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Morphological investigations on the lower Salzach River downstream of Salzburg

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ABSTRACT This morphological investigation on the River Salzach, prompted by the intention of a water power company to install hydroelectric plants, consists of a geological and historical review, a study of bed erosion and bed load transport, and some conclusions. Bed erosion is demonstrated by three methods: firstly by analysis of the hydrographs of annual mean water level from several gauges for which about 150 years of staff gauge observations exist; secondly by longitudinal surveys carried out at low water under comparable discharges, and finally by cross section surveys (thalweg or mean bed level of several years). The causes of bed erosion, namely river training, removal of bed material and the installation of upstream supporting weirs are discussed. It is hoped that this case study will be of interest to those investigating similar problems.

INTRODUCTION

The Salzach is the largest tributary of the River Inn, its source is in the Central Alps at a height of 2200 m. At first it flows about 90 km in an eastern direction parallel to the Hohe Tauern where its flow is rapidly increased by several torrents coming from these high mountains (>3000 m) formed of igneous rock, and then it turns sharply to the north. The Nördliche Kalkalpen are crossed in a huge gorge and entering the wide Salzburg Basin, the river reaches the undulating foreland and begins its lower course. The Salzach reaches the Inn after a course of about 225 km. Some 70 km downstream the Inn itself meets the Danube at Passau (Fig.1).

The Salzach is a typical mountain river and it transports a considerable volume of solid material because its channel gradient is steep. The highest point of the basin is the famous Grossglockner (3798 m), the highest peak of Austria, and the altitude at the mouth is 345 m. Although the investigated reaches are located in the lower course in the so-called Alpenvorland, the river maintains its alpine character as far as its mouth. Downstream of Salzburg the River Salzach marks the border between Bavaria and Austria.

The reason for the special research on the channel of the Salzach from the junction with its tributary the Saalach* as far as its confluence with the River Inn was the proposal by an Austrian-

* *The meaning of the name Salzach and that of its tributary Saalach is the same, salty river, although both have not salty but fresh water.*

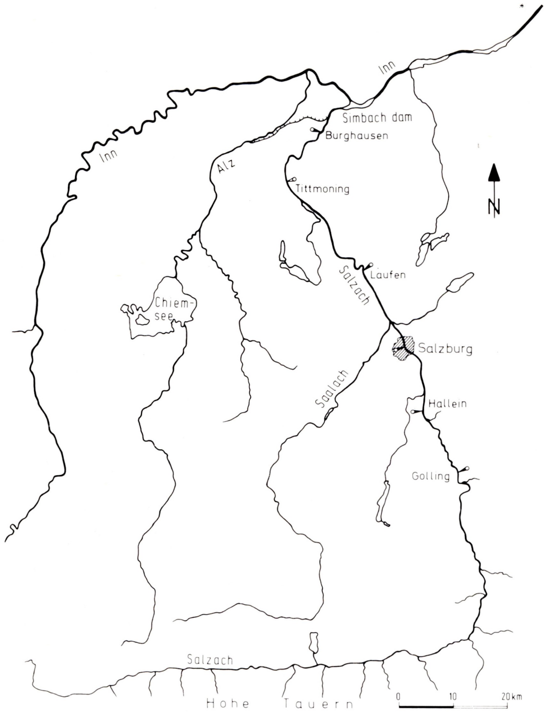

FIG.1 Location map.

Bavarian consortium to build four hydroelectric power plants. In order to predict the resultant changes in river morphology, especially the expected downcutting produced by a lack of bed material, a geological and morphological study of the channel was undertaken. The results should provide an improved knowledge of the sediment balance. The underlying geology has been investigated by numerous boreholes sunk both near and within the channel (Bayer. Landesamt, 1980).

GEOLOGICAL BACKGROUND AND RIVER HISTORY

During the Quaternary when the channel patterns of all alpine rivers were initiated, the Salzburg Basin was on several occasions one of the routes by which glaciers left the Alps to form a foreland glacier. During the interglacials, large meltwater rivers and lakes occupied the area. The same happened after the final Würm glaciation. A system of braided channels and lakes developed between the end moraines and the melting ice, although only a few lakes remain today. From the geological point of view the present river course may be the fourth or fifth "Salzach", taking account of the number of interglacials and a predecessor, since the beginning of the Quaternary. The postglacial Salzach had to cross a series of several lakes but with time they were infilled with silt and clay material ("lake clay") and by fans. These are today represented by the extensive Salzburg Basin and by the basins of Laufen and Tittmoning which are of particular interest in this study.

The present Salzach does not exhibit a natural channel pattern

FIG.2 Portion of an old map dating from 1817.

because it was intensively trained during the last century. An old map from 1817 illustrates the situation before training (Fig.2). Until 1820 the river was largely braided, sometimes with one main channel which changed its course during every flood. Downstream of Salzburg there are three natural rock thresholds where the braided river is embanked, i.e. near the village of Bergheim a threshold of Flysch (sandstone and marl from the Tertiary), near Laufen (sandstones and conglomerates from the Molasse, Tertiary, overlain by moraines) and near Nonnreit.

The narrow gorges at Laufen (Laufen means quickly flowing water or cascade) and Nonnreit are points where the river cuts through moraines of the last glaciation. Above these gorges are the basins discussed previously. The fourth and last narrow gorge is further downstream near Burghausen and is formed by Tertiary rocks and moraines from the Lower Pleistocene, but there is no basin between Nonnreit and the town of Burghausen since there are two gorges in close succession (Fig.3).

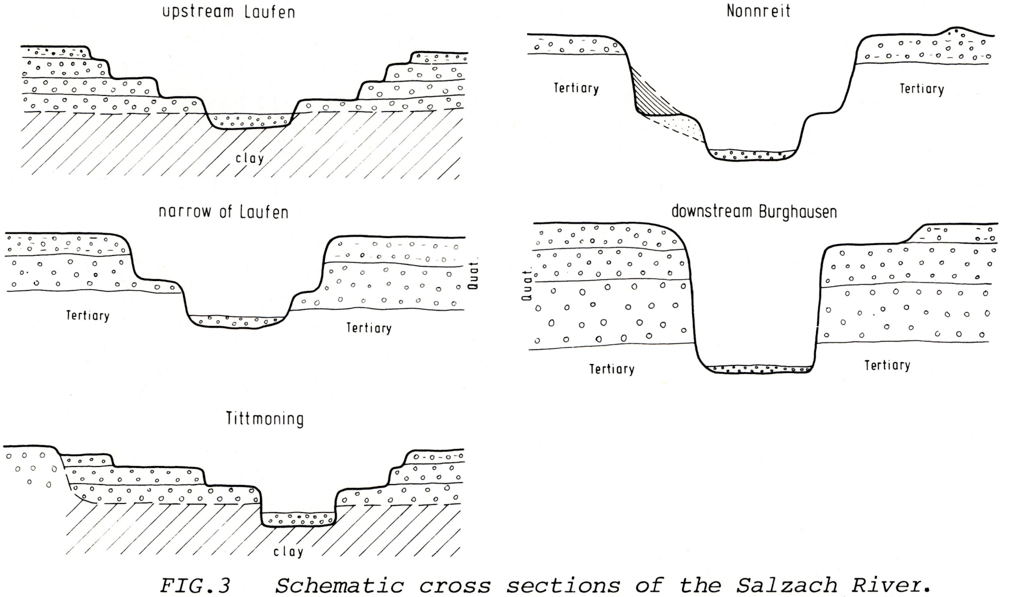

FIG.3 Schematic cross sections of the Salzach River.

As a result of the agreement of 1820 between the Kingdom of Bavaria and the Empire of Austria "for common training of the Rivers Salzach and Saalach", which formed the border between the two countries, the Salzach was trained into a single channel with an average width of 152 m. This in fact proved too broad and from 1873 it was reduced to 113.8 m. Shortening of the river removed the bed load storage provided by the braided reaches and the channel was rapidly incised. Nevertheless, the degree of downcutting was initially restricted because of the undisturbed bed load transport out of the Alps. In addition, the downcutting was retarded by the narrow gorges at Laufen and the hard sandstone outcrops at Burghausen. The Salzach incised a relatively narrow canyon in the former braided area, partly into the very soft silty clay of the silted basins but still retaining a gravel layer of about 1-3 m as protection. Destruction of this thin layer is a permanent danger. The river has subsequently maintained a delicate balance between status quo and incision but there is now a tendency to incise.

BED EROSION

Three different methods have proved suitable for investigating bed erosion:

(a) A general study of the records of annual mean water level from a number of gauges (Oexle, 1933).

(b) Cross section surveys undertaken over several years.

(c) Periodic low water surveys undertaken at comparable discharges.

Hydrographs of annual mean water level at the gauges

In the reach under study there are three gauges, the first in the upper region at Laufen, the second in the middle zone at Tittmoning and the third in the lower region at Burghausen. Records are available since 1826, and analysis can be applied to a series of about 150 years. The data obtained from analysis of the gauge readings only provide preliminary conclusions on the behaviour of the river course because they only relate to the particular location

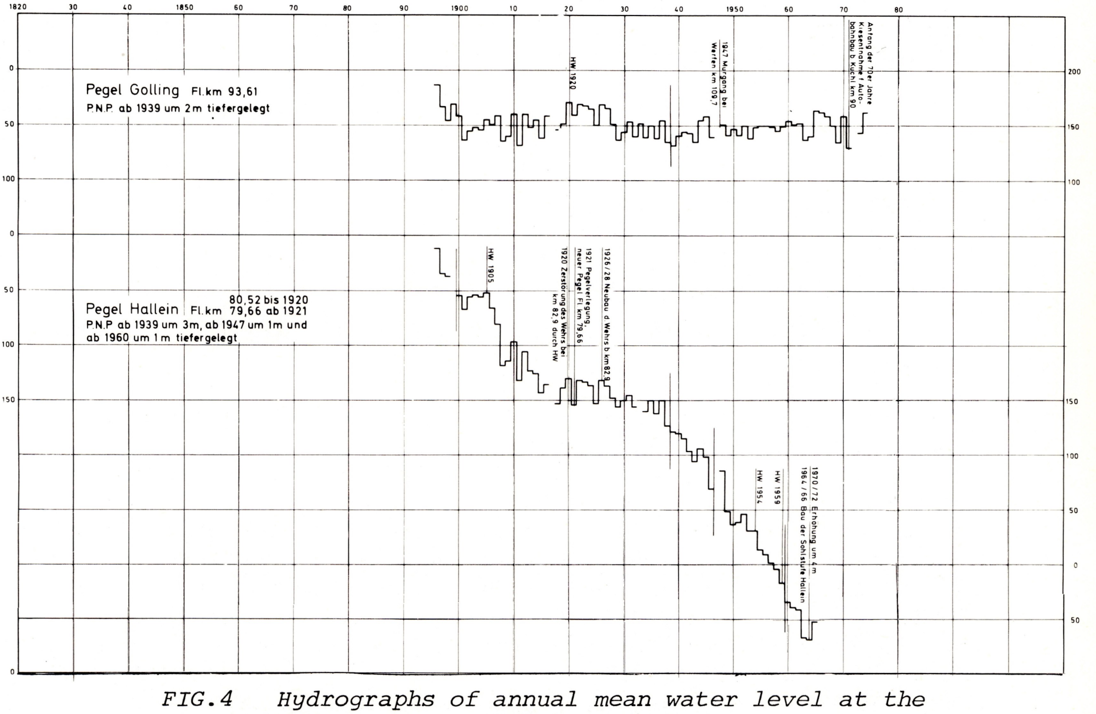

FIG.4 Hydrographs of annual mean water level at the gauges between Golling and Burghausen.

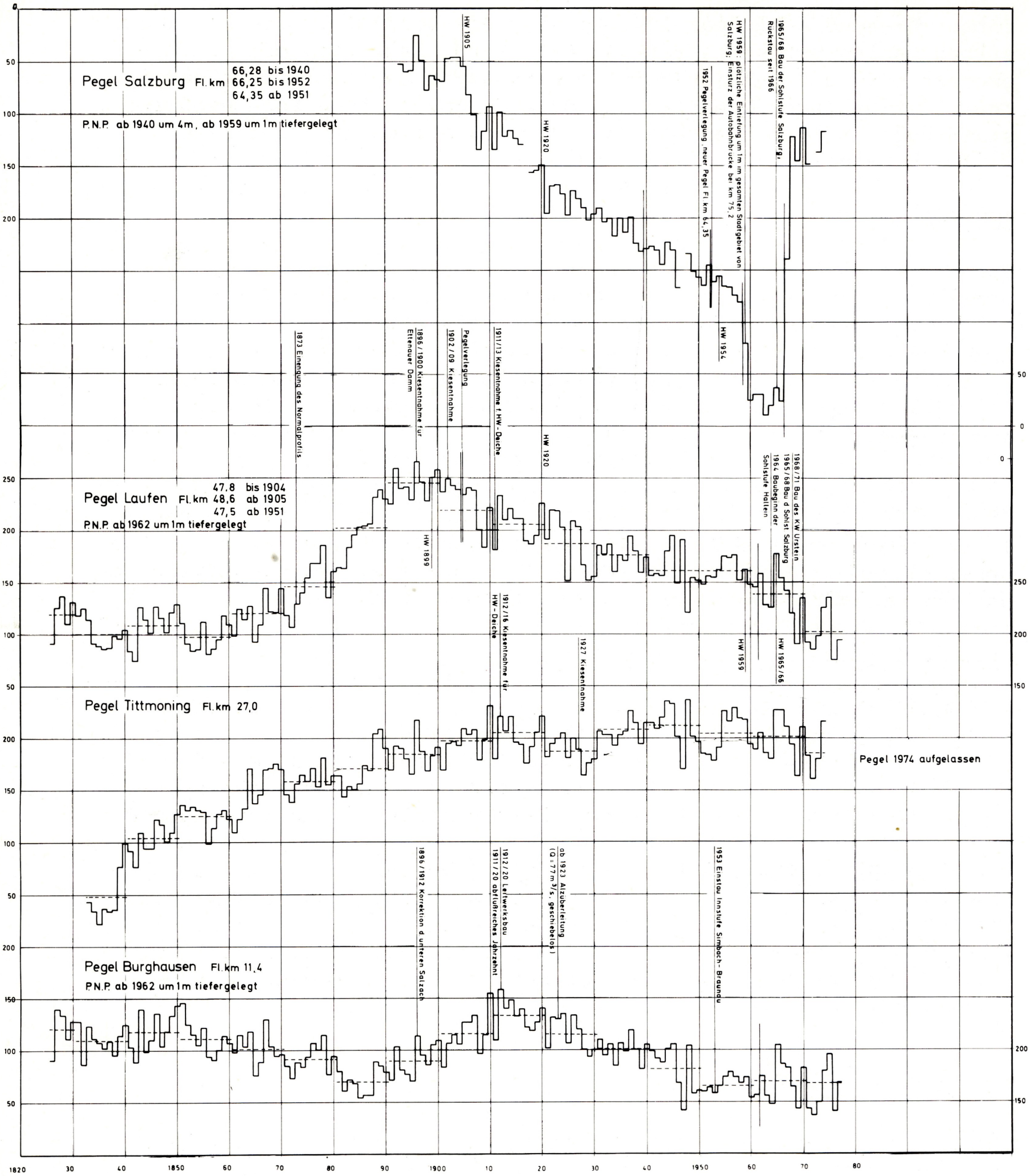

FIG.4 continued

of the gauge. To extend the analysis data have also been obtained from the upstream gauges at Golling, Hallein and Salzburg in Austria for which observations have been published since 1985 (Fig.4). Whilst the highest gauge at Golling exhibits a stable level over a long period, the bed level at the Hallein gauge had been lowered by about 3.20 m by 1965, largely as a result of river training in the last century and removal of bed material in the tributaries.

The erosion at the gauge at Salzburg amounted to 5.20 m by 1960.

The flood of 1959 penetrated the hard gravel layer. The result was a rapid 1 m degradation of bed level within the city of Salzburg cutting into the fine grained lake sediments with the final effect that a highway bridge collapsed near Salzburg (Kerschbaumer, 1969). To stop the erosion between Salzburg and Hallein weirs were constructed near Salzburg and Hallein (Mittellehner, 1978) and one hydroelectric plant was built near Urstein (Flögl & Neururer, 1970) during the years 1964-1972.

The aggradation evident for the gauges at Laufen and Tittmoning is the result of bed load deposition from the upstream works, promoted by the backwater of the gorges near Laufen and Nonnreit. The planned lowering of river bed was only attained by dredging and constraining the channel. The degradation commencing at the end of the fifties is a clear expression of the deficit of bed material. The aggradation in the region of Tittmoning initially led to a downstream degradation near Burghausen, but the upstream training then was followed by an increase in hydrograph levels. The subsequent degradation of this accumulation was then achieved by the construction of jetties and promoted by inflow of sediment-free water from a canal from the neighbouring River Alz at km 6.5. The state of permanent stability existing since 1950 has been caused by the dam of the Inn power plant near Simbach-Braunau.

Low water surveys and cross section surveys

A more detailed picture of the changes of bed level, especially their development in the longitudinal section, is provided by the lower water surveys undertaken since 1929 and the thalwegs developed from the cross sections. The continuous lowering of the comparable low water stages and the thalwegs clearly reflect the interrupted movement of bed load. One can establish the current position of the lowest point of erosion from the cumulative curves of change in bed material storage between individual cross section surveys (Fig.5). Whereas the erosion base in 1954 was located at km 51, it slowly shifted downstream to km 42 by 1969 and reached km 28 in 1973 (Tittmoning bridge). By the last survey in 1977 the erosion base has already reached km 15.

BED LOAD

The bed load transport capacity of the River Salzach at Burghausen has been computed to be approximately 320 000 m^3 $year^{-1}$ by the equation of Meyer-Peter (1948) with a mean diameter of particles of 17 mm in 1966. By the next survey in 1976 the particles became coarser. This implies a reduction in transport capacity to a half. The present bed load transport rate is only known for the lower part of the river course, where it was estimated to be 122 600 m^3 $year^{-1}$ (1953-1977) from measurements of the amount of bed material removed at the inlet to the Simbach-Braunau reservoir.

The bed load transport rate of the Salzach at its junction with its tributary the Saalach has been calculated by the equation of continuity. This equation states that the bed load transport rate at the upstream point of the reach under investigation must be

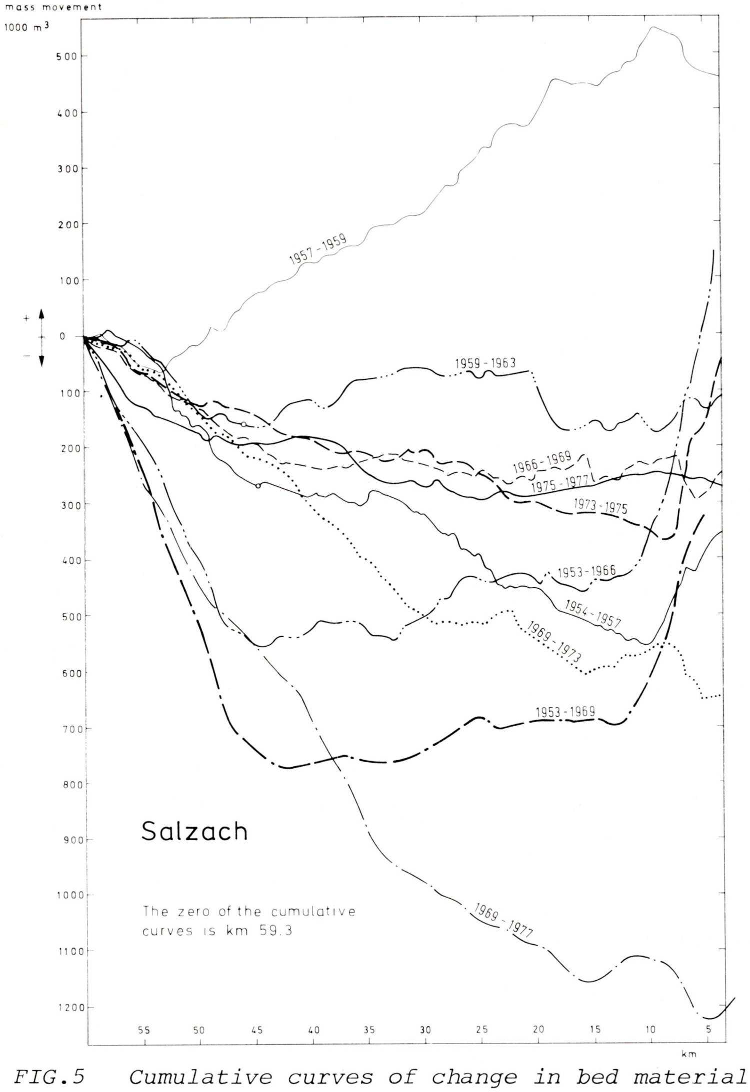

FIG.5 Cumulative curves of change in bed material storage.

equivalent to the transport rate at the outlet of the reach adjusted to take account of removal of bed material, degradation, aggradation and abrasion of the particles within the reach. The mass degradation has been calculated from the cumulative curve (Fig.5), and the abrasion by the abrasion coefficient of Sternberg (Mangelsdorf & Scheurmann, 1980). The quantity of bed material removed is known from the annual reports of the Bavarian Water Resources Board and the statements of Austrian experts. It can be estimated at about 40 000 m^3 $year^{-1}$ (average 1953-1977), although values for single years exceed this by more than 100%. More detailed information is given in the 1980 report (Bayer. Landesamt, 1980).

From the approximate estimate of the bed load balance, the mean annual bed load transport rate of the River Salzach was calculated to be 160 000 m^3 $year^{-1}$ before 1969 (average 1953-1969). After 1969, i.e. after the construction of the three Austrian controlling weirs, this was reduced by more than 50% to about 76 000 m^3 $year^{-1}$ (average 1969-1977). As a result of this change in the bed load balance, increased by continuous removal, the river is forced to compensate the bed load deficit by eroding bed material from its channel at increasing rates. This is demonstrated by the increased bed erosion, especially between the junction with the River Saalach and Laufen where it increased from 3.5 cm $year^{-1}$ to 4.9 cm $year^{-1}$ (average 1969-1977).

CONCLUSIONS

From boreholes situated in the channel fill and on the levees it is known that the layer of gravel moved in the channel is only 1-3 m thick. This thin layer of alluvial gravel could be suddenly removed by any flood. Of course it is not known when it will happen, but removal of the gravel bed would result in severe erosion in the channel because of the underlying soft and erodible silty clay. It will not then be possible to predict the rate of downcutting. Incision could increase from the several centimetres occurring at present to several metres. Further examples of such a situation are to be found near Salzburg and Hallein as well as in the lower Isar and other rivers in southern Bavaria.

From the longitudinal profile, it can be seen that the thalweg has nearly reached erodible material at km 41 and km 14. At present the bed load transport is being stopped or severely retarded by the new weirs at Salzburg and upstream of this town. No more bed material will be transported downstream until they are eventually silted up. This can be expected to take several years on the premise that no more bed material will be taken from the channel.

It is clear that something must be done to control the bed erosion. The progressive degradation of the River Salzach has also been noted as a serious problem on the Austrian side and a solution involving supporting weirs has been discussed as a solution if it proves impossible to install the proposed waterpower plants.

In developing such controls works, the use of minor structures should be avoided because low weirs are not sufficiently effective from the hydraulic point of view. The better strategy for protecting the river from further erosion, taking into account energy-economic considerations, would seem to be weirs with good hydraulic conditions or the power plants. Until such a programme is implemented, the removal of bed material must be significantly reduced or preferably stopped.

REFERENCES

Bayerisches Landsamt für Wasserwirtschaft (1980) Die flußmorphologische Entwicklung der Salzach von der Saalachmündung bis zur Mündung in den Inn. *Official Report* no. 2.

Flögl, H. & Neururer, H. (1970) Die Mehrzweckanlage Salzach-Kraftwerk Urstein. *Österreichische Wasserwirtschaft* no. 1-2.

Kerschbaumer, W. (1969) *Geschiebemessungen an der Salzach und Salzachstufenplan*. Bericht über die 8. Flußbautagung in Salzburg.
Mangelsdorf, J. & Scheurmann, K. (1980) *Flußmorphologie*. Oldenbourg, München.
Mittellehner, F. (1978) Die Salzachsanierung in Hallein. *Österreichische Wasserwirtschaft* no. 11-12.
Oexle, L. (1933) Wasserwirtschaftliches über die Salzach bei Burghausen. *Dtsch. Wasserw.* nos. 3 & 5.