passau-Ingling). In the latter case, bays are fixed with rock anchors to absorb uplift forces. The spillway and powerhouse structures are provided with sheet piling cutoffs and/or appropriate keys. Concrete volumes are all between 150000 m³ and 180000 m³ per power station. All the power stations were constructed in the original river bed in two successive pits, with diversion of part of the river

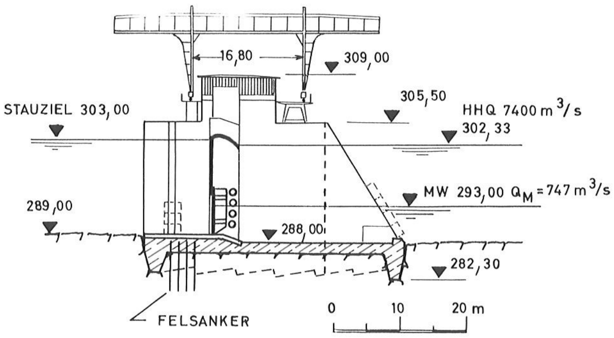


Fig. 7. Inn: Weir at Passau-Ingling

flow. Pit-enclosures consisted of caisson walls as well as gravelfill dams with sheet piling cores or partly anchored sheet piling or sheet pile cofferdams.

The structural design of the whole development is called "Inn-type" and is characterised by flat buildings serviced by a main gantry crane moving over the whole installation.

Structural measures in the backwater areas included dykes up to 9 or 10 m high, especially at Braunau-Simbach and Schärding-Neuhaus. Waterside slopes (1 : 1.75) are protected with poured in-place concrete blankets with breakwaters on top and sheet piling at the toes (Fig. 5). This shows that construction of thin diaphragms, later to be applied on the Danube and on the Drau, was not used before 1960. Recipient and drainage channels and, where required for topographical reasons, pumping stations had to be provided outside the dykes.

As mentioned above, Nussdorf, the second power stations downstream of Kufstein, near the boundary, has been in operation since 1982; this is of the pierhead type. The foundation is made up of largely impervious fine sand. Sheet piling and a heavy spillway floor safe from uplift were required. Dykes received concrete blankets on the slopes and thin-diaphragm foundation cutoffs as impervious elements. Nussdorf is capable of 48 MW and generates 226 GWh p. a. Austria's share accounts for 23.5 per cent (i. e. 11.3 MW and 53 GWh p. a.).

The planned Oberaudorf station will be fairly similar to Nussdorf, except that horizontal-shaft Kaplan turbines (bulb turbines) will be provided in the powerhouse piers. Generation from this power station will be divided in equal shares between Bavaria and Austria.

By way of summary, it can be said that the almost completed development of the Austrian-German Boundary Inn is evidence of successful technological efforts and, as a uniform whole serves international utilisation. Development after the Second World War was undertaken by the Österreichisch-Bayerische Kraftwerke AG (ÖBK) in Schärding.

The Prutz-Imst station, mentioned at the beginning of this chapter, is situated between the Swiss boundary and Innsbruck and was completed in 1956. It utilises the fall of the river Inn near Landeck by cutting across a large river bend by means of a 12.3 km-long tunnel. The station is designed for a discharge of 75 m³/s, the developed head is approximately 140 m. The weir is situated at a narrow valley section near Prutz, the site of the large Kaunertal power station with the Gepatsch seasonal-storage reservoir, and consists of three bays arranged polygonal in plan to allow hydraulically favourable discharge, and closed by hook-type double-leaf gates. A sand catching installation next to the weir forms the transition to the power tunnel; the power station, accommodated in a cavern, is equipped with three Francis turbines with a total capacity of 82 MW. Annual energy, enhanced by the storage effects from the Kaunertal scheme and from reservoirs in the upper river course in Switzerland, is 537 GWh.

The second power station on the Inn, Kirchbichl, was constructed as a run-of-river station between 1938 and 1941. Its headrace canal, 1020 m in length, cuts across a pronounced river bend upstream of Kufstein. With a capacity of 23 MW and an annual generation of about 134 GWh, this station is of no more than local importance. The four-bay weir structure, equipped with hook-type double-leaf gates, is capable of discharging a Q_{max} of about 1200 m³/s. Next to it is the turbine inlet admitting 250 m³/s; head is 8.10 m. Foundation of the weir on coarse gravel called for a large amount of sheet piling.

At present, the Austrian electricity supply derives from the utilisation of the river Inn, that is, 50 per cent in the lower Boundary Inn (Braunau to Passau), 23.5 per cent at Nussdorf, as well as Kirchbichl and Prutz-Imst, 217 + 11 + 105 = *333 MW* and 1235 + 53 + 671 = *1959 GWh p. a.* of run-of-river power. The above-mentioned Oberaudorf boundary station will presumably be constructed in the near future. Planned projects for the Tyrolean reach of the river Inn include a diversion-type power station utilising the 160 m head of the Austrian-Swiss boundary section and the adjacent purely Austrian section down to Prutz, as well as several run-of-river stations.

5. **Mur** (see Table: Mur)

The river Mur rises on the southern flank of the main ridge of the Alps (Niedere Tauern). It first flows in an easterly direction, then continues southward, passing through the city of Graz, and finally reaches the Austro-Yougoslav boundary zone. Its catchment area is approximately 10000 km² and its mean flow 158 m³/s. Development of this river began before 1904, then was carried on at large intervals and is now nearing completion in the middle reach upstream and downstream of Graz. Over the last few years, development has been started in the uppermost reach, which is partly on Salzburg territory. Thus, projects are under construction at Einach (28 MW, 125 GWh) and St. Georgen; Bodendorf has been in operation since 1982. The latter two, however, have capacities less than 10 MW. Over the last two decades, development has proceeded stage-wise, mainly in the reach between Graz and Spielfeld (where the Boundary Mur begins). All the projects are run-of-river stations with three-bay spillways and adjacent powerhouses equipped with 2 bulb turbines each. Development of the reach upstream of Graz, up to the Dionysen station, dates back to the period between 1908 and the time of the Second World War. In accordance with the state of engineering at that time, these power stations are mainly of the diversion type, with long open headrace canals, which allowed heads of up to 19 m to be accomplished. Construction and operation is in the hands of two companies, Steirische Wasserkraft- und Elektrizitätsgesellschaft (Steweag), Graz, and Steiermärkische Elektrizitäts AG (StEG), Graz.

The five major power stations (of more than 10 MW each) situated upstream of the provincial capital, Graz, at Dionysen, Pernegg, Laufnitzdorf, Peggau and Weinzödl, have a total capacity of 76 MW and generate 429 GWh p. a. In some time, this total output will substantially be increased by existing minor power stations and projects under construction, especially in the upper course of the river. — Downstream of Graz, the power stations at Mellach, Gralla, Gabersdorf, Obervogau and Spielfeld have about the same total output, i. e. 71 MW and 373 GWh; reconstruction of a minor station at Lebring will add another 14 MW and 60 GWh.
As mentioned before, almost all the stations in the upper reach of the river are of the diversion type equipped according to the state of engineering at the time of their construction: vertical-lift gates, roller drum gates and hook-type double-leaf gates; concrete-lined trapezoidal channels; powerhouses equipped with Francis turbines, some of which have meanwhile been replaced by Kaplan turbines. The Weinzödl power station, completed in 1982, is equipped with two Straflo units, where the generators are arranged around the turbines.
With about 150 MW and approximately 800 GWh p. a., the series of power stations on the river Mur, although counting among the smaller developments, is interesting in conveying an idea of hydro development in Austria over the past 80 years. Many a valuable impetus has come from engineering feats accomplished on the Mur, both in the past and in our time. Substantial hydro reserves are still available, both in the upper course and along the reach forming the boundary with Yougoslavia over a length of about 36 km with a fall of about 50 m.

6. **Salzach** (see Table: Salzach-Traun)

The Salzach drains the northern flank of the Hohe Tauern mountains and flows over almost its whole length of 225 km (source to junction with the river Inn) on the rerritory of the province of Salzburg. It is only over its lowest reach of 59 km that it forms the boundary between Bavaria (Federal Republic of Germany) and Salzburg and then Upper Austria. At its junction with the Inn it has a catchment area of 6734 km². In spite of the substantial energy potential of this river, only a small station of about 3 MW capacity was constructed in 1928 for a paper mill at Hallein. It is only after the construction of the Glockner-Kaprun group of storage schemes that the reach with the highest gradient, between Bruck and Golling, below the mouth of the tributary Kapruner Ache, was developed. The Schwarzach power station, constructed on the Salzach between 1953 and 1958, is a special case in that it resembles the Prutz-Imst station in enjoying the advantage of an increased streamflow during the winter season from upstream reservoirs, which belong in the Glockner-Kaprun group of storage schemes and the schemes owned by the Austrian railways in the Stubach valley. — Schwarzach has in fact often been called the "lower stage of Kaprun".
The three-bay weir, capable of discharging a maximum flood flow of about 900 m³/s, diverts a maximum flow of 90 m³/s. After passing through sand traps (of the Dufour type), this is conveyed through a tunnel 16.9 km in length and 5.50 m in diameter, which ends in a daily-storage reservoir with a capacity of 1.5 million m³, allowing generation to be scheduled in accordance with the demand. The power station is located downstream of the reservoir and is equipped with four Francis turbines of 30 MW capacity each. The Schwarzach power station generates 480 GWh p. a.
It was for the construction of the long and large-diameter power tunnels of the Prutz-Imst (1953—56:) and Schwarzach (1954—58) power stations that the most outstanding progress in modern tunnel engineering was achieved, now universally known as the New Austrian Tunnelling Method. This is based on the principle of immediate application of the tunnel lining using shotcrete and rock bolting or anchorage, so as to include the rock mass surrounding the opening as a load-bearing element. This method can even be applied in rock of poor mechanical properties.
Operation of the seasonal-storage schemes on the tributaries of the river Salzach (Kaprun and Stubach) bring a substantial increase in streamflow during the midwinter months (for instance from 11 m³/s to 27 m³/s in February, from 15 m³/s to 30 m³/s in March), but also an about 10 per cent decrease during the mid-summer months.
Following the Schwarzach power station, study of a great number of project possibilities led to the selection of a Middle Salzach series of six power stations covering a length of about 20 km and affording a head of 61 m, to be constructed in several phases. Work was started on the two power stations in the middle, of which Bischofshofen has been in operation since 1984—85. The Urreiting power station immediately upstream, of practically equal design, is under construction and will be placed into operation in 1986. By that time, more than one-third of the planned total of 90 MW and 418 GWh p. a. (30 per cent in winter and 70 per cent in summer) will be completed. Each station consists of a powerhouse block with horizontal-shaft bulb turbines and an adjacent low three-bay spillway block (Fig. 8). The relatively low dykes have an asphalt facing overlain by dry stone pitching and a thin diaphragm cutoff extending almost 20 m into the foundation for imperviousness. The next stations to be built are those at Grafenhof and St. Johann (upstream of the Urreiting power station), followed by Kreuzberg-Maut and Pfarrwerfen (downstream of Bischofshofen).
In the much flatter reach between Golling and the river's junction with the Inn, a single power station, Urstein, has so far been built. It was completed in 1971. With a rated discharge of 250 m³/s it has a capacity of 20 MW and generates 107 GWh p. a. A special feature of this power station is the inclined bulb turbines in the low powerhouse block. In terms of stream engineering, Urstein has to fulfil the additional function of preventing further degradation of the river bed. A similar project is planned to be realised in the near future some 5.5 km further upstream, at Hallein.
For several decades, plans have been considered which provide for the construction of a series of power stations in the reach downstream of the city of Salzburg, below the mouth of the tributary Saalach, where the Salzach forms the boundary with Bavaria. Construction would be in conjunction with Bavaria as practised on the projects in the Boundary Inn. A definite date for the implementation of this project is not known.
At present, the river Salzach with its three power sta-

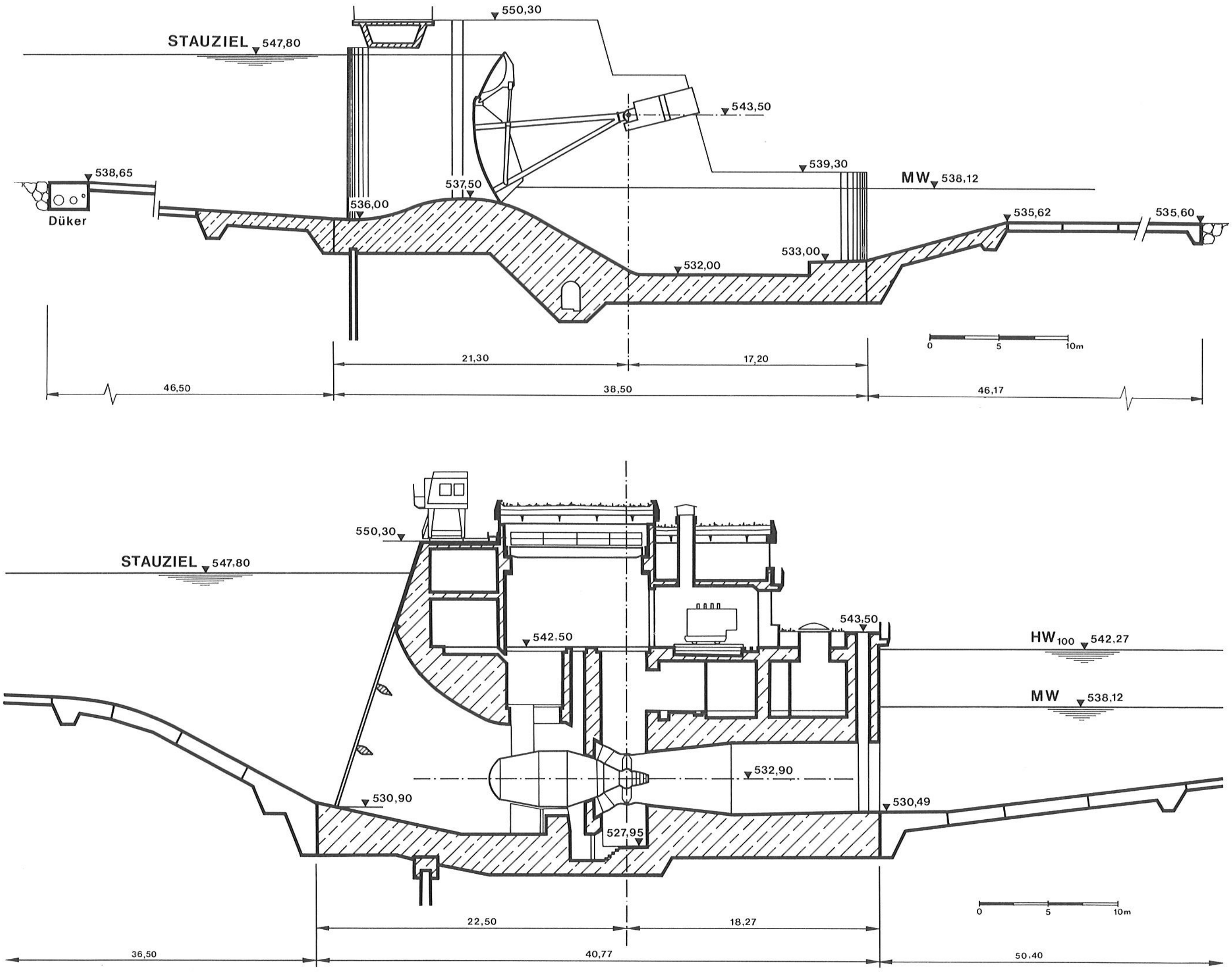


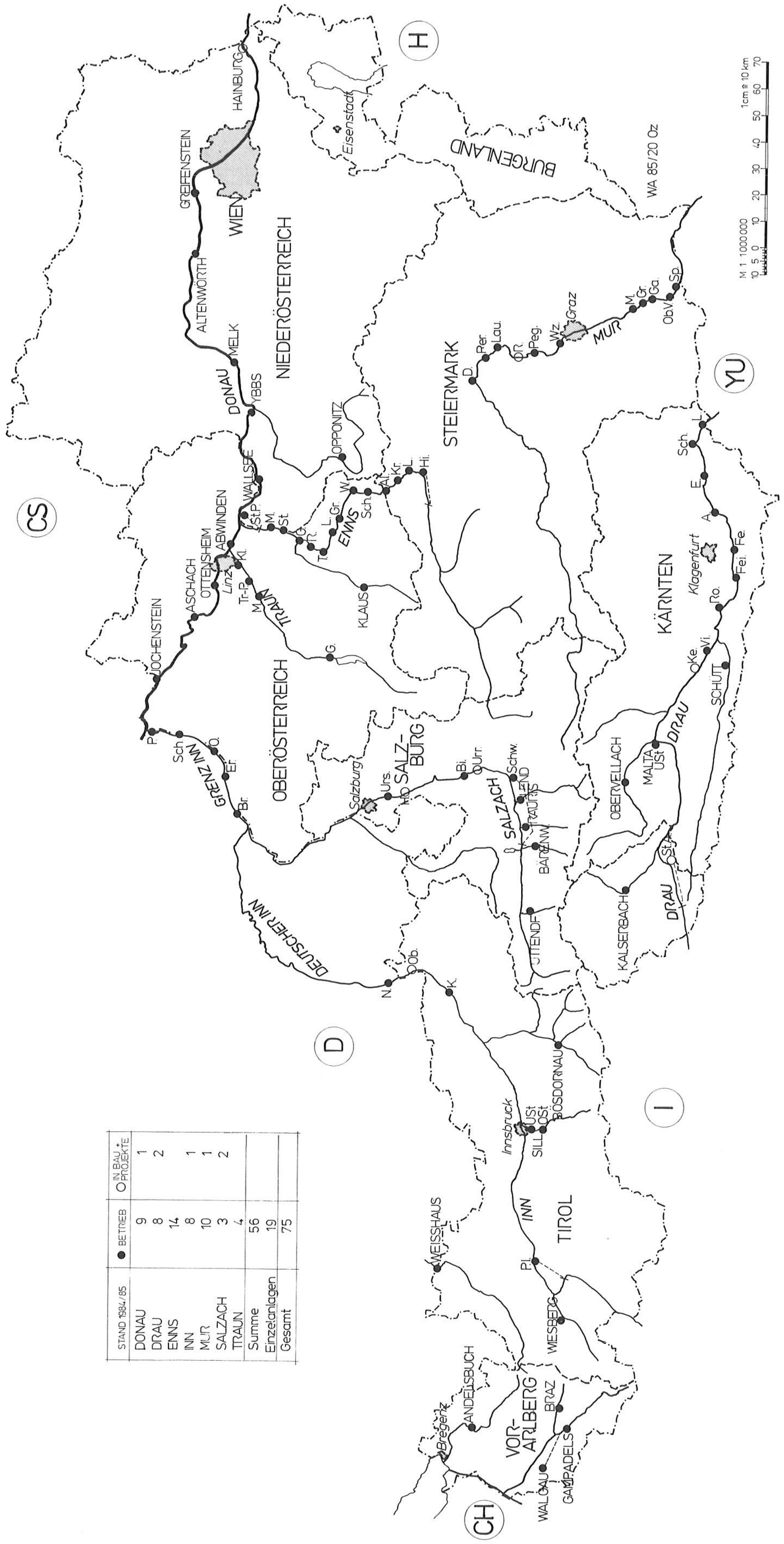
Fig. 8. Salzach: Weir and powerstation at Bischofshofen

tions, Schwarzach, Bischofshofen and Urstein, affords a capacity of 156 MW and 660 GWh p. a. of run-of-river energy, which will be brought to 173 MW and 740 GWh p. a. with the completion of Urreiting.

Whereas Schwarzach, as a lower stage to the Kaprun scheme, was constructed and is operated by Tauernkraftwerke AG (TKW) in Salzburg, development of the middle course of the Salzach is jointly undertaken by TKW and SAFE (Salzburger AG für Elektrizitätswirtschaft, Salzburg), Urstein by SAFE alone. The river Salzach still offers substantial reserves upgraded by the winter releases from the storage reservoirs in the Hohe Tauern mountains.

7. **Traun** (see Table: Salzach-Traun)

Rising in the Aussee and Dachstein region in the Salzkammergut, the river Traun flows through the Hallstättersee and Traunsee lakes. Leaving Traunsee at Gmunden, it flows through the lowlands near Wels for a length of 75 km and discharges in the Danube right below Linz. The water power offered by this river has for a long time been used to advantage by local industries. In fact, development at several points began already before 1900, first by crafts, later by larger enterprises, in particular by the paper industry. First small hydro stations were built near Steyrermühl, Laakirchen and Lambach. All of them had relatively low heads and rated discharges, and hence limited capacities. Subsequent reconstruction, however, rendered possible the installation of larger power units. The Traunleiten power station owned by the Wels electricity supply company was substantially enlarged as recently as 1970. Between 1969 and 1982, major run-of-river stations were commissioned on the Traun. These are Gmunden, (Traunfall, however of only 8.8 MW capacity), Marchtrenk and Traun-Pucking constructed by Oberösterreichische Kraftwerke AG (OKA) and Kleinmünchen by the second provincial company of Upper Austria, ESG, in Linz. Further hydro stations — partly to replace existing small plant — are planned to be built in accordance with a master plan that has been prepared for the river Traun. The Salzkammergut reach of the Traun, including Traunsee, is not utilised by major power facilities. The catchment area above the lake outlet near Gmunden is



STAND 1984/85	● BETRIEB	○ IN BAU + PROJEKTE
DONAU	9	1
DRAU	8	2
ENNS	14	
INN	8	1
MUR	10	1
SALZACH	3	2
TRAUN	4	
Summe	56	
Einzelanlagen	19	
Gesamt	75	

Fig. 9. Austria, location of run-of-river plants

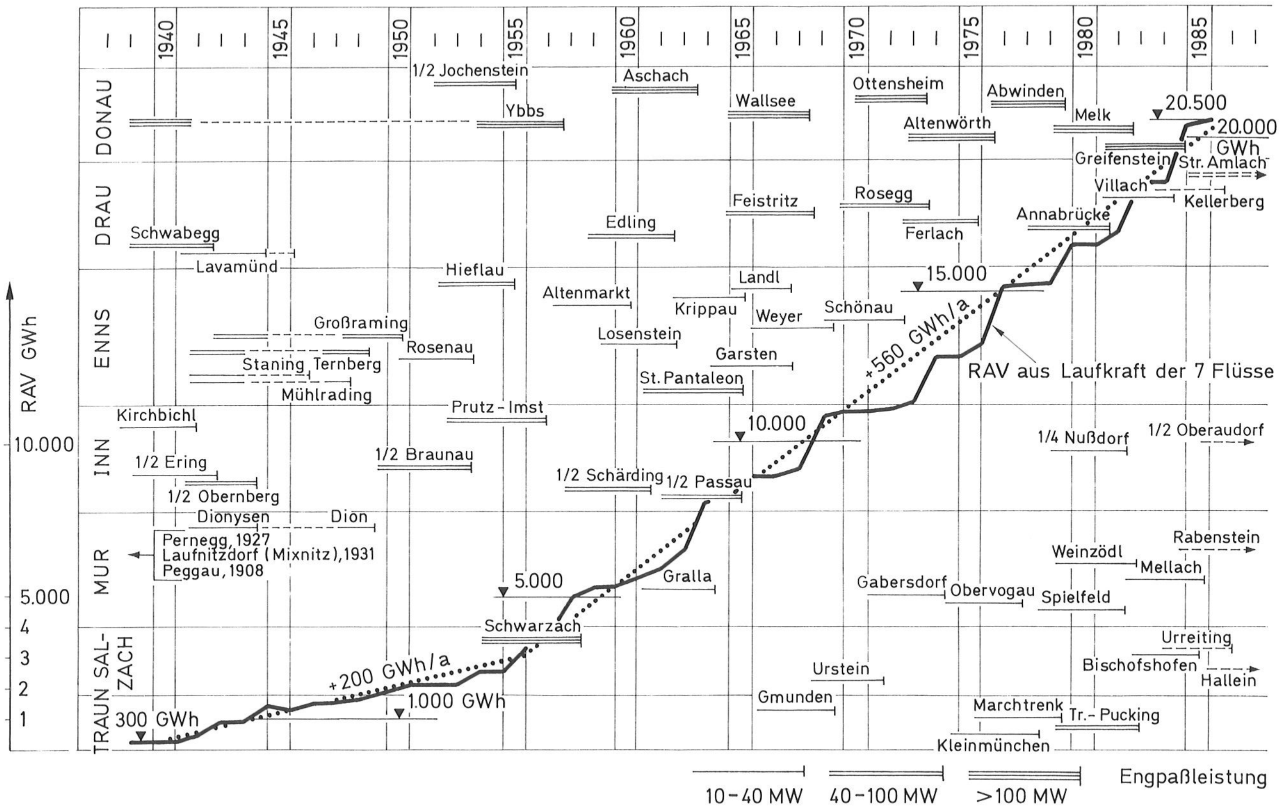


Fig. 10. Chronological table of run-of-river plants

approximately 1400 km² and mean flow is 72 m³/s. The lakes in the upper course, especially Traunsee, have an equalising effect on the flow regime. Over the 75 km reach down to the junction with the Danube, the catchment area increases to 4300 km² and mean flow to 138 m³/s.

An interesting fact from the engineering point of view is the installation, for the first time in Austria, of two bulb turbines, in an inclined position, at the Gmunden power station. The recent stations in general have 3-bay spillway structures and adjacent powerhouses. It is only at the most downstream station, Kleinmünchen, that an open headrace canal, some 5.7 km in length, was constructed. Impounding by the three lower power stations has greatly improved the groundwater conditions in the Welser Heide plain and the whole area extending between Wels and Linz, where unacceptable river bed degradation had occurred. In addition, development of this reach of the river Traun gave the decisive impetus for tackling the severe waste water problems mainly caused by the paper and cellulose industries on the Traun, Krems and Ager. The development of the Traun demonstrates that run-of-river power projects may very well fulfil several functions at the same time.

Electricity generation on the Traun, in the four power stations at Gmunden, Marchtrenk, Pucking and Kleinmünchen, is 526 GWh p. a., with a capacity of 103 MW. Addition of the two stations of slightly less than 10 MW capacity, Traunfall and Traunleiten (Wels), would bring this to 655 GWh and 121 MW. Including the small industrial power stations, the river Traun produces slightly more than 700 GWh p. a. This will substantially be increased when the master plan is realised.

8. Other Run-of-River Plant

As mentioned above, the bulk of Austria's run-of-river power is supplied from the power stations on the country's seven main rivers. In addition, there are a number of run-of-river stations with or without daily storage which have capacities greater than 10 MW. Together, they account for about 7.5 per cent of total run-of-river energy. This corresponds to about 5.5 per cent of the developed hydro potential or 4 per cent of total electricity production. Not included is total generation by minor power stations (of less than 10 MW), which are almost exclusively of the run-of-river type.

Table 3 presents "other run-of-river plant" of more than 10 MW capacity, listed in geographical order from west to east. 3 stations owned by Österreichische Bundesbahnen (ÖBB) and schemes operated as daily-storage reservoirs are listed separately. In total, these power stations correspond to 425 MW and 1760 GWh p. a.

Classified in terms of water engineering, there are four stations acting as lower stages to existing storage schemes, i. e. Walgau as part of the Illwerke group, Braz as part of the Spullersee scheme, Uttendorf as part of the Stubach group, and Malta lower stage as part of the Malta and Reisseck groups. The Klaus power station on the Steyr is a true dam power station, where head is created by impoundment only. All the other stations utilize downgrade sections with more or less high heads. They were mainly built to meet local requirements of communes and industries in an early phase of water power development, especially between the two world wars. Having tunnels between power intakes and power stations, almost all these stations are of the diversion

Table 3. Other run-of-river plants

Power Station	Owner	Energy (AAE) GWh/a			Capacity (MC) MW			
		R.*	dst.**	ÖBB***	R.*	dst.**	ÖBB***	
Walgau	VIW	356			86			Vorarl-berg
Andelsbuch	VKW		47			14		
Gampadels	VKW		26			12		
Braz	ÖBB			100			30	
Wiesberg	DoCh	80			17			Tirol
Oberes Sillwerk	EWJ	94			13			
Unteres Sillwerk	EWJ	135			28			
Weißhaus-Reutte	EWR	72			13			
Bösdornau	TKW	64			25			
Kalserbach	Tiwag		61			12		
Uttendorf	ÖBB			75			27	Salzburg
Bärenwerk	SAFE	57			12			
Rauris-Kitzloch	SAG	97			14			
Klammstein-Lend	SAG	114			21			
Ober-Vellach	ÖBB			75			15	Kärnten
Malta-Unterstufe	ÖDK	114			41			
Schütt	Kelag	64			14			
Klaus	EKW	73			20			OÖ.
Opponitz	WstW	56			11			NÖ.
		1376	134	250	315	38	72	
		1760 GWh			425 MW			

* R. = run-of-river station
** dst. = daily storage
*** ÖBB = Austrian railway

type. Heads vary between about 30 m (Opponitz and Schütt) and 400 m (Gampadels). Naturally, the stations termed above as "lower stages" have their hydro potential considerably upgraded by the presence of upstream storage reservoirs.

Summary

(Map of Austria, Fig. 9)

The preceding chapters have presented a description of run-of-river plant on the main rivers in Austria as well as other isolated stations of more than 10 MW capacity. Tables at the end of this report list in the direction of flow the individual units of the series of power stations, their main plant data such as rated discharge, head, capacity and annual energy, as well as their technical details and general arrangements. The tables also indicate owners and/or operating companies as well as years of initial operation. Details for these lists have been made available by the electricity undertakings concerned, for which thanks are due to them.

By way of summary, it can be stated that run-of-river power in Austria, as mentioned at the beginning of this report, meets a large proportion of total electricity requirements, in general more than half the domestic requirements. As demonstrated by Table 4, the seasonal pattern of flow availability is surprisingly favourable for an Alpine country.

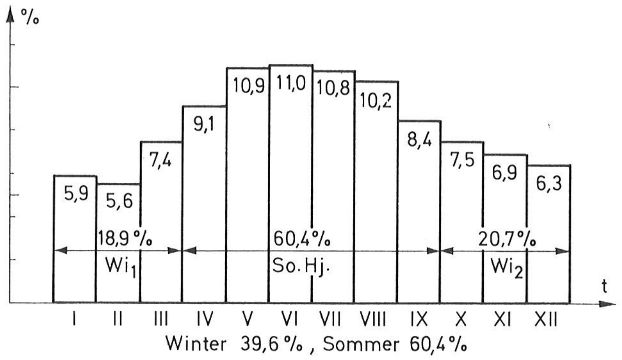


Table 4. Annual pattern of mean monthly generation by total run-of-river plants

Figure 10 is a chronological table of run-of-river stations. Construction periods are shown only schematically for the sake of clearness. No allowance has been made for partial or phase-wise placing into service of individual power units. The chronological table also presents increases in the annual run-of-river energy produced on the seven rivers; these clearly show two distinct periods. Annual generation by run-of-river plant in these river basins rose from 290 GWh in 1940 to 3200 GWh in 1955, which corresponds to an average increase of 200 GWh p. a. In the following 30 years to 1985, annual generation rose to 20500 GWh, corresponding to an annual increase of about 560 GWh. This has mainly been rendered possible by the development of the rivers Danube, Drau and Enns. For the sake of completeness, the increase in storage hydro plant should be entered on this chronological table. Here too, the main development has taken place these past 30 years, from 1955.

I must insist on emphasising that river basin development planning should be aimed at the eventual provision of continuous series of power stations, as this is the only way of finding optimal solutions to the effects of river basin development on river morphology and ecology. An example of this is the complete development of the Boundary Inn, the whole Enns series, the lower and middle Drau, and above all the Danube. In the latter case, additional advantage is afforded to navigation, for which an alternation of backwater areas and free flow reaches is to be avoided by all means. This fact has always been taken into account in the preparation of master plans.

Lately, however, further development of water power, especially run-of-river power, has increasingly been rendered difficult or impossible, especially by conservationist movements, although energy production from water power is the cleanest conversion of a natural resource into service energy, without using primary energy. There are no emissions, and impact on the environment is minimal. In the particular case of the Danube, an additional benefit is afforded by the improvement of navigation, a means of transport that exhibits the lowest specific energy demand and thus also contributes towards air pollution control. Moreover, other hydraulic engineering problems besides power generation have always been allowed for in run-of-river power project planning. These may concern for instance sewage, river bed degradation, local flood control, the provision of traffic routes and recreation areas. The fact that backwater areas above the power stations in the river Inn have been classified as nature reserves because of their flora and fauna demonstrates that run-of-river power and ecology or nature conservation are compatible factors, provided though that all the parties concerned will contribute their cooperation as well as constructive, not only conservationist, thinking to the solution of the problems involved. It is the vital service to the population, rather than pursuit of profit, that has been the purpose of water power development during the past decades. Supplying our country with the necessary electricity is of equal priority as food and water supply. After all, agriculture, too, has altered what once was virgin landscape, and it has done so with much more consequence than is necessary in water power development. It is hoped that in future the problems linked with further water power development in general and the construction of run-of-river stations in particular will not be tackled with emotions but with objectivity and expert knowledge. It is only by such an approach that our activities will be appreciated by future generations. An epoch is not judged by what it has prevented, but by what well-considered feats it has achieved.

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Vocabulary
for the Tabels (7 riversystems)

(Bau) .... (constr.)
T. Sp. .... daily storage

Gates:

Dpl. Haken .... hook-double leaf
Segment (Segm.) .... tainter
Klappe .... flap
Staubalken .... (concrete) beam
Grundschütz .... bottom gate
Oberschütz .... top leaf
Schützentafel .... leaf
Hubschütze .... lifting gate

Conduit

Stollen .... tunnel
OW-Kanal .... headrace canal
UW-Kanal .... tailrace canal

Powerhouse

hoch .... high
mittel .... medium
nieder .... low
flach .... flat
Pfeiler KW .... pierhead station
Kaverne .... underground station

Table: Danube

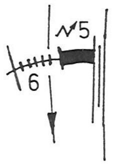
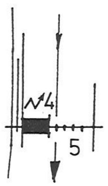
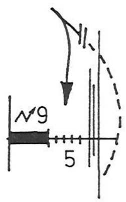
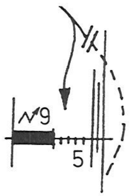
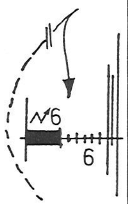
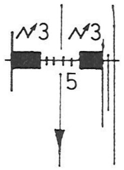
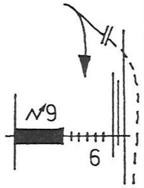
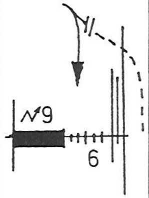
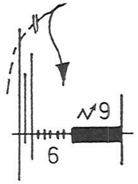
Power station	Unit	Jochenstein	Aschach	Ottensheim-Wilhering	Abwinden-Asten	Wallsee-Mitterkirchen	Ybbs-Persenbeug	Melk	Altenwörth	Greifenstein	Hainburg
Owner		DKJ	DoKW	DoKW	DoKW	DoKW	DoKW	DoKW	DoKW	DoKW	DoKW
Operation since		1955	1963	1973	1979	1968	1957	1982	1976	1984	Projekt
Stationing	km	2 203,3	2 162,7	2 146,7	2 119,5	2 093,6	2 060,4	2 038,0	1 979,8	1 949,2	1 883,1
Storage level	m	290,3	280,0	264,0	251,0	240,0	226,20	214,0	193,5	177,0	152,0
Flow Q_{mean}	m³/s	1 430	1 450	1 450	1 600	1 730	1 750	1 807	1 830	1 882	1 915
Flow Q_{max}	m³/s	8 900	8 900	8 900	9 500	11 100	11 100	11 170	11 170	10 750	10 300
Flow Q_{rated}	m³/s	1 750	2 000	2 250	2 475	2 600	2 100	2 700	2 750	3 150	3 150
Head H_{mean}	m	10,20	15,30	10,70	9,30	10,90	11,0	8,4	14,80	12,6	15,17
Capacity (MC)	MW	(132) 66	286	179	168	210	200	187	335	293	360
Energy (AAE)	GWh	(850) 425	1 648	1 143	1 028	1 320	1 282	1 180	1 950	1 720	2 075
Layout											
Spillway/Weir											
Bays x width	m	6 × 24	5 × 24	5 × 24	5 × 24	6 × 24	5 × 30	6 × 24	6 × 24	6 × 24	6 × 24
Pier width/height	m	5–6/31	7,10/41	7,50/37	6,0/37	7,50/37	7,50/34	6,0/31	7,0/37	6,0/31	7,0/37
Q max_{100}	m³/s	8 900	8 900	5 940	8 450	8 600	11 100	11 170	9 785	8 650	8 850
Gates		Dpl.-Haken	Dpl.-Haken	Dpl.-Haken	Segm. + Klappe	Dpl.-Haken	Dpl.-Haken	Segm. + Klappe	Segm. + Klappe	Segm. + Klappe	Segm. + Klappe
Powerhouse											
Construction, type		hoch	mittel	nieder	nieder	nieder	mittel	nieder	nieder	nieder	nieder
max height	m	52	53	39	40	42	42	39	46	44	49
Turbines, number and type		5 Kaplan ↓	4 Kaplan ↓	9 Kaplan →	9 Kaplan →	6 Kaplan ↓	6 Kaplan ↓	9 Kaplan →	9 Kaplan →	9 Kaplan →	9 Kaplan →
Backwater area											
Length	km	27	40	16	27	26	33	22	32	31	44
Overflow flood	m³/s	–	–	2 960	1 050	2 500	–	–	1 385	2 100	1 550

Table: Drau

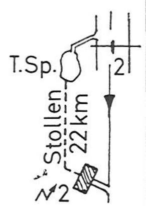
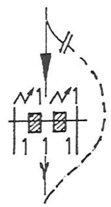
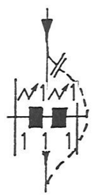
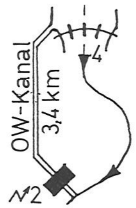
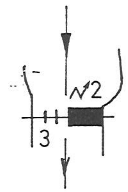
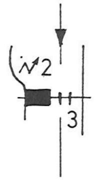
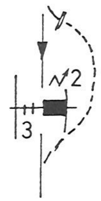
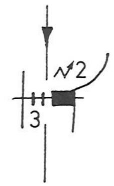
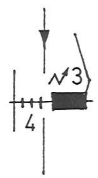
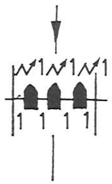
Power station		Strassen-Amlach	Kellerberg	Villach	Rosegg-St. Jakob	Feistritz-Ludmannsdorf	Ferlach-Maria Rain	Annabrücke	Edling	Schwabegg	Lavamünd
Owner		TIWAG	ÖDK	ÖDK	ÖDK	ÖDK	ÖDK	ÖDK	ÖDK	ÖDK	ÖDK
Operation since		1988 (Bau)	1985 (Bau)	1984	1973	1968	1975	1981	1962	1942	1944
Stationing	km	253/230	130 (85)	119 (96)	100/93 (115/122)	78 (137)	69 (146)	54 (161)	30 (185)	13 (202)	7 (208)
Storage level	m	1 069	505,3	495,6	485,5	461,5	437,5	416,4	390,8	369,0	348,7
Flow Q_{mean} / Q_{max} / Q_{rated}	m^3/s / m^3/s / m^3/s	10 (+1,4) 210 20	151 1 690 320	154 1 700 320	220 2 300 430	220 2 300 420	225 2 300 450	231 2 450 440	260 2 700 440	269 2 700 405	274 2 700 405
Head H_{mean}	m	370	9,7	10,1	22,7	23,7	21,0	25,6	21,1	20,5	9,0
Capacity (MC)	MW	60	24	24	80	80	75	90	70	60	25
Energy (AAE)	GWh	233	103	107	370	390	336	416	375	340	140
Layout											
Spillway/Weir											
Bays width	m	2 × 9	3 × 16	3 × 16	4 × 15	3 × 15	3 × 15	3 × 18	3 × 15	4 × 19	4 × 24
Pier width/height	m	2,0/9,9	20/24,5	20/25	4,3/22	2,4/39	4,6/40	5,0/40	5,7/36	5,0/33	16/17
Gates		Segm. + Klappe	Segm. + Klappe	Segm. + Klappe	Segm. + Klappe	Staubalken Segm. + Klappe	Segm. + Klappe	Segm. + Klappe	Segm. + Klappe	Dpl.-Haken	Dpl.-Haken
Power conduit	km	Stollen 22	–	–	OW-Kanal 3,4	–	–	–	–	–	–
Powerhouse											
Construction, type		hoch	Pfeiler-KW	Pfeiler-KW	hoch	hoch	hoch	hoch	hoch	flach	Pfeiler-KW
max height	m	34	27,5	28	44	47	42	40	38	34	28
Turbines, number and type		2 Francis ↓	2 Kaplan ↓	2 Kaplan ↓	2 Kaplan ↓	2 Kaplan ↓	2 Kaplan ↓	2 Kaplan ↓	2 Kaplan ↓	3 Kaplan ↓	3 Kaplan ↓
Backwater area											
Length	km	1	10,6	10,1	15	15	9	15	24	17	6

Table: Enns

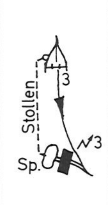
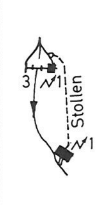
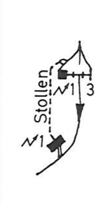
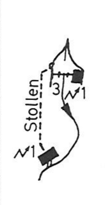
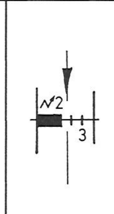
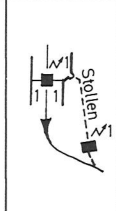
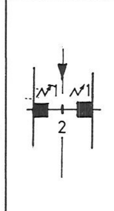
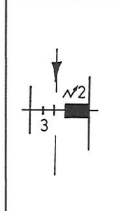
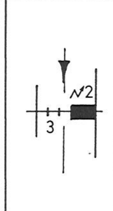
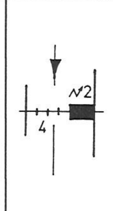
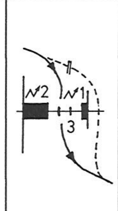
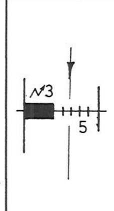
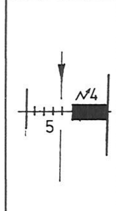
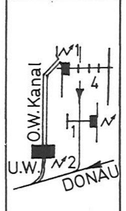
Power station		Hieflau	Landl	Krippau	Alten-markt	Schönau	Weyer	Groß-raming	Losen-stein	Ternberg	Rosenau	Garsten	Staning	Mühl-rading	St. Pantaleon
Owner		Steweag	Steweag	Steweag	Steweag	EKW	EKW	EKW	EKW	EKW	EKW	EKW	EKW	EKW	EKW
Operation since		1955/56	1967/68	1965/66	1960/61	1972	1969	1950	1962	1949	1953	1967	1946	1948	1965
Stationing	km	126/117	114/111	108/101	98/91	86	77,5/76,5	64,4	55,7	47,9	40,2	34,3	20,0	13,8	8,1
Storage level	m	564,5	479,0	453,0	425,0	400,5	388,0	371,0	346,5	331,0	315,0	302,0	283,2	268,3	260,0
Flow Q_{mean} Q_{max} Q_{rated}	m^3/s m^3/s m^3/s	78 1 000 90	94 1 100 120+(20)	126 1 400 120+(45)	129 1 400 106+(18)	147 1 870 280	148 1 900 280	156 2 000 280	162 2 100 280	163 2 120 280	164 2 130 280	166 2 150 280+15	208 3 000 315	208 3 000 315	209 3 000 315+10
Head H_{mean}	m	78,4	21,4 (15,3)	23,0 (14,0)	23,9 (13,4)	11,2	15,7/16,1	23,5	14,8	15,0	12,7	12,3	14,2	8,0	18,8
Capacity (MC)	MW	63	25	29	23	26	37	65	38	40	28	32	37	21	54
Energy (AAE)	GWh	269	123	153	136	117	163	246	166	168	134	143	190	101	264
Layout															
Spillway/Weir															
Bays width	m	3 × 12	3 × 12	3 × 12	3 × 12	3 × 12	2 × 18	2 × 22,5	3 × 13,5	3 × 16	4 × 16	3 × 14	5 × 17	5 × 17,2	4 × 14
Pier width/height	m	4,4/19,5	4,7/21,0	4,1/20,0	3,0/19,2	4,0/25,5	18,0/35,0	4,0/37,0	5,2/31,0	5,7/32,2	5,5/28,0	4,0/23,0	5,0/26,0	4,8/23,0	4,0/21,5
Gates		Segm. + Klappe	Segm. + Klappe	Segm. + Klappe	Segm. + Klappe	Segm. + Klappe	Segm. + Klappe	Klappe Grund-schütz	Dpl.-Haken	Klappe Grund-schütz	Dpl.-Haken	Segm. + Klappe	Oberschütz Segm. Schütz	Dpl.-Haken	Segm. + Klappe
Power conduit	km	Kanal 0,5 Stollen 5,6	Stollen 2,6	Stollen 4,4	Stollen 2,4	–	Stollen 1,0	–	–	–	–	–	–	–	Ka-nal OW 6,8 UW 2,2
Powerhouse															
Construction, type		hoch	hoch	Kaverne	Kaverne	nieder	Pfeiler-KW Kaverne	hoch	nieder	hoch	mittel	hoch	hoch	mittel	hoch
max height	m	29,5	34,3	32,0	33,5	29,5	35,0/35,0	45,3	36,6	36,5	32,0	37,4	31,0	24,0	42,6
Turbines, number and type		3 Francis ↓	1 Kaplan +1 Kaplan ↓	1 Kaplan +1 Kaplan ↓	1 Kaplan +1 Francis ↓	2 Kaplan ↓	1 Kaplan 1 Kaplan ↓	2 Kaplan ↓	2 Kaplan ↓	2 Kaplan ↓	2 Kaplan ↓	2 Kaplan 1 Kaplan ↓	3 Kaplan ↓	4 Kaplan ↓	2 Kaplan 1 Francis ↓
Backwater area															
Length	km	2,0	2,5	3,0	2,9	7,0	8,9	12,1	8,7	7,8	7,7	5,9	10,0	6,2	5,7

Table: Inn

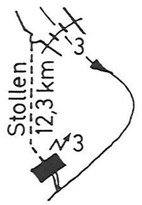
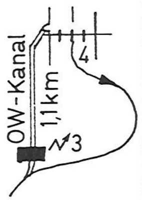
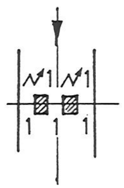
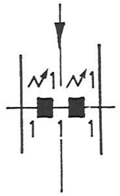
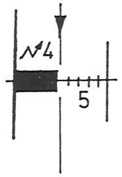
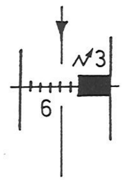
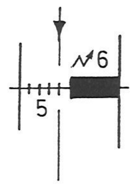
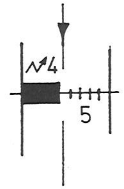
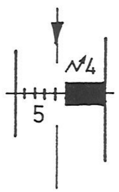
Power station		Prutz-Imst	Kirchbichl	Oberaudorf	Nußdorf		Braunau-Simbach	Ering-Frauenstein	Egglfing-Obernberg	Schärding-Neuhaus	Passau-Ingling
Owner		TIWAG	TIWAG	ÖBK	IWAG 53 % ÖBK 47 %		ÖBK	IWAG	IWAG	ÖBK	ÖBK
Operation since		1956	1941	1988 (Projekt)	1982		1953	1942	1944	1961	1965
Stationing	km	387/360	233/230	211	198		61	48	35	19	4
Storage level	m	858,5	497,0	477,4	464,4		348,5	336,2	325,9	314,9	303,0
Flow Q_{mean} Q_{max} Q_{rated}	m³/s m³/s m³/s	80 600 80	320 1 800 250	320 2 400 580	320 2 400 550	Deutscher Inn-Abschnitt; IWAG L = 123 km, H = 104 m 9 Kraftwerke: Rosenheim bis Stammham 296 MW, 1781 GWh	706 6 200 1 000	715 6 400 1 040	721 6 600 990	732 6 800 1 000	746 7 400 1 000
Head H_{mean}	m	145,0	8,1	12,5	11,6		11,6	9,6	10,5	11,2	10,0
Capacity (MC)	MW	82	23	(58) 29	(48) 11		(96) 48	(72) 36	(84) 42	(96) 48	(86) 43
Energy (AAE)	GWh	537	134	(262) 131	(226) 53		(554) 277	(428) 214	(468) 234	(540) 270	(480) 240
Layout											
Spillway/Weir											
Bays width	m	3 × 13	4 × 20	3 × 16	3 × 18		5 × 23	6 × 18	5 × 23	5 × 23	5 × 23
Pier width/height	m	5–1/16	5/17	20/35,3	25/30,4		6/30	5/31	6/28	6/25	6/27
Gates		Dpl.-Haken	Dpl.-Haken	Segm. + Klappe	Segm. + Klappe		Dpl.-Haken	Dpl.-Haken	Dpl.-Haken	Dpl.-Haken	Dpl.-Haken
Power conduit	km	Stollen 12,3	OW-Kanal 1,1	–	–		–	–	–	–	–
Powerhouse											
Construction, type		Kaverne	hoch	Pfeiler-KW	Pfeiler-KW		flach	flach	flach	flach	flach
max height	m	30	37	35	30		34	34	27	32	32
Turbines, number and type		3 Francis ↓	3 Kaplan ↓	2 Kaplan →	2 Kaplan ↓		4 Kaplan ↓	3 Kaplan ↓	6 Kaplan ↓	4 Kaplan ↓	4 Kaplan ↓
Backwater area											
Length	km	3	9	11	13		14	13	13	17	15

Table: Mur

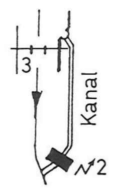
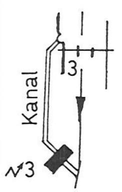
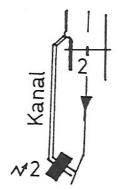
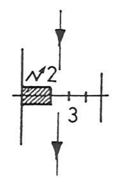
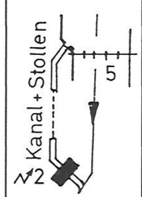
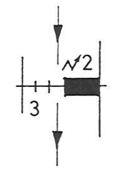
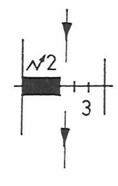
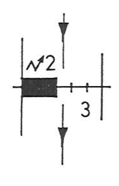
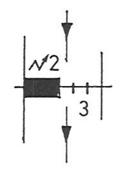
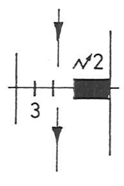
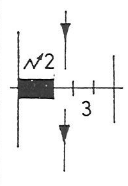
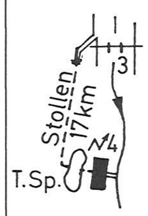
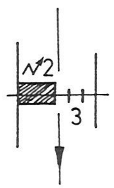
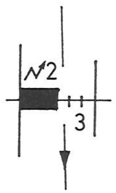
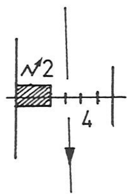
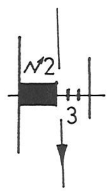
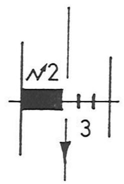
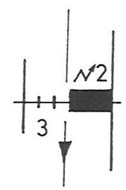
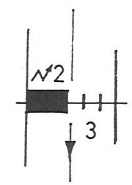
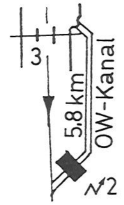
Power station		Dionysen	Pernegg	Laufnitz-dorf	Rabenstein	Peggau	Weinzödl	Mellach	Gralla	Gabersdorf	Obervogau	Spielfeld
Owner		Steweag	Steweag	Steweag	StEG	StEG	StEG	Steweag	Steweag	Steweag	Steweag	Steweag
Operation since		1944	1927	1931	1987 (Bau)	1908	1982	1985	1964	1974	1977	1982
Stationing	km	244,2/239,9	229,6/226,7	222,7/214,8	207,5	205,2/200,8	184,0	159,1	147,6	142,2	137,6	132,3
Storage level	m	504,3	467,3	448,3	418,8	410,0	363,0	305,5	281,0	271,5	262,0	254,0
Flow Q_{mean} Q_{max} Q_{rated}	m^3/s m^3/s m^3/s	80 1 200 85	105 1 500 140	108 1 500 110	115 1 250 180	115 1 250 110	115 1 250 180	124 1 250 180	135 1 250 200	135 1 250 220	140 1 250 240	157 1 500 240
Head H_{mean}	m	16,5	16,7	18,6	8,2	14,4	9,0	9,6	8,3	8,2	7,1	7,0
Capacity (MC)	MW	12	18	17	13	13	16	16	14	15	13	13
Energy (AAE)	GWh	70	105	108	62	78	68	84	71	74	68	76
Layout												
Spillway/Weir												
Bays width	m	3 × 15	3 × 15	2 × 25	3 × 15,5	2 × 14/3 × 12	3 × 16,5	3 × 15,0	3 × 15	3 × 15	3 × 20	3 × 22
Pier width/height	m	3,8/15,5	5,0/27,0	5,0/13,5	3,0/18,0	2,0/11,0	3,0/18,0	2,5/19,8	4,0/17,0	4,0/18,0	2,4/18,5	2,4/18,5
Gates		Dpl.-Haken	Dpl.-Haken	Walzen	Segm. + Klappe	Schützen-tafel	Segm. + Klappe	Segm. + Klappe	Segm. + Klappe	Segm. + Klappe	Segm. + Klappe	Segm. + Klappe
Power conduit	km	Kanal OW 3,7 UW 0,4	Kanal OW 2,3 UW 0,3	Kanal OW 7,0 UW 0,2	–	Kanal 2,1 Stollen 1,0	–	–	–	–	–	–
Powerhouse												
Construction, type		hoch	hoch	hoch	hoch	hoch	hoch	hoch	hoch	hoch	hoch	hoch
max height	m	33	32	31,4	20,4	17,0	23,0	27,0	29,9	25,7	26,0	26,0
Turbines, number and type		2 Kaplan ↓	3 Francis ↓	2 Kaplan ↓	2 Kaplan ↓	2 Kaplan ↓	2 Kaplan Straflo →	2 Kaplan →	2 Kaplan ↓	2 Kaplan →	2 Kaplan →	2 Kaplan →
Backwater area												
Length	km	1,5	5,3	4,0	4,0	2,5	1,2	3,4	3,8	5,4	4,6	5,3

Table: Salzach – Traun

Power station		Schwarzach	Urreiting	Bischofs-hofen	Hallein	Urstein		Gmunden	Marchtrenk	Traun-Pucking	Klein-münchen
Owner		TKW	SAFE/TKW	SAFE/TKW	SAFE	SAFE		OKA	OKA	OKA	ESG
Operation since		1958	1986 (Bau)	1985	1987 (Bau)	1971		1969	1979	1982	1978
Stationing	km	154/135	124	120	80	75		72	24	14	8/2
Storage level	m	738,0	559,2	547,8	440,7	434,0		422,6	309,5	289,3	262,5
Flow Q_{mean} Q_{max} Q_{rated}	m^3/s m^3/s m^3/s	60 1 100 90/110	103 1 320 186	106 1 356 202	154 2 200 220	174 2 730 250		72 950 150	128 1 500 200	128 1 500 200	138 1 500 124
Head H_{mean}	m	132	10,8	9,7	6,7	8,9		10,3	20,2	26,8	10,1
Capacity (MC)	MW	120	16	16	12	20		12	38	42	11
Energy (AAE)	GWh	480	80	73	66	107		48	181	222	75
Layout											
Spillway/Weir											
Bays width	m	3 × 10	3 × 10	3 × 10	4 × 25	3 × 16		3 × 22,5	3 × 13	3 × 13	3 × 18
Pier width/height	m	3,5/15,0	3,0/21,7	3,0/21,7	1,5/18,6	4,5/21,0					
Gates		Segm. + Klappe	Segm. + Klappe	Segm. + Klappe	Klappen	Segm. + Klappe		Klappen	Segm. + Klappe	Segm. + Klappe	Hub-schützen
Power conduit	km	Stollen 17	–	–	–	–		–	–	–	Kanal 5,8
Powerhouse											
Construction, type		hoch	flach	flach	flach	flach		flach	nieder	nieder	hoch
max height	m	25,0	27,3	27,3	29,0	26,0					
Turbines, number and type		4 Francis ↓	2 Kaplan →	2 Kaplan →	2 Kaplan →	2 Kaplan ↘		2 Kaplan ↘	2 Kaplan ↓	2 Kaplan ↓	2 Kaplan →
Backwater area											
Length	km	1,5	4,5	4,7	2,4	5,3		Traunsee 14	8	10	6

Austria's Contribution Towards the Development of Water Power

By **H. Lauffer***

1. Introduction

After mentioning several outstanding Austrian scientists and engineers who played an important rôle in the history of water power development, the author will discuss several innovations which, devised to solve particular problems presented by the Austrian development possibilities, have come to be successfully applied in general hydro development practice. In doing so, the author claims neither exhaustiveness nor originality, as in fact similar solutions, unknown to him, may have been found in other countries to problems discussed in this article.

2. Pioneers in Relevant Sciences and Special Fields

Among the great number of Austrians that have done pioneer work in the sciences and special fields relevant to the development of water power are the following:

In the field of engineering hydraulics,
Philipp Forchheimer (1852 to 1933)
should be named. He developed the complete hydraulic basis for water power development already before the First World War.

As a great master in engineering geology,
Josef Stini (1880 to 1958)
gave his expert opinion and advice on the greater part of Austrian hydro projects for many decades. His manner of cooperating with construction engineers was exemplary and was to be continued and developed by others, in particular by Eberhard Clar.

The founder of soil mechanics,
Karl von Terzaghi (1883 to 1963),
was an expert at introducing engineering considerations where the theoretical knowledge available did not suffice to allow satisfactory judgement of foundation problems.

Among those who continued his work was
Arthur Casagrande (1902 to 1981),
who had an important influence on embankment dam construction all over the world.

Among the first pioneers of rock mechanics is
Leopold Müller,
who founded the "Salzburger Kreis" ("Salzburg Circle") and the GEOMECHANICS COLLOQUY, first held in 1951, thus creating a singular meeting-place where construction engineers were able to discuss rock problems in theory and practice with geologists, geophysicists and mining engineers.

The fundamentals of sediment transport and scour prevention were studied by
Armin Schoklitsch (1888—1969),
mainly in connexion with hydro power projects.

The development of diaphragm walls using bentonite suspension is due to
Christian Veder (1907 to 1984),
who thus rendered possible the construction of deep cut-offs.

The utilisation of minor heads was greatly facilitated by the invention of a new turbine by
Viktor Kaplan (1876 to 1934).
Power stations equipped with Kaplan turbines account for more than half the hydro generation in Austria.

The development of water power in Austria certainly received its strongest impetus from
Hermann Grengg (1891 to 1978),
by a lifetime's work carried out in several functions: first, that of an executive director responsible for design and construction of hydro power projects in Styria, in the Hohe Tauern mountains and along the lower course of the river Drau, which included the introduction in Austria of the arch dam type and the realisation of the first pierhead power stations; then, that of a university teacher, giving incitement to many young engineers; and finally that of an expert and consultant, putting his stamp on a great number of hydro projects.
The following paragraphs will first deal with the dams and waterways of storage power schemes in mountainous regions, and then discuss the low head run-of-river plants developing Austria's rivers. The References at the end of this article are arranged in the same order.

3. Innovations and Progress in the Construction of Large Dams in Austria

In the field of large dams forming storage reservoirs, there has been an intensive exchange of experience within the International Commission On Large Dams (ICOLD). Such exchange is carried on to an even greater extent among the Alpine countries owing to their neighbourly relations. Therefore, most of the innovations in large dam construction discussed in this article are adjustments to the local conditions and possibilities of power sites.
The first example concerns the gravity dam, which is not only the oldest, but also the most frequently used dam type in Austria. The *gravity dams,* 46 m in maximum height, of ÖDK's[1] *Reisseck scheme,* have, directly above their foundation contacts, large base galleries with cross sections designed to follow the lines of force. Ensuring the same amount of stability, this design allowed concrete savings of some 10 %, which were particularly appreciated in view of the difficult access to the dam sites situated at elevations more than 2300 m above sea-level.
The same design was used for the 48 m-high *Neue Tauernmoos dam,* owned by ÖBB[2] and completed in 1973. The alignment of the right-hand lateral dam consists of

* Dipl.-Ing. Dr. techn. Dr. techn. h. c. Baurat h. c., retired Executive Director of Tiroler Wasserkraftwerke Aktiengesellschaft (TIWAG), Honorary Chairman of the Austrian National Committee on Large Dams.

[1] Österreichische Draukraftwerke AG, Klagenfurt.
[2] Österreichische Bundesbahnen, Generaldirektion, Vienna.

reverse curves following the rocky ridge on which it is founded. In the main dam portion which spans the valley cutting through the ridge, joints were grouted, which made it the first *economy type of gravity dam with arch action* ever to be built.

Since the end of the Second World War, preference has in general been given to arch dams. Among these, the 53 m-high *Hierzmann dam,* owned by STEWEAG[3], is remarkable for its particular shape designed to fit an extremely *unsymmetrical valley cross section* without calling for major correction of the slopes.

As variable curvature of horizontal sections is an advantage in wide-span arch dams, *conic sections* are mainly used for the arch elements in Austria, as they allow continuous adjustment of dam curvature to the terrain. Thus, the Schlegeis dam, owned by TKW[4] and completed in 1971, with an unusual length (770 m) in relation to its height (130 m), was given a curvature increasing towards the crown at crest level and towards the abutments in the lower dam portion.

As to concrete technology, it should be mentioned that *separation of ultra-fine particles* and dedusting of the sand fraction by means of decanting installations were introduced in 1952—1955 for the construction of the Mooser and Drossen dams (Kaprun scheme owned by TKW), totalling more than 1 million m³ in concrete. Achieving a substantial improvement of concrete quality and, in particular, frost resistance even with low cement contents, these measures have since been applied on all major concrete construction projects.

For the construction of its *Kölnbrein arch dam,* 200 m high and 1.6 million m³ in volume, completed in 1977, ÖDK applied a practice developed for the dams on the river Danube. This consisted of automatic water batching based on aggregate moisture as continuously measured by neutron gauges, so as to reduce scatter substantially. An Austrian type of climbing formwork designed for the Kölnbrein dam, with elements of up to 30 m² in surface area, was used for the Itaipú dam recently put into service on the Paraná in South America (with a concrete volume of 12 million m³, this is so far the largest concrete dam in the world).

As to embankment dams, remarkable progress has been made in the *placement of quarry-run rockfill material.* This is very well demonstrated by a comparison between the TIWAG[5]-owned Gepatsch and Finstertal dams, both about 150 m high. Whereas at the Gepatsch dam, completed in 1964, lifts were placed 2.0 m high and compacted by 8-ton vibratory rollers, lifts at the Finstertal dam, constructed between 1978 and 1980, had to be not higher than 1.0 or 0.75 m and had to be compacted by 15-ton vibratory rollers, partly with addition of water. This reduced deformations of the Finstertal Dam to about one-fifth, and horizontal displacement at the crest during first filling was not more than about 14 cm. Good compaction of the rockfill was important in rendering feasible the construction of a *96 m-high asphaltic concrete core* as an impervious element, which was the first continuously sloping core in an embankment of such height. Part of the upstream shoulder of the Finstertal dam rests on steeply sloping *rock surfaces polished by glacial action,* which hat to be *roughened* by blasting notches into them. The required extent of roughening and notch dimensions were determined on the basis of systematic large-scale shear tests conducted at the Innsbruck university.

Screened talus material with a maximum particle size of 80 mm proved well suited for the impervious cores of the above mentioned Gepatsch and the 85 m-high Durlassboden embankment dams.

Asphalt concrete facings, much used on embankment dams in Austria, have conquered high-level sites exposed to severe climatic conditions such as those of KELAG's[6] Fragant group of power developments situated at elevations around 2400 m above sea-level. An additional advantage is their suitability for stage-wise construction schemes. E. g. the Oscheniksee dam, having a final total height of 106 m and a facing height of 60 m, was constructed in four stages.

Satisfactory results obtained in the use of reinforced-concrete cores that had been in operation for some time gave rise to thorough investigations at the Innsbruck university with the aim of testing their suitability for high embankment dams. The result was that such cores are indeed suited provided sliding layers are applied on both sides to prevent excessive loading of the core by dam settlement.

Particularly *difficult foundation conditions* at TKW's Durlassboden and Eberlaste embankment sites and at Bolgenach, owned by VKW[7], were overcome by special measures, on which detailed reports are available.

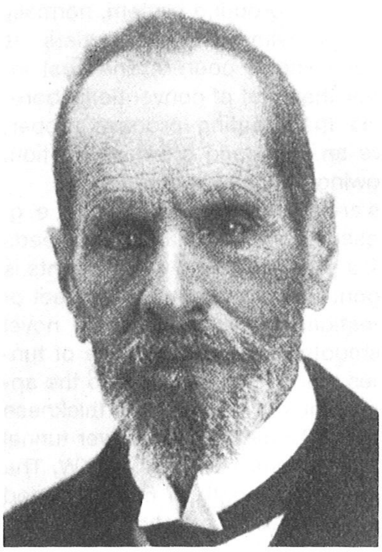
Important progress has also been achieved in the field of *embankment dam instrumentation* as e. g.:

— *Horizontal plate gauges,* developed for TIWAG's Gepatsch dam as a simple means of determing from the dam surface horizontal displacement and settlement within the fill so as to obtain better information on the behaviour of high embankments. These gauges now form part of the standard instrumentation of high embankment dams as recommended by ICOLD.
— The *"suspended shaft" consisting of independent precast annular members* embedded in the fill of the Finstertal dam. This was the first to be made up of two staggered sections connected by a gallery to follow the slope of the core. Equipped with a teletransmitted plumb line installation, this allows direct observation of embankment and core deformations as well as short paths for the great number of instrument leads towards the measuring station at the foot of the shaft, so as to reduce potential line failures.
— A new device developed for the measurement of transverse strain in the asphaltic concrete core of the Finstertal dam. This indicates changes in core density by means of magnetic field measurements, thus obviating the need of piercing the core.

In Austria strict official regulations have long been in force for the approval and supervision of large dams. Among these, the following deserve special mention:

— The *Staubeckenkommission,* a storage reservoir commission within the Ministry of Agriculture and Forestry, consisting of 25 experts in the various special fields of large dam construction and the various

[3] Steirische Wasserkraft- und Elektrizitäts AG, Graz.
[4] Tauernkraftwerke AG, Salzburg.
[5] Tiroler Wasserkraftwerke AG, Innsbruck.
[6] Kärntner Elektrizitäts-AG, Klagenfurt.
[7] Vorarlberger Kraftwerke AG, Bregenz.


Philip Forchheimer (1852—1933)

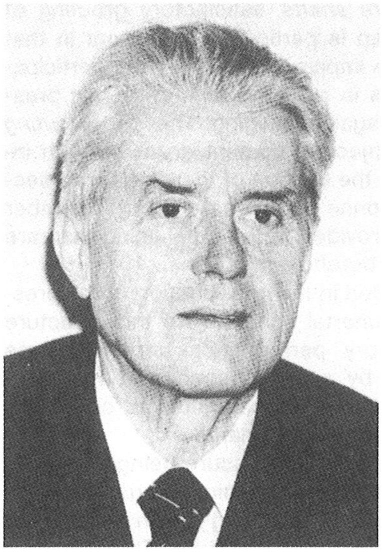

Josef Stini (1880—1958)


Karl v. Terzaghi (1883—1963)

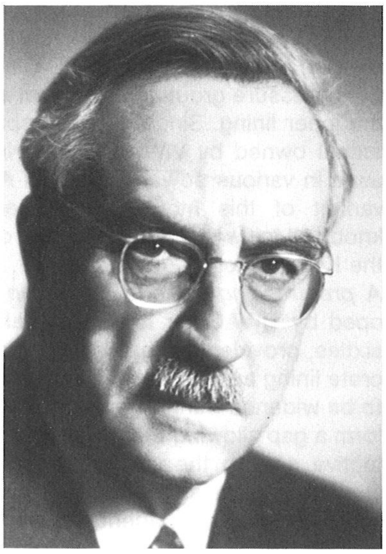

Arthur Casagrande (1902—1981)


Leopold Müller


Armin Schoklitsch (1888—1969)


Christian Veder (1907—1984)


Viktor Kaplan (1876—1934)


Hermann Grengg (1891–1978)

relevant sciences, and preparing interdisciplinary expertises on large dam projects.
— Incumbent on each dam owner is the nomination, for each dam, of a *person responsible,* who will be in charge of all matters of safety.

Additional knowledge concerning solids transport has been derived from evaluating sand trap flushings at the stream intakes of transbasin diversions needed to fill storage reservoirs. The preferred type of stream intake in the Alps is the horizontal-rack drowned weir, where solids carried along by streamflow settle in a sand catching chamber, which is flushed now and then by hand or automatically. For the Kaunertal development, an automatic trip mechanism based on the depth of accumulated solids was developed. This allowed for the first time routine determination of the intensity and the volume of solids transport in mountain streams, where use of the usual wire baskets is not possible.

4. New Developments in Power Conduit Construction

Other developments concern power conduits, which, in the case of high and medium heads, normally consist of power tunnel, surge tank, and penstock or pressure shaft.

The excavation of large-diameter tunnels and shafts in difficult ground has greatly been facilitated all over the world by the use of the New Austrian Tunneling Method. Its basic principles were developed for the excavation of the power tunnel of TIWAG's Imst power station on the Inn river in 1953—1956. The allowance that was made for the stand-up time as a function of the span of unsupported rock mass proved of great advantage in classifying rock mass.

Simple *concrete linings* are normally applied in the power tunnels, usually of major length, to save time and money. It was already during the Second World War that concrete pouring in annular sections, without longitudinal joints, by means of mobile steel formwork and a concrete pump was developed for the Kaprun scheme. This method is now generally applied. As a result of the poor tensile strength of concrete, major internal pressures can be absorbed only if the lining is *prestressed against the rock mass.* This idea was first translated into practice by the Austrian A. Kieser, whose *Kernring method* was patented in 1943. This consists of sectionwise pressure grouting an annular space left free around the inner lining. Since its first application for the Valüla tunnel owned by VIW[8], the Kernring method has been used in various power tunnels in Austria and abroad. A variant of this method, extended by the use of a knobbed foil, was applied for part of the power tunnel of the Kops scheme, owned by VIW.

A prestressing method based on gap grouting, developed by TIWAG for the Kaunertal scheme in the early sixties, provides for the construction joint between concrete lining and excavation surface, or preliminary lining, to be widened during the prestressing grouting so as to form a gap allowing the grouting pressure to become effective aroung the whole circumference and to seize also the rock mass around the opening. To facilitate gap formation, a parting agent, usually a whitewash spray or plastic foil, is applied and the grouting system, normally consisting of plastic pipe with valve-like outlets, is placed before the inner lining is poured. The cost involved tends to be lower than that of conventional borehole grouting, whereas the grouting process proper, which tends to involve an increased grout absorption, takes less time by allowing continuous working.

Where major demands are made on watertightness, e. g. where the internal pressure level substantially exceeds the ground water level, a sealing foil with welded joints is placed as a parting agent. This has been the subject of various extensive investigations involving some novel testing set-ups. The smooth excavation surface of tunnels driven by machines lends itself very well to the application of sealing foils. Thus, a foil of 5 mm thickness was used for the low-lying 3.3 m-diameter power tunnel of the Langenegg power scheme, owned by VKW. The foil was applied in a transition length of 600 m, loaded with a maximum pressure of 35 bar, between a steel-lined section and simple concrete lining. The invert part of the foil was laid beneath the precast invert elements placed immediately behind the full-section tunnelling machine.

After having stood its test in the operation of the power tunnel of the Kaunertal scheme, the gap grouting method has been used for ever increasing loads, as e. g. on for the Kühtai upperstage of TIWAG's Sellrain-Silz scheme, over a length of 1.1 km with a diameter of 4.0 m and for static pressures of up to 48 bar and dynamic pressures of up to 70 bar, with foil being placed over about one-third of the total length; in South Africa, for the 1 000 MW Drakensberg pumped storage scheme, over a length of 2.2 km with a diameter of 5.5 m and for a maximum internal pressure of 52 bar.

A condition of permanent prestressing against the rock mass and of a permanent good performance of the rock mass in picking up internal pressure is that the stresses present in the rock mass exceed the prestressing pressure, or the percentage of internal pressure to be absorbed by the ground. Otherwise there is a potential risk of failure. On the pressure shafts of the Sellrain-Silz scheme, the hydrofracturing method was used to determine whether sufficient stresses were present in the rock mass.

In *steel-lined pressure shafts,* satisfactory grouting of the circumferential gap is particularly important in that an open gap tends to impair substantially the participation of the rock mass in resisting to the internal pressure, and the safety against bulging. The *gap grouting method* consists of injecting cement grout through injection piping fixed to the outside of the steel-lining sections. This requires connexion bores smaller in number and diameter to be provided in the steel-lining than are needed for the usual borehole injections.

This method was applied in the construction of the pressure shaft of the Kaunertal scheme. As this structure has shown satisfactory performance under extreme loads, as confirmed by a great number of measurements, gap grouting has since been applied on a large number of steel-lined pressure shafts.

With the permissible grouting pressure being limited by the bulging safety of the steel-lining, larger grouting pressures can be applied if grouting is carried out with the steel-lining-full and under pressure. This was first tried in the pressure shaft, designed to withstand a max-

[8] Vorarlberger Illwerke AG, Bregenz.

imum internal pressure of 140 bar, of KELAG's Oscheniksee scheme, with grout being injected through the main drain.

The stress-strain curve method, introduced in Austria more than 20 years ago, has proved an efficient means of designing and testing all types of linings, by clearly revealing the effects of a prestressing system or its changes, or those of a potential gap. The radial jack improved at that time by TIWAG allowed the yielding properties of the rock mass, tending to vary substantially along the circumference of the lining, to be exactly determined for the first time. The stress-strain curves obtained from this method can be used as such, without conversion, for lining design. Geophysical methods such as sound velocity measurement along radial boreholes have been used for the interpolation of measured values.

Damage so far experienced in steel-lined pressure shafts has mainly been caused by *bulging inward* under external pressure. Bulging that occurs during emptying, after the shaft has been placed into operation, is particularly annoying because the steel-lining may deform unnoticed over several hundreds of metres. The most vulnerable zones are the upper portions of pressure shafts where the lining has to be designed to withstand external pressure rather than internal pressure; and external pressure assumptions usually involve great uncertainties.

In order to *enhance bulging safety,* the following novel methods have been applied in Austria:

— *Filling the circumferential gap completely* by use of the gap grouting method, which experience gained at Kaunertal has shown to be more efficient if carried out after a pressure test of the shaft.
— *Anchoring the steel lining* in the concrete backfill by means of head bolt anchors instead of the normally used dowels and claws, which mainly act by shear. Austrian power companies, steel construction firms and universities have cooperated these last few years to study systematically the effect of such anchors on bulging resistance by means of a bulging test installation previously developed by TIWAG. Thus, reliable design is now possible provided, however, that the head bolt anchors are firmly embedded in the backfill concrete.
— Installation of an *inner concrete ring* as had already been applied earlier for the thin-walled steel-linings of the power tunnels of the Gerlos lower stage and the Kaunertal scheme. An improved version of this method was used in the upper portion of the power shaft, 2.7 m in internal diameter, of TIWAG's Sellrain-Silz lower stage. An inner ring of high-strength concrete B 500, 10 cm in wall thickness, was constructed of individual sections produced in a precast factory. The amount of time and money required by this method hardly exceeds that needed for protection against corrosion in conventional structures, but the permissible external pressure involved is much higher. This method is also planned to be applied in the pressure shaft of TKW's Ziller upper stage.

Ever since the construction of the Lünersee project, thrust blocks for *penstocks* have been constructed without concrete tops. In the Ausserfragant and Malta main stage penstocks, longitudinal forces are transmitted to the thrust block concrete foundations through web plates with head bolt anchors, welded to the underside of the pipe. Following minor applications in the sag pipes of VIW's Upper Ill-Lünersee development, concrete embedded steel pipes in trenches have been used to a major extent on KELAG's Fragant power scheme. This method requires no thrust blocks even at pipe bends and allows better adjustment to the configuration of the terrain. Buried pressure pipes without expansion joints were used on several projects, e. g. on ÖDK's Reisseck storage scheme, over the lowest section of the penstock designed to resist a maximum pressure of 196 bar.

A main condition of the safe performance of penstocks and steel-linings subjected to major loadings is the use of durable structural steels resistant to brittle fracture. For this purpose, the much tested ALDUR steels have been available in Austria since Hauttmann started their development with VÖEST in 1948.

In the *surge tanks,* provided as oscillation absorbers between power tunnels and penstocks, the *reverse-flow control throttle,* first used by TIWAG on the Kaunertal development, has brought about a substantial reduction in dampening time, so that the increasing requirements of the power system have been satisfied without calling for an increase in surge tank volumes. The new type of surge tank, which affords particular advantages where major reservoir level variations are involved, has also been applied on TKW's Zemm-Ziller and ÖDK's Malta developments.

5. New Developments in the Run-of-river Schemes on Austria's Rivers

In Austria, rivers are mainly developed by *run-of-river schemes involving heads* of between 8 and 25 m. Continuous chains of power schemes exist over many river stretches. To answer local hydrological requirements and also for historical reasons, several *typical construction methods* have developed on a number of rivers.

The power schemes of the Austrian reach of the Danube, the only navigable river in this country, utilise a design flow of 2000 to 3150 m³/s and heads of 10 to 15 m. Out of the 11 planned projects, not including boundary reaches, eight are in operation and a ninth has been submitted for authorization of construction. Particulars of the Danube construction method developed by DoKW[9] will be discussed later in this report.

On the *lower Inn,* where this river forms the boundary with Bavaria, development in common with Germany has been completed by ÖBK[10] and IW[11], by the construction of five power projects with a design flow of 1000 m³/s and heads varying between 10 and 11 m. All the projects were constructed by use of a *flat construction method* introduced in the Bavarian section of the Inn. The construction method used on the Inn provides for no rising powerhouse structure, with a single gantry crane serving both the weir and the adjacent power station and placing the emergency gates for weir and turbines. Emergency gates are introduced from the tailwater on sloping tracks.

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[9] Donaukraftwerke AG, Vienna.

[10] Österreichisch-Bayerische Kraftwerke AG, Simbach (Germany) and Braunau (Austria).

[11] Innwerke AG, Töging am Inn (Germany).

International cooperation, first practised on the Inn projects, proved a great advantage in connexion with the uniform construction and operation of the power stations.

On the other Austrian rivers lending themselves to development by series of low head power plants—in particular, the Drau, Mur, Enns, Traun, Salzach and Tyrolean Inn rivers, most of which allow a design flow of between 200 and 400 m³/s—the *conventional construction method* has preferably been used. This provides for a rising powerhouse structure adjacent to the weir and equipped with vertical-shaft Kaplan turbines, whereas bulb turbines are still rare. Local conditions at the sites of the great number of power projects constructed have given rise to the development of special features, which cannot be treated in this report.

A novelty that should, however, be mentioned in this context is the *pierhead power station,* first realised on the lower Drau, where the power units are accommodated in widened weir piers. On the model of the Inn flat construction method, the station is equipped with a main gantry crane serving the whole installation.

Some of the advantages of this design are the straight-line flow of both power water and flood water, more efficient handling of floating debris and bed load due to the absence of a power station bay, and the smaller total width, which is of particular importance in the case of minor heads. Where the so-called wet construction method with several successive construction pits is applied, the pierhead power station will allow earlier completion dates.

Apprehensions regarding increased personnel requirements because power units are not concentrated in a single hall, or of potential risks to the power station piers from ice or floods have not come true although the oldest power stations of this type have been in operation for forty years. Neither are such disadvantages expected to arise as remote plant control is now generally practised.

Since pierhead power stations were first built — Lavamünd and Dravograd on the river Drau, commissioned in 1943/44 and utilising a head of approximately 9 m and a flow of 400 m³/s, the following stations of this type, equipped with vertical-shaft Kaplan turbines, have been constructed:

to 1960 — another four stations on the Jugoslav section of the Drau, each consisting of four weir bays and three turbine piers, utilising heads of between 14 and 17 m and flows of between 400 and 450 m³/s,

to 1970 — the Weyer power station on the river Enns, owned by EKW[12], utilising a head of 16.5 m and having a single turbine pier for 125 m³/s and a diversion-type power station of equal capacity,

to 1978 — Perach power station, owned by IW, on the river Inn, utilising a head of only 5 m and having three turbine piers for 510 m³/s,

to 1982 — Nussdorf power station, owned by ÖBK, on the Inn section forming the boundary between Bavaria and Tyrol, utilising a head of about 10 m and having two turbine piers for 550 m³/s,

to 1983 — Villach power station, owned by ÖDK, on the river Drau, utilising a head of about 10 m and having two turbine piers for 300 m³/s.

A similar method, using bulb turbines, was used on the Argentat power project in the Dordogne in France in the mid-fifties.

The following are features particular to the *Austrian Danube construction method:*

- *integrated construction method* by uniting the twin locks, the weir and the powerhouse in a single structure served by gantry cranes,
- use of the locks for the discharge of catastrophic floods, during which periods navigation has to be stopped anyway,
- water intake and discharge for lock operation from the headwater and to the tailwater above and below the weir rather than by the lock approaches,
- weir with five or six bays 24.0 m wide each, hydraulic-driven tainter gates with flaps,
- low powerhouse structure with nine large-capacity Kaplan bulb turbines.

The so-called *flat-country power stations* on the Austrian Danube are remarkable for the following features:

- dykes with sections overflown by major floods to maintain flooding of the riverine woodlands and to accomplish a flood-retarding effect, tested on large-scale open air models,
- provision in these dykes of impervious cores consisting of particularly fine-grained riverside sand mixed with riverbed gravel, with deep slurry-trench or thin diaphragm cutoffs, the latter consisting of I-beams driven or jetted into place and a cement-based slurry being injected into the space forming as the beams are slowly withdrawn,
- construction in a single flood-free pit protected by cofferdams, most of which are sealed with plastic foil.

These features, combined with careful scheduling of design and construction, allowed the Greifenstein power scheme to be completed within a period of not more than 30 months, which is unusually short for the construction of a dam across a navigable river.

6. Environmental Requirements

The development of the Danube is also a convincing example of a regard for the environment that has long been a matter of course in water power development in Austria and is achieved by a design and construction aimed at minimum interference with the natural landscape. This has also been accomplished to a very large extent in the Austrian storage schemes.

Any unbiassed visitor will realise that hydro power development in Austria at its present stage does no real harm to nature or landscape and, thus, can be continued with a good conscience.

[12] Ennskraftwerke AG, Steyr.

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REGISTER OF
LARGE DAMS IN AUSTRIA

(including large river barrages)

(from ICOLD's World Register of Dams — 1984 Edition)

REGISTRE DES BARRAGES EN AUTRICHE
REGISTER OF DAMS IN AUSTRIA

FOLIO No. 1

49

1 LIGNE *LINE* No.	2 NOM DU BARRAGE *NAME OF DAM*	3 ANNÉE D'ACHÈVEMENT *YEAR OF COMPLETION*	4 SITUATION – *LOCATION*: COURS D'EAU *RIVER*	5 SITUATION – *LOCATION*: VILLE LA PLUS PROCHE *NEAREST CITY*	6 SITUATION – *LOCATION*: ÉTAT PROVINCE OU DÉPARTEMENT *STATE PROVINCE OR COUNTRY*	7 TYPE	8 SITUATION ET TYPE D'ÉTANCHÉITÉ *POSITION AND NATURE OF SEALING ELEMENT*	9 FONDATION *FOUNDATION*	10 HAUTEUR AU-DESSUS DE LA PLUS BASSE FONDATION *HEIGHT ABOVE LOWEST FOUNDATION* (m)	11 LONGUEUR DE CRÊTE *LENGTH OF CREST* (m)	12 VOLUME DU BARRAGE *VOLUME CONTENT OF DAM* (10^3 m³)	13 CAPACITÉ TOTALE DU RÉSERVOIR / SURFACE DU RÉSERVOIR *GROSS CAPACITY OF RESERVOIR / RESERVOIR AREA* (10^3 m³) / (10^3 m²)	14 DESTINATION *PURPOSE*	15 CAPACITÉ MAXIMALE DES ÉVACUATEURS *MAXIMUM DISCHARGE CAPACITY OF SPILLWAYS* (m³/s)	16 TYPE DES ÉVACUATEURS *TYPE OF SPILLWAYS*	17 PROPRIÉTAIRE *OWNER*	18 BUREAU D'ÉTUDES *ENGINEERING BY*	19 CONSTRUCTEUR *CONSTRUCTION BY*	LIGNE *LINE* No.
1	ERLAUFKLAUSE	1911	Erlauf	Mariazell	Lower Austria	PG		R	37	88	22	1720/232	H	160	L/V	N E W A G	N E W A G	N E W A G	1
2	GOSAU	1911	Gosausee	Hallstatt	Upper Austria	TE	ic	R/S	17	50	23	24700/675	H	60	V	O K A	Stern & Hafferl	Stern & Hafferl	2
3	WIESTAL	1913	Almbach	Hallein	Salzburg	PG		R	28	66	12	800/n	H	470	V	Municipality Salzburg	Müller - Georgini	Municipality Salzburg	3
4	LANGHALSEN	1924	Gr.Mühl	Rohrbach	Upper Austria	PG		R	17	117	10	800/220	H	400	V	O K A	G. Beurle	Spychinger & Harttmann	4
5	STRUBKLAMM	1924	Almbach	Hallein	Salzburg	PG		R	36	86	9	270/n	H	300/30 } 330	L/V	Municipality Salzburg	Mayrhofer	Pittel & Brausewetter	5
6	LANGMANN	1925	Teigitsch	Voitsberg	Styria	PG		R	26	85	12	320/69	H	160/40) 200	V/L	S T E W E A G	S T E W E A G	Steirisches Wasserbausyndikat	6
7	SPULLERSEE SOUTH	1925 / 1965 a)	Tr. Alfenz	Bludenz	Vorarlberg	PG		R	39	298	66	13100/535	H	37	L	Federal Railways	Federal Railways	Innerebner & Mayer	7
8	Spullersee North	1925 / 1965 a)	Tr. Alfenz	Bludenz	Vorarlberg	PG		R	28	200	27	"	H	-	-	Federal Railways	Federal Railways	Innerebner & Mayer	8
9	PERNEGG	1927	Mur	Bruck/Mur	Styria	PG/TE		R	25	161	24/7	1650/210	H	1500	V	S T E W E A G	S T E W E A G	n	9
10	MIXNITZ	1931	Mur	Bruck/Mur	Styria	PG/TE		R	12	143	8/15	550/180	H	1500	V	S T E W E A G	S T E W E A G	n	10
11	PACK	1931	Tr.Teigitsch	Köflach	Styria	PG/TE		R	33	183/90	39/5	5600/580	H	190	V	S T E W E A G	S T E W E A G	Alpenland Tiefbau	11
12	VERMUNT	1931	Ill	Schruns	Vorarlberg	PG		R	53	386	[illegible]	5200/360	H	129/46) 175	L/V	V I W	Lalmayer & Co	J.V. Universale-Dyckerhoff et alia	12
13	ENZINGERBODEN	1940	Stubache	Mittersill	Salzburg	PG		R	29	68	11	250/60	H	140	L	Federal Railways	Federal Railways	Universale	13
14	KIRCHBICHL	1941	Inn	Wörgl	Tyrol	PG		S	17	106	8	3500/7000	H	2000	V	T I W A G	Innerebner & Mayer	Innerebner & Mayer	14
15	SCHWABECK	1943	Drau	Völkermarkt	Carinthia	PG		R	34	141	160	26000/1600	H	3500	V	Ö D K	Alpenelektrowerke Grzywienski	Ast & Co	15
16	MÖTSCHLACH	1944	Mur	Bruck/Mur	Styria	PG		S	19	53	10	540/170	H	1200	V	S T E W E A G	S T E W E A G	n	16
17	GERLOS	1945 (1964)	Gerlosbach	Zell/Ziller	Tyrol	VA (+PG)		R	39	69	10 +22	880/125	H	245	L/V	T K W	Alpenelektrowerke - TKW	Unionbau	17
18	LAVAMÜND	1945	Drau	Völkermarkt	Carinthia	PG		R	19	144	52	5000/1200	H	3500	V	Ö D K	Alpenelektrowerke	Ast & Co	18
19	STANING	1946	Enns	Steyr	Upper/Lower Austria	PG		S	27	160	72	14100/2500	H	3500	V	E K W	Siemens	Holzmann	19
20	BÜRG	1947	Kapruner Ache	Zell/See	Salzburg	PG		R	19	73	11	236/105	H	108	L/V	T K W	T K W	J.V. Rella et alia	20
21	MÜHLRADING	1948	Enns	Steyr	Upper/Lower Austria	PG		S	21	200	75	4900/1100	H	3500	V	E K W	Siemens	Holzmann	21
22	SILVRETTA	1948	Ill	Schruns	Vorarlberg	PG		R	80	432	407	39100/1310	H	104/61) 165	L/V	V I W	V I W - Lalmayer	Kunz - Beton Monierbau	22
23	Biel	1948	Ill	Schruns	Vorarlberg	TE	ic	R/S	25	730	375	"	H	-	-	V I W	V I W - Lalmayer	Kunz - Beton Monierbau	23
24	HOLLERSBACH	1949	Hollersbach	Mittersill	Salzburg	TE	ie	R/S	16	87	16	200/n	H	200	L/V	S A F E	S A F E - Interplan	Hinteregger - Fischer	24
25	SALZA	1949	Tr. Enns	Liezen	Styria	VA		R	53	121	23	11000/800	H	140/8) 148	L/V	S T E W E A G	S T E W E A G	Mayreder-Teiml & Spitzy	25

NOTES
FOOTNOTES

a) Dam of 1925 raised by 4 m in 1965

DoKW	Österreichische Donaukraftwerke AG
EKW	Ennskraftwerke AG
KELAG	Kärntner Elektrizitäts AG
NEWAG	Niederösterreichische Elektrizitätswerke AG
ÖDK	Österreichische Draukraftwerke AG
OKA	Oberösterreichische Kraftwerke AG
SAFE	Salzburger Aktiengesellschaft f. Elektrizitätswirtschaft
STEWEAG	Steirische Wasserkraft- und Elektrizitäts AG
TIWAG	Tiroler Wasserkraftwerke AG
TKW	Tauernkraftwerke AG
VIW	Vorarlberger Illwerke AG
VKW	Vorarlberger Kraftwerke AG
J.V.	Joint Venture
n	no data available

REGISTRE DES BARRAGES EN AUTRICHE
REGISTER OF DAMS IN AUSTRIA

FOLIO No. 2

50

1 LIGNE *LINE* No.	2 NOM DU BARRAGE *NAME OF DAM*	3 ANNÉE D'ACHÈVEMENT *YEAR OF COMPLETION*	4 SITUATION – *LOCATION*: COURS D'EAU *RIVER*	5 SITUATION – *LOCATION*: VILLE LA PLUS PROCHE *NEAREST CITY*	6 SITUATION – *LOCATION*: ÉTAT PROVINCE OU DÉPARTEMENT *STATE PROVINCE OR COUNTRY*	7 TYPE	8 SITUATION ET TYPE D'ÉTANCHÉITÉ *POSITION AND NATURE OF SEALING ELEMENT*	9 FONDATION *FOUNDATION*	10 HAUTEUR AU DESSUS DE LA PLUS BASSE FONDATION *HEIGHT ABOVE LOWEST FOUNDATION* (m)	11 LONGUEUR DE CRÊTE *LENGTH OF CREST* (m)	12 VOLUME DU BARRAGE *VOLUME CONTENT OF DAM* ($10^3 m^3$)	13 CAPACITÉ TOTALE DU RÉSERVOIR / SURFACE DU RÉSERVOIR *GROSS CAPACITY OF RESERVOIR / RESERVOIR AREA* ($10^3 m^3$)/($10^3 m^2$)	14 DESTINATION *PURPOSE*	15 CAPACITÉ MAXIMALE DES ÉVACUATEURS *MAXIMUM DISCHARGE CAPACITY OF SPILLWAYS* (m^3/s)	16 TYPE DES ÉVACUATEURS *TYPE OF SPILLWAYS*	17 PROPRIÉTAIRE *OWNER*	18 BUREAU D'ÉTUDES *ENGINEERING BY*	19 CONSTRUCTEUR *CONSTRUCTION BY*	LIGNE *LINE* No.
1	TERNBERG	1949	Enns	Steyr	Upper Austria	PG		R	29	14o	95	5900/7oo	H	25oo	V	E K W	Stahlwerke Linz (VÖEST)	Ast & Co	1
2	GROSSRAMING	195o	Enns	Weyer	Upper Austria	PG		R	41	122	225	136oo/122o	H	242o	V	E K W	Siemens	Kunz - Rella	2
3	HIERZMANN	195o	Teigitsch	Köflach	Styria	VA		R	58	172	43	76oo/52o	H	18o/2o) 2oo	L/V	S T E W E A G	S T E W E A G	Ast - Universale	3
4	RANNA	195o	Ranna	Rohrbach	Upper Austria	VA		R	45	126	32	235o/3oo	H	16o	L	O K A	Beurle - Grengg	Ferro Betonit - Teiml & Spitzy	4
5	BÄCHENTAL	195o	Dürrach	Jenbach	Tyrol	VA		R	34	7o	3	none	H	15o	L	T I W A G	T I W A G	Ast & Co	5
6	LIMBERG	1951	Kapruner Ache	Zell/See	Salzburg	VA		R	12o	357	446	86ooo/153o	H	9o/26) 116	V/L	T K W	T K W	J.V. Rella et alia	6
7	MÖLL	1952	Möll	Heiligenblut	Carinthia	VA		R	93	164	35	38oo/21o	H	64) 274	V	T K W	T K W	Porr	7
8	Margaritze	1952	Möll	Heiligenblut	Carinthia	PG		R	39	17o	33	"	H	21o)	L	T K W	T K W	Porr	8
9	THURNBERG	1952	Kamp	Horn	Lower Austria	PG/TE	fc	R/S	25	248	23)/46) 69	25oo/8oo	H	5oo	V	N E W A G	Siemens Bautechnik	Mayreder Kraus	9
10	WEISSEE	1952	tr. Stubache	Mittersill	Salzburg	PG		R	39	235	64	16ooo/5oo	H	23	L	Federal Railways	Federal Railways	Kunz	10
11	DOBRA	1953	Kamp	Zwettl	Lower Austria	VA		R	52	234	9o	21ooo/15oo	H	5oo/8o	L/V	N E W A G	Siemens Bautechnik	Rella	11
12	ROSENAU	1953	Enns	Steyr	Upper Austria	PG		R	25	14o	1oo	68oo/1ooo	H	2575	V	E K W	E K W	Mayreder-Hamberger-Ast	12
13	WIEDERSCHWING	1953	Weissenbach	Villach	Carinthia	VA		R	3o	74	8	12oo/n	H	1o8	L/V	K E L A G	K E L A G	Mayreder, Teiml & Spitzy	13
14	BRAUNAU-SIMBACH *)	1954	Inn	Braunau	Upper Austria/Bavaria	PG		S	22	24o	14o	38ooo/85oo	H	62oo	V	Österr.-Bayer. Kraftwerke AG	Ö B K	J.V. Ast & Co - Sager Wörner et alia	14
15	GSTATTERBODEN	1955	Enns	Hieflau	Styria	PG		S	18	45	9	84o/17o	H	1ooo	V	S T E W E A G	S T E W E A G	Mayreder, Teiml & Spitzy	15
16	MOOSER	1955	Kapruner Ache	Zell/See	Salzburg	PG		R	1o7	494	665	87ooo/166o	H	13o) 16o	V	T K W	T K W	J.V. Rella et alia	16
17	Drossen	1955	Kapruner Ache	Zell/See	Salzburg	VA		R	112	357	355	"	H	3o)	V	T K W	T K W	J.V. Rella et alia	17
18	JOCHENSTEIN *)	1956	Danube	Engelhartszell	Upper Austria/Bavaria	PG		R	2o	383	44o	5oooo/75oo	H.N	11ooo	V	Donaukraftwerk Jochenstein	D K J	J.V. Philipp Holzmann - Rella et alia	18
19	OTTENSTEIN	1956	Kamp	Zwettl	Lower Austria	VA		R	69	24o	124	73ooo/429o	H	436	V	N E W A G	Siemens Bautechnik	J.V. Rella et alia	19
20	RUNSERAU	1956	Inn	Landeck	Tyrol	PG		R/S	16	52	14	9oo/3ooo	H	75o	V	T I W A G	T I W A G	Rella - Hinteregger - Polensky - Unionbau	20
21	GROSSER MÜHLDORFERSEE	1957	tr. Möll	Spittal	Carinthia	PG		R	46	433	153	77oo/21o	H	13/4) 17	L/V	Ö D K	Ö D K	J.V. Universale et alia	21
22	ROTGÜLDENSEE	1957	tr. Mur	St. Michael	Salzburg	ER	ia	R/S	18	112	35	3ooo/29o	H	61	L/V	S A F E	S A F E - Posch	Polensky Zöllner - Heinz - Ferro Betonit	22
23	AMERSEE	1958	tr. Salzach	Mittersill	Salzburg	PG		R	3o	162	2o	55oo/2o6	H	8	L	Federal Railways	Federal Railways	Kunz - Unionbau	23
24	FREIBACH	1958	tr. Drau	Ferlach	Carinthia	TE	ic	R/S	41	15o	235	55oo/39o	H	2oo/8 } 2o8	L/V	K E L A G	K E L A G	Isola - Weyss & Freitag	24
25	HOCHALMSEE	1958	tr. Möll	Spittal	Carinthia	PG/TE	ic	R	24	237/12o	29/5	41oo/16o	H	15	L/V	Ö D K	Ö D K	J.V. Universale et alia	25

NOTES
FOOTNOTES

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STEWEAG Steirische Wasserkraft- und Elektrizitäts AG
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J.V. Joint Venture
n no data available

REGISTRE DES BARRAGES EN AUTRICHE
REGISTER OF DAMS IN AUSTRIA

FOLIO No. 3

51

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	
LIGNE *LINE* No.	NOM DU BARRAGE *NAME OF DAM*	ANNÉE D'ACHÈVEMENT *YEAR OF COMPLETION*	SITUATION – *LOCATION*: COURS D'EAU *RIVER*	VILLE LA PLUS PROCHE *NEAREST CITY*	ÉTAT PROVINCE OU DÉPARTEMENT *STATE PROVINCE OR COUNTRY*	TYPE	SITUATION ET TYPE D'ÉTANCHÉITÉ *POSITION AND NATURE OF SEALING ELEMENT*	FONDATION *FOUNDATION*	HAUTEUR AU DESSUS DE LA PLUS BASSE FONDATION *HEIGHT ABOVE LOWEST FOUNDATION* (m)	LONGUEUR DE CRÊTE *LENGTH OF CREST* (m)	VOLUME DU BARRAGE *VOLUME CONTENT OF DAM* ($10^3 m^3$)	CAPACITÉ TOTALE DU RÉSERVOIR / SURFACE DU RÉSERVOIR *GROSS CAPACITY OF RESERVOIR / RESERVOIR AREA* ($10^3 m^3$)/($10^3 m^2$)	DESTINATION *PURPOSE*	CAPACITÉ MAXIMALE DES ÉVACUATEURS *MAXIMUM DISCHARGE CAPACITY OF SPILLWAYS* (m^3/s)	TYPE DES ÉVACUATEURS *TYPE OF SPILLWAYS*	PROPRIÉTAIRE *OWNER*	BUREAU D'ÉTUDES *ENGINEERING BY*	CONSTRUCTEUR *CONSTRUCTION BY*	LIGNE *LINE* No.
1	KLEINER MÜHLDORFERSEE	1958	tr. Möll	Spittal	Carinthia	PG		R	41	159	60	2800/110	H	16	L/V	Ö D K	Ö D K	J.V. Universale et alia	1
2	LÜNERSEE	1958	tr. Ill	Bludenz	Vorarlberg	PG		R	30	380	41	94000/1530	H	12) / 20) 32	L/V	V I W	V I W	Kunz & Co	2
3	RADLSEE	1958	tr. Lieser	Gmünd	Carinthia	ER	ic	R	16	212	22	2600/120	H	21	L/V	Ö D K	Ö D K	J.V. Porr et alia	3
4	SALZPLATTEN	1958	tr. Salzach	Mittersill	Salzburg	PG		R	17	88	5	1100/50	H	4	L	Federal Railways	Federal Railways	Kunz - Unionbau	4
5	LUTZ	1959	Lutz	Bludenz	Vorarlberg	PG		R	19	40	4	129/60	H	570	V	V K W	V K W	Hinteregger	5
6	YBBS-PERSENBEUG	1959	Danube	Ybbs	Lower/Upper Austria	PG		R	25	437	690	74000/10000	H,N	11200	V	D o K W	D o K W	J.V. Porr-Rella et alia	6
7	ESSLING	1960	Enns	Hieflau	Styria	PG		R	19	44	10	950/180	H	1400	V	S T E W E A G	S T E W E A G	Mayreder - Teiml & Spitzy	7
8	EDLING	1962	Drau	Völkermarkt	Carinthia	PG		R	36	104	168	83000/10500	H	3500	V	Ö D K	Ö D K	J.V. Ast - Mayreder et alia	8
9	LOSENSTEIN	1962	Enns	Steyr	Upper Austria	PG		R	30	102	86	6600/730	H	2500	V	E K W	E K W	Unionbau	9
10	SCHÄRDING-NEUHAUS *)	1962	Inn	Schärding	Upper Austria/Bavaria	PG		S	25	241	168	38000/5900	H	6800	V	Österr. Bayerische Kraftwerke AG	Ö B K	J.V. Rella-Holzmann et alia	10
11	DIESSBACH	1963	tr. Saalach	Saalfelden	Salzburg	ER	fa	R	36	204	165	5000/250	H	61) / 6) 67	L/V	S A F E	S A F E	J.V. Hinteregger et. alia	11
12	ASCHACH	1964	Danube	Eferding	Upper Austria	PG		R	34	398	1050	114000/9500	H,N	8920	V	D o K W	D o K W	J.V. Rella - Porr - Dyckerhoff et alia	12
13	GRALLA	1964	Mur	Leibnitz	Styria	PG		S	18	91	23	1300/320	H	1250	V	S T E W E A G	S T E W E A G	Porr - Hinteregger	13
14	GEPATSCH	1965	Faggenbach	Landeck	Tyrol	ER	ie	R/S	153	600	7100	140000/2600	H	250) / 75) 325	L/V	T I W A G	T I W A G	J.V. Porr-Schaffir Muglin - Hochtief et alia	14
15	GROSSREIFLING	1965	Enns	Hieflau	Styria	PG		R/S	20	45	11	1350/220	H	1400	V	S T E W E A G	S T E W E A G	Rella - Mayreder - Teiml & Spitzy	15
16	KOPS	1965	tr. Ill	Schruns	Vorarlberg	VA/PG		R	122 / 43	400) / 214) 614	485) / 178) 663	44600/1000	H	42) / 60) 102	L/V	V I W	V I W - Lombardi&Gellera	J.V. Porr-Losinger et alia	16
17	THURNSDORF	1965	Enns	Steyr	Upper/Lower Austria	PG		S	21	94	32	6400/n	H	3500	V	E K W	E K W	Mayreder - Hamberger- Unionbau	17
18	DURLASSBODEN	1966	Gerlosbach	Zell/Ziller	Tyrol	TE	ie	R/S	83	470	2520	53500/1880	H	200) / 45) 245	V	T K W	T K W	J.V. Porr et alia	18
19	PASSAU-INGLING*)	1966	Inn	Passau	Upper Austria/Bavaria	PG		R	22	242	135	22000/3900	H	7400	V	Österr. Bayerische Kraftwerke AG	Ö B K	J.V. Rella-Holzmann et alia	19
20	GARSTEN	1967	Enns	Steyr	Upper Austria	PG		R/S	23	89	65	3700/600	H	2600	V	E K W	E K W	Mayreder - Hamberger - Unionbau	20
21	RAGGAL	1967	Lutz	Bludenz	Vorarlberg	PG		R	48	105	42	2400/160	H	615	V	V K W	V K W	Kunz & Co	21
22	WANDAU	1967	Enns	Hieflau	Styria	PG		R/S	21	45	11	1200/150	H	1100	V	S T E W E A G	S T E W E A G	Rella - Mayreder - Teiml & Spitzy	22
23	STILLUP (EBERLASTE)	1968	tr. Zemm	Mayrhofen	Tyrol	TE	ia	S	28	480	790	8200/600	H	450) / 55) 505	L/V	T K W	T K W	J.V. Oberranzmeyer, Strabag et alia	23
24	FEISTRITZ	1968	Drau	Klagenfurt	Carinthia	PG		R/S	38	95	160	50000/4800	H	3100	V	Ö D K	Ö D K	Mayreder - Porr - Isola Boravia	24
25	WALLSEE	1968	Danube	Grein	Upper/Lower Austria	PG		R	32	470	905	53000/7800	H,N	8600/2600	V/L	D o K W	D o K W	J.V. Mayreder-Rella-Porr-Hofman Maculan et alia	25

NOTES
FOOTNOTES

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J.V. Joint Venture
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REGISTRE DES BARRAGES EN AUTRICHE
REGISTER OF DAMS IN AUSTRIA

FOLIO No. 4

52

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	
LIGNE / *LINE* No.	NOM DU BARRAGE / *NAME OF DAM*	ANNÉE D'ACHÈVEMENT / *YEAR OF COMPLETION*	SITUATION – *LOCATION*: COURS D'EAU / *RIVER*	VILLE LA PLUS PROCHE / *NEAREST CITY*	ÉTAT PROVINCE OU DÉPARTEMENT / *STATE PROVINCE OR COUNTRY*	TYPE	SITUATION ET TYPE D'ÉTANCHÉITÉ / *POSITION AND NATURE OF SEALING ELEMENT*	FONDATION / *FOUNDATION*	HAUTEUR AU DESSUS DE LA PLUS BASSE FONDATION / *HEIGHT ABOVE LOWEST FOUNDATION* (m)	LONGUEUR DE CRÊTE / *LENGTH OF CREST* (m)	VOLUME DU BARRAGE / *VOLUME CONTENT OF DAM* (10^3 m^3)	CAPACITÉ TOTALE DU RÉSERVOIR / SURFACE DU RÉSERVOIR / *GROSS CAPACITY OF RESERVOIR / RESERVOIR AREA* (10^3 m^3) / (10^3 m^2)	DESTINATION / *PURPOSE*	CAPACITÉ MAXIMALE DES ÉVACUATEURS / *MAXIMUM DISCHARGE CAPACITY OF SPILLWAYS* (m^3/s)	TYPE DES ÉVACUATEURS / *TYPE OF SPILLWAYS*	PROPRIÉTAIRE / *OWNER*	BUREAU D'ÉTUDES / *ENGINEERING BY*	CONSTRUCTEUR / *CONSTRUCTION BY*	LIGNE / *LINE* No.
1	GMUNDEN	1969	Traun	Gmunden	Upper Austria	PG		R	21	103	35	5140 / 25700	H	1300	V	O K A	Siemens-Bautechnik	Hinteregger-Stern & Hafferl	1
2	WEYER	1969	Enns	Weyer	Upper Austria	PG		R	26	54	70	5400 / 700	H	2280	V	E K W	E K W	Mayreder-Hamberger-Union	2
3	SCHLEGEIS	1971	tr.Zemmbach	Mayrhofen	Tyrol	VA		R	131	725	960	129000 / 2200	H	324) / 146) 470	L / V	T K W	T K W'	J.V. Rella et alia	3
4	URSTEIN	1971	Salzach	Hallein	Salzburg	PG		S	19	85	n	2200 / 560	H	2730	V	S A F E	S A F E - Flögl	Hinteregger-Porr-Heinz	4
5	WURTEN	1971	tr.Fragant	Obervellach	Carinthia	TE	fa	R/S	42	282	265	2800 / 220	H	160) / 60) 220	L / V	K E L A G	K E L A G	Negrelli	5
6	SCHÖNAU	1972	Enns	Weyer	Upper Austria	PG		R	25	95	60	3300 / 400	H	2240	V	E K W	E K W	Hinteregger-Ferro Betonit	6
7	OSCHENIKSEE	1972 / 1978b)	tr. Fragant	Obervellach	Carinthia	ER	fa	R/S	116 / 81	530	2250	33000 / 430	H	6	L	K E L A G	K E L A G	Soravia-Isola-Strabag	7
8	OTTENSHEIM	1973	Danube	Linz	Upper Austria	PG		R	31	408	800	34000 / 5000	H,N	5940 / 2980	V / L	D o K W	D o K W	J.V. Mayreder-Rella-Porr-Hofman Maculan et alia	8
9	ST. MARTIN	1973	Drau	Villach	Carinthia	PG		R/S	26	73	64	19000 / 2200	H	3100	V	Ö D K	Ö D K	J.V. Mayreder-Porr et alia	9
10	TAUERNMOOS a)	1973	Stubache	Mittersill	Salzburg	PG		R	53	1100	250	57000 / 1850	H	108) / 32) 140	L / V	Federal Railways	Federal Railways	J.V. Stuag et alia	10
11	GABERSDORF	1974	Mur	Leibnitz	Styria	PG		S	18	85	24	1600 / 430	H	1250	V	S T E W E A G	S T E W E A G	Hinteregger - Teiml & Spitzy-Porr-Universale	11
12	GALGENBICHL	1974	Malta	Gmünd	Carinthia	TE / PG	fa	R	50 / 15	115 / 85	65 / 7	4800 / 270	H	30) / 196) 226	V / L	Ö D K	Ö D K	Oberranzmeyer	12
13	GROSSEE	1974 / 1978c)	tr. Möll	Heiligenblut	Carinthia	ER	fa	R	57	445	740	1330 / 310	H	8	L	K E L A G	K E L A G	Beyer - Strabag	13
14	HOCHWURTEN	1974 / 1979c)	tr. Fragant	Obervellach	Carinthia	TE	fa	R/S	55	260	600	1270 / 425	H	21	L	K E L A G	K E L A G	Soravia - Isola- Strabag	14
15	FERLACH	1975	Drau	Ferlach	Carinthia	PG		R/S	40	97	93	33000 / 3900	H	3300	V	Ö D K	Ö D K	J.V. Mayreder-Porr et alia	15
16	GÖSSKAR	1975	tr. Malta	Gmünd	Carinthia	TE	fa	R/S	55	260	540	2000 / 120	H	96) / 38) 134	L / V	Ö D K	Ö D K	Rella - Strabag	16
17	KLAUS	1975	Steyr	Kirchdorf	Upper Austria	VA		R	55	188	39	12600 / 900	H,C	340) / 418) 758	L / V	E K W	E K W - T K W	Ferro Betonit-Held & Franke	17
18	LATSCHAU	1975	tr. Ill	Schruns	Vorarlberg	TE	fa	R/S	50	500	865	2300 / 100	H	75	L/V	V I W	V I W	J.V. Hilti-Jäger-Innerebner-Kunz	18
19	ALTENWÖRTH	1976	Danube	Tulln	Lower Austria	PG		R	37	457	1280	93000 / 11000	H,N	9300 / 1900	V / L	D o K W	D o K W	J.V. Mayreder-Rella-Porr-Hofman Maculan et alia	19
20	KÖLNBREIN	1977	Malta	Gmünd	Carinthia	VA		R	200	626	1580	205000 / 2550	H	138) / 50) 188	L / V	Ö D K	Ö D K - T K W	J.V. Porr et alia	20
21	OBERVOGAU	1977	Mur	Leibnitz	Styria	PG		R	17	93	23	1100 / 370	H	1250	V	S T E W E A G	S T E W E A G	Tiefbau AG	21
22	ROTLECH	1977	tr. Lech	Reutte	Tyrol	PG / ER	ic	R	32	80) / 48) 128	14 / 11	1260 / n	H	200	V	Elektrizitätswerk Reutte	Siemens - Bautechnik	Storf	22
23	BOLGENACH	1978	Bolgenach	Bregenz	Vorarlberg	TE	ie	R/S	92	240	1200	8350 / 240	H	530	V	V K W	V K W - V I W	Hilti Jehle-Jäger-Kunz Universale	23
24	SÖLK	1978	Grosse Sölk	Schladming	Styria	VA		R	39	128	17	1700 / 130	H	200	L	S T E W E A G	S T E W E A G - T K W	Mayreder - Ast	24
25	SUBERSACH	1978	Subersach	Bregenz	Vorarlberg	PG		R	15	95	8	150 / 30	H	285	L	V K W	V K W - V I W	Oberranzmeyer	25

NOTES
FOOTNOTES

a) replaced and submerged ealier dam of same name but 2om lower, built from 1926 to 1929
b) stepwise construction as planned; first dam of 1972 raised in 1973, 1976 and 1979 by 7+20+16m.
c) Dam of 1974 raised by 1om in 1978/79.

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n no data available

REGISTRE DES BARRAGES EN AUTRICHE
REGISTER OF DAMS IN AUSTRIA

53

FOLIO No. 5

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	
LIGNE *LINE* No.	NOM DU BARRAGE *NAME OF DAM*	ANNÉE D'ACHÈVEMENT *YEAR OF COMPLETION*	SITUATION – *LOCATION*: COURS D'EAU *RIVER*	VILLE LA PLUS PROCHE *NEAREST CITY*	ÉTAT PROVINCE OU DÉPARTEMENT *STATE PROVINCE OR COUNTRY*	TYPE	SITUATION ET TYPE D'ÉTANCHÉITÉ *POSITION AND NATURE OF SEALING ELEMENT*	FONDATION *FOUNDATION*	HAUTEUR AU DESSUS DE LA PLUS BASSE FONDATION *HEIGHT ABOVE LOWEST FOUNDATION* (m)	LONGUEUR DE CRÊTE *LENGTH OF CREST* (m)	VOLUME DU BARRAGE *VOLUME CONTENT OF DAM* (10^3 m^3)	CAPACITÉ TOTALE DU RÉSERVOIR / SURFACE DU RÉSERVOIR *GROSS CAPACITY OF RESERVOIR / RESERVOIR AREA* (10^3 m^3) / (10^3 m^2)	DESTINATION *PURPOSE*	CAPACITÉ MAXIMALE DES ÉVACUATEURS *MAXIMUM DISCHARGE CAPACITY OF SPILLWAYS* (m^3/s)	TYPE DES ÉVACUATEURS *TYPE OF SPILLWAYS*	PROPRIÉTAIRE *OWNER*	BUREAU D'ÉTUDES *ENGINEERING BY*	CONSTRUCTEUR *CONSTRUCTION BY*	LIGNE *LINE* No.
1	ARWINDEN-ASTEN	1979	Danube	Mauthausen	Upper Austria	PG		R	31	395	850	46000/9500	H,N	8460/1040	V/L	D o K W	D o K W	J.V. Mayreder-Rella-Porr Hofman Maculan et alia	1
2	MARCHTRENK	1979	Traun	Wels	Upper Austria	PG		R	38	98	100	5800/720	H	2300	V	O K A	Siemens Bautechnik	J.V. Mayreder et alia	2
3	FINSTERTAL	1980	tr. Nederbach	Ötz	Tyrol	ER	ia	R/S	150	652	4500	60500/10400	H	20)/3) 23	V/L	T I W A G	T I W A G	J.V. Hochtief-Oberranzmeyer-Strabag et alia	3
4	LÄNGENTAL	1980	Nederbach	Ötz	Tyrol	TE	fa	R/S	37	418	400	3300/240	H	106)/20) 126	L/V	T I W A G	T I W A G	Mayreder-Universale-Ilbau-Innerebner	4
5	ANNABRÜCKE	1981	Drau	Klagenfurt	Carinthia	PG		S	40	104	108	36000/3500	H	3300	V	Ö D K	Ö D K	J.V. Mayreder-Porr et alia	5
6	BOCKHARTSEE	1982	tr. Gasteiner Ache	Badgastein	Salzburg	ER	ic	R	33	238	225	14800/410	H	44)/12) 56	L/V	S A F E	S A F E - Siemens Bautechnik	Porr	6
7	BODENDORF	1982	Mur	Murau	Styria	PG		R	23	67	30	900/100	H	560	V	S T E W E A G	S T E W E A G	Hinteregger-Fritz	7
8	PAAL (Bodendorf)	1982	tr. Mur	Murau	Styria	VA-PG		R	39	118	20	300/35	H	200	L/V	S T E W E A G	S T E W E A G	Strabag-TS Bau-Stettin	8
9	MELK	1982	Danube	Melk	Lower Austria	PG		R/S	29	442	900	54000/7500	H,N	11170	V	D o K W	D o K W	J.V. Mayreder-Rella-Porr Hofman Maculan et alia	9
10	SPIELFELD	1982	Mur	Leibnitz	Styria	PG		S	19	99	27	1300/440	H	1660	V	S T E W E A G	S T E W E A G	Universale	10
11	TRAUN-PUCKING	1982	Traun	Linz	Upper Austria	PG		R	45	101	110	7600/830	H	2300	V	O K A	Siemens Bautechnik	J.V. Mayreder et alia	11
12	WEINZÖDL	1982	Mur	Graz	Styria	PG		R	20	93	n	n	H	1800	V	Steiermärkische Elektrizitäts AG (S T E G)	Suiselektra	Ast - Mayreder - VÖEST	12
13	ZIRMSEE	c (1983)	tr. Möll	Heiligenblut	Carinthia	ER	fa	R	44	315	525	870/300	H	12	L	K E L A G	K E L A G	Strabag	13
14	GREIFENSTEIN	c (1984)	Danube	Stockerau	Lower Austria	PG		R/S	31	455	n	37000/10000	H,N	8640/2110	V/L	D o K W	D o K W	J.V. Mayreder-Rella-Porr Hofman Maculan et alia	14
15	MELLACH	c (1985)	Mur	Wildon	Styria	PG		S	20	87	26	1260/300	H	1650	V	S T E W E A G	S T E W E A G	Universale	15
16	ZILLERGRÜNDL	c (1986)	Ziller	Mayrhofen	Tyrol	VA		R	186	506	1355	90000/1410	H	165)/50) 215	L/V	T K W	T K W	J.V. Hofman Maculan et alia	16
17																			17
18																			18
19																			19
20																			20
21																			21
22																			22
23																			23
24																			24
25																			25

NOTES
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J.V. Joint Venture
n no data available

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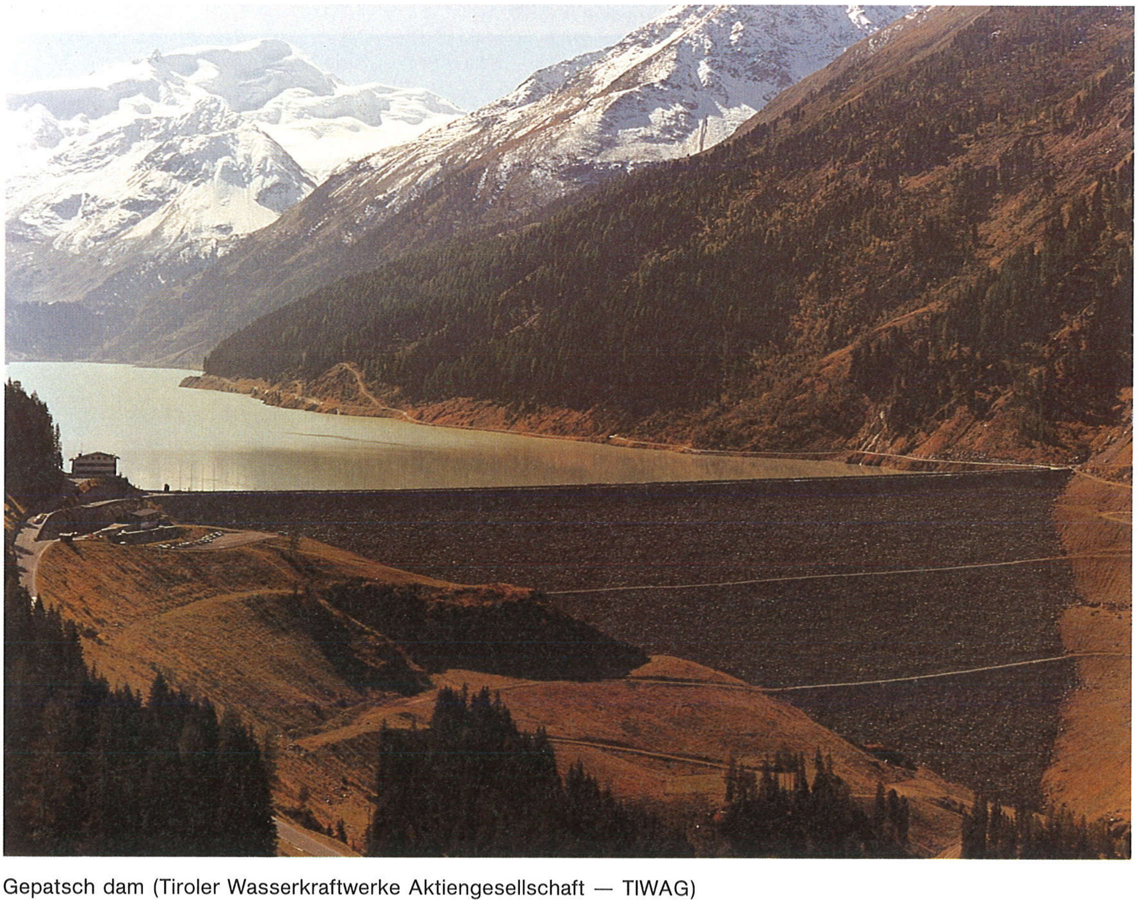
Finstertal dam (centre) and Längental dam (right)
(photo released for publication by BMLV unter Zl. 13080/252 — 1. 6./82)



Gepatsch dam (Tiroler Wasserkraftwerke Aktiengesellschaft — TIWAG)

Mooserboden reservoir with Drossen and Mooser dams as well as Wasserfallboden reservoir with Limberg dam (Tauernkraftwerke Aktiengesellschaft — TKW)
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Margaritze dam (left) and Möll dam (right)

Schlegeis dam (Tauernkraftwerke Aktiengesellschaft — TKW)


Oscheniksee dam (Kärntner Elektrizitäts-Aktiengesellschaft — KELAG)


Tauernmoos dam (Österreichische Bundesbahnen — ÖBB)

Kölnbrein dam

Annabrücke dam and power plant (Österreichische Draukraftwerke Aktiengesellschaft — ÖDK)
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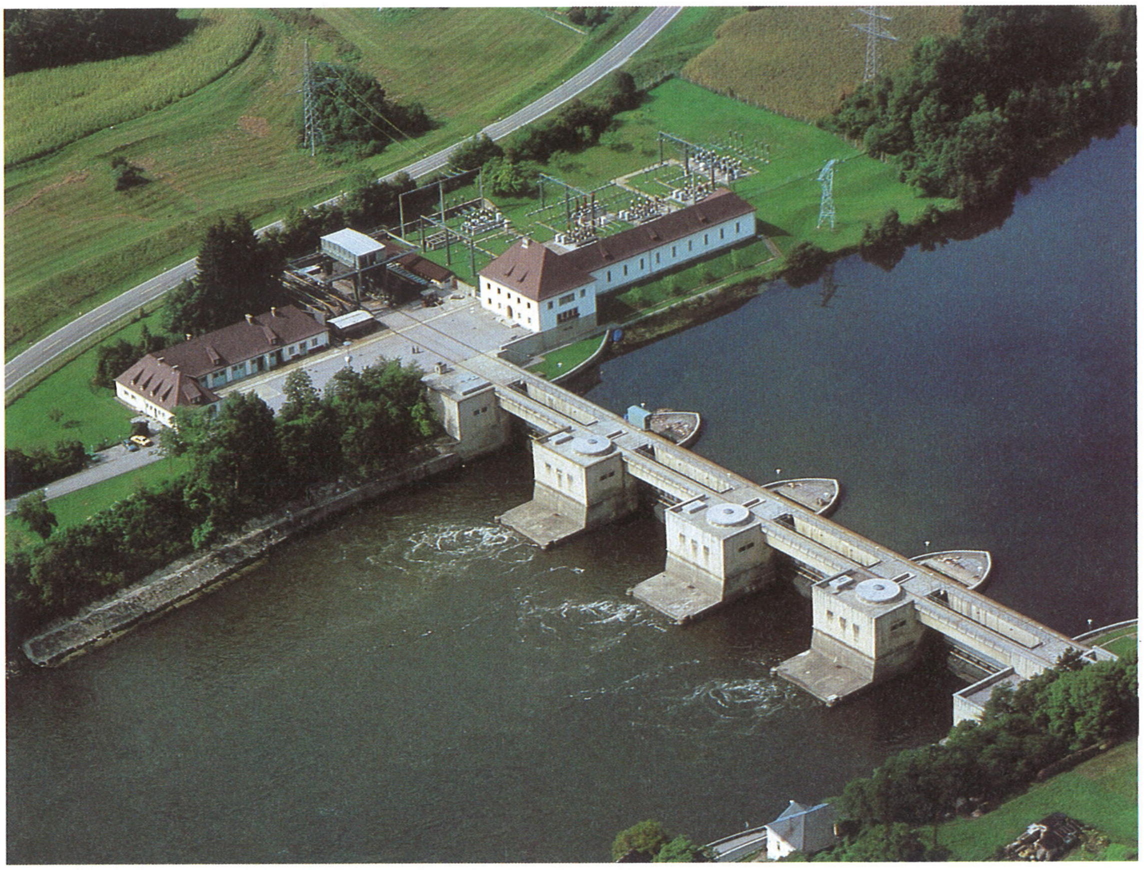

Lavamünd power station on the Drau river, the first pier head power station
(Österreichische Draukraftwerke AG — ÖDK)

Losenstein power station on the Enns river (Ennskraftwerke AG — EKW)

Wallsee-Mitterkirchen power station on the Danube (Österr. Donaukraftwerke AG — DoKW)
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