ECOSYSTEM STUDY ALTEN WORTH: IMPACTS OF A HYDROELECTRIC POWER-STATION ON THE RIVER DANUBE IN AUSTRIA

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Introduction

The Danube, with a length of c. 2850 km, is the second largest river in Europe. It rises in the Black Forest (Germany), discharges into the Black Sea (Romania, former USSR) and crosses five other countries: Austria, Czechoslovakia, Hungary, former Yugoslavia, and Bulgaria (Fig. 1). Nearly 90 million people live in its catchment area of c. 805 300 km^2. Including its tributaries, twelve countries and about 447 million people are linked to the Danube. These figures show the extraordinary international importance of this river.

The Austrian part of the Danube decreases by 156 metres in altitude over its 351 km length (Fig. 2). Historically, developments on this part of the Danube took place in three phases up to (1) its regulation in the 19th century, (2) the first barrage constructed in the early 1950s, and (3) the past decade, in which the river has been developed into a power-generating waterway so that the continuity of the river is now interrupted by nine transverse barrages or dams used for hydroelectric purposes (Figs 3-5).

Recently, there has been increasing concern in several countries, including Austria, about the construction and management of large "runoff river schemes", mainly due to their adverse environmental impacts. In 1981, the Austrian National Committee of the International Working Group on Danube Research initiated a research project for a better understanding of the multiple effects of the Danube barrages in Austria. The model area chosen for study was an impounded section of river upstream from the Altenworth barrage, which is situated 1981 km from the river mouth and was commissioned in 1976. The study was financially supported by Danube Hydro Austria and the Austrian Man and Biosphere Programme, run by the Austrian Academy of Sciences. About 120 scientists were involved in the 4-year programme which started in 1985. Three tasks were explicitly specified: (1) identification of impacts due to construction and operation of the Altenworth barrage, (2) identification of sound management alternatives, considering both economic and ecological aspects, and (3) generalization of the results to develop recommendations for the design and operation of similar hydropower schemes in Austria. The research programme, the study area and a review

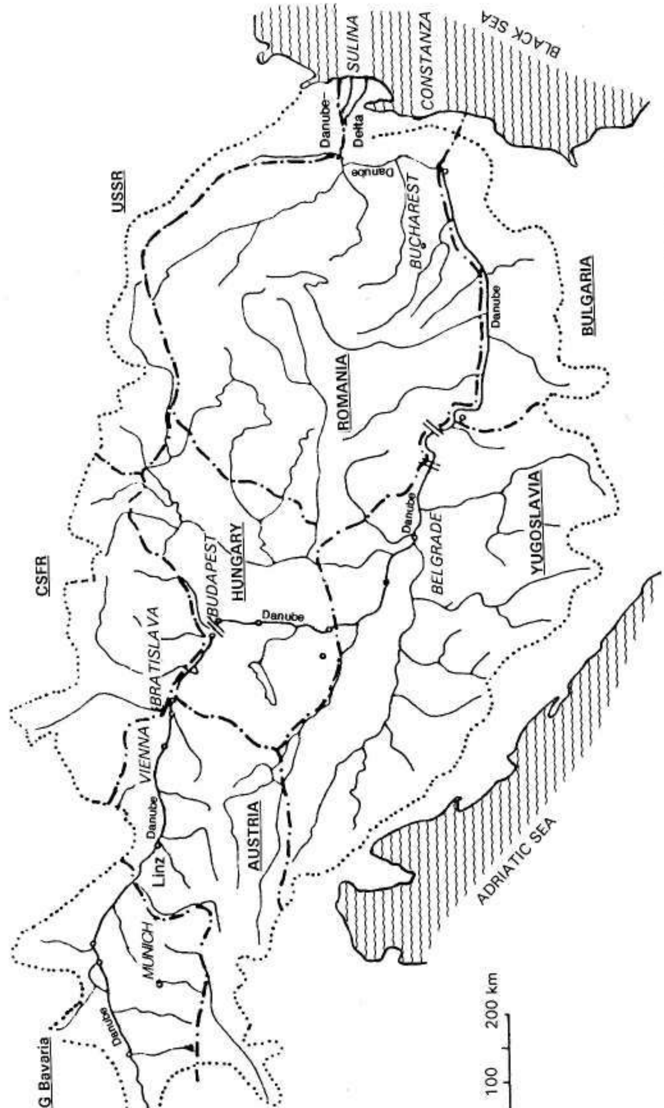


FIG. 1. Catchment area of the River Danube: . . . . , catchment border; —•—•, State boundary; ll, Iron Gate. (Adapted from Fig. 14.1 in Meybeck, Chapman & Helmer 1990). Capital cities are shown in *italics*.

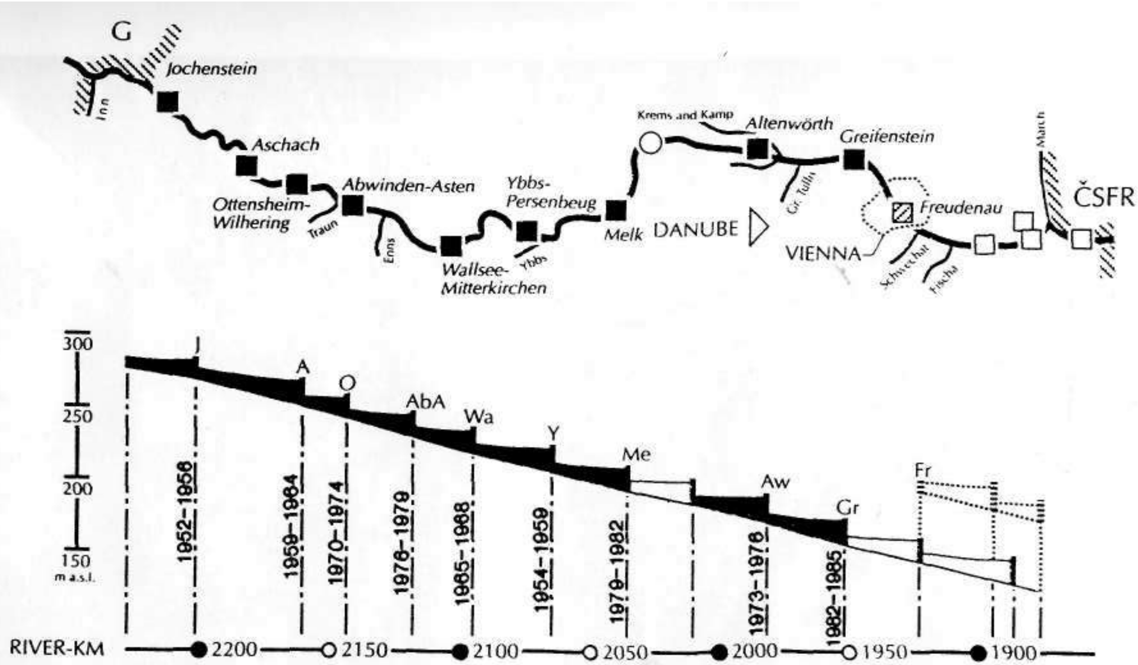


FIG. 2. Hydropower schemes of the Danube in Austria and construction periods of the power-stations. ■, power-stations in operation; ▨, power-station project applied for consent; □, project variants downstream from Vienna; ○, possible project location.

FIGS 3–5. Aerial photographs of the River Danube near Vienna. Copyright: "Luftreportagen Hausmann/Wien".

FIG. 3 (*Top left*). River Danube, looking upstream from km 1907 (from the river mouth), showing the main river with bankside forests and oxbows providing a diversity of habitats containing 41 species of fish.

FIG. 4 (*Bottom left*). The regulated River Danube, looking upstream from km 1918, showing (left to right) the harbour of Albern, mouth of the Danube Canal with the harbour of Freudenau, the main river, the Danube island with parts of the "new Danube" and storage tanks for oil.

FIG. 5 (*Above*). River Danube, looking downstream from km 1934, showing (left to right) parts of the "new Danube", the Danube island, the main river, the Danube Canal and parts of the city of Vienna.

of the relevant literature are given by Grosina (1985). The results, under the general title of "Ecosystem Study Altenworth", have been described in detail by Hary & Nachtnebel (1989).

The aim of this article is to briefly describe the effects of the dam on some physical variables and their consequent effects on water chemistry and the biota of the river, starting with a brief summary of the methods used for biological sampling - especially those developed and used in the limnological part of the study (for details, see Humpesch & Elliott 1990). Comparisons are then made between the impounded section of river immediately above the dam and two unimpounded free-flowing sections of the river: (1) further upstream in the Wachau region where the river (above a discharge of 1800 cubic metres per second) is barely affected by the impoundment, and (2) downstream near the city of Vienna.

Methods for biological sampling in the Danube

Samplers used in the study were modified in order to function within the ranges of water velocity and depth of the Danube, and the various particle sizes of the bottom substrata. The sampling devices, which can be recommended as suitable for use in large rivers, are summarized in Fig. 6, which also shows the regions of the river where the samplers were used.

Qualitative sampling

The following samplers are adequate for producing a list of species, estimating their relative abundances and calculating some community or biotic indices, based on rank order or diversity. Fast dredge for the bottom fauna; slurp-gun and colonization sampler for the fauna of the bottom and the banks; automatic continuous drift sampler for drifting invertebrates.

Quantitative sampling

The following samplers are adequate for estimating biomass and numbers of plants and animals per unit area, and to compare spatial or temporal differences in populations when using parametric tests to detect small changes in water quality, rates of growth, reproduction and mortality.

In the water column: Schindler plankton trap for phytoplankton and zooplankton. On board the boat: a deck-incubator for the phytoplankton.

In coarse substrata: N_2-freezing corer for invertebrates in shallow water; Petersen-grab for invertebrates in deep water; colonization sampler for invertebrates in both shallow and deep waters.

Near the banks of the river: echosounder for macrophytes; "box" sampler for epiphytic invertebrates; colonization sampler for epilithic invertebrates.

In fine bottom sediments: "RINIMUCC'-multicorer for invertebrates.

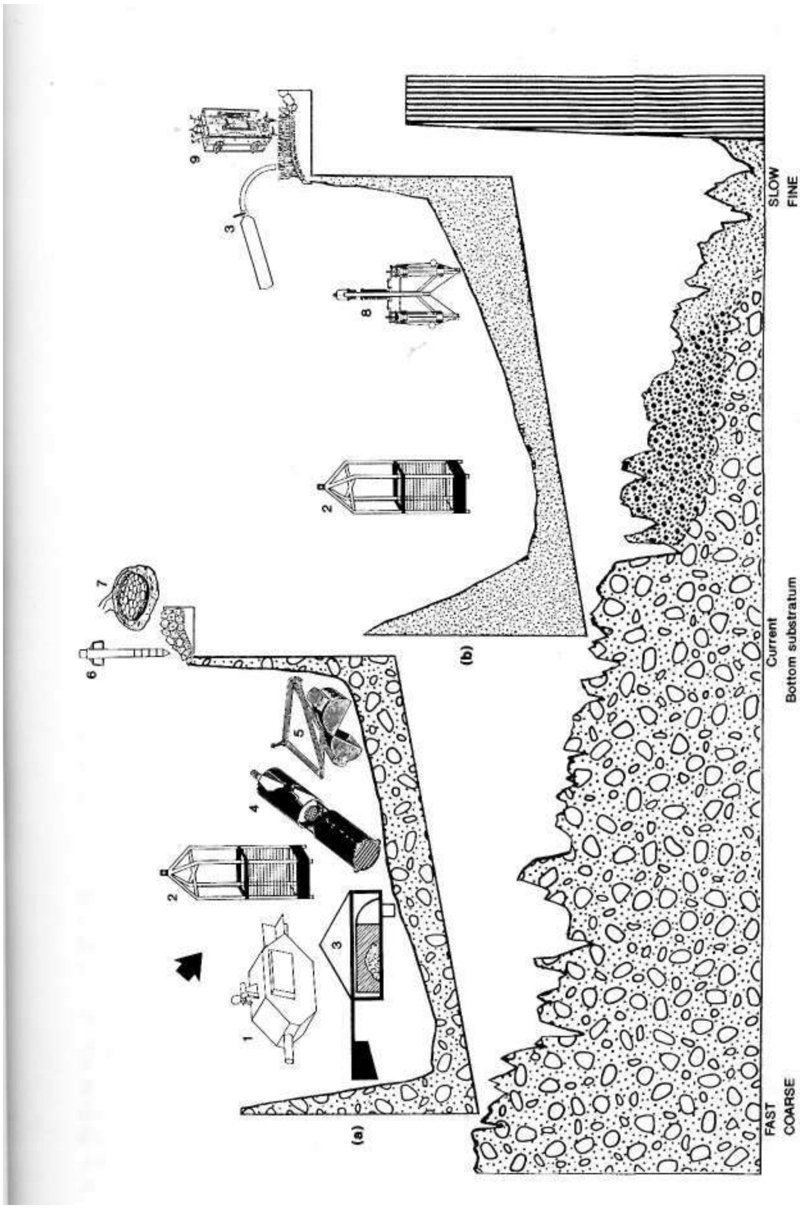


FIG. 6. Summary of information on methods of biological sampling in the Danube, showing the apparatus used (a) in fast current and coarse bottom substratum and (b) in slow current and fine bottom substratum. 1, drift sampler; 2, Schindler plankton trap; 3, slurp gun; 4, Fast dredge; 5, Petersen grab; 6, N_2-freezing corer; 7, colonization sampler; 8, RINIMUCO-multicorer; 9, "box" sampler. The arrow indicates the direction of flow. (From Humpesch & Elliott 1990).

Characteristics of the free-flowing river (Figs 3, 4, 7)

General features

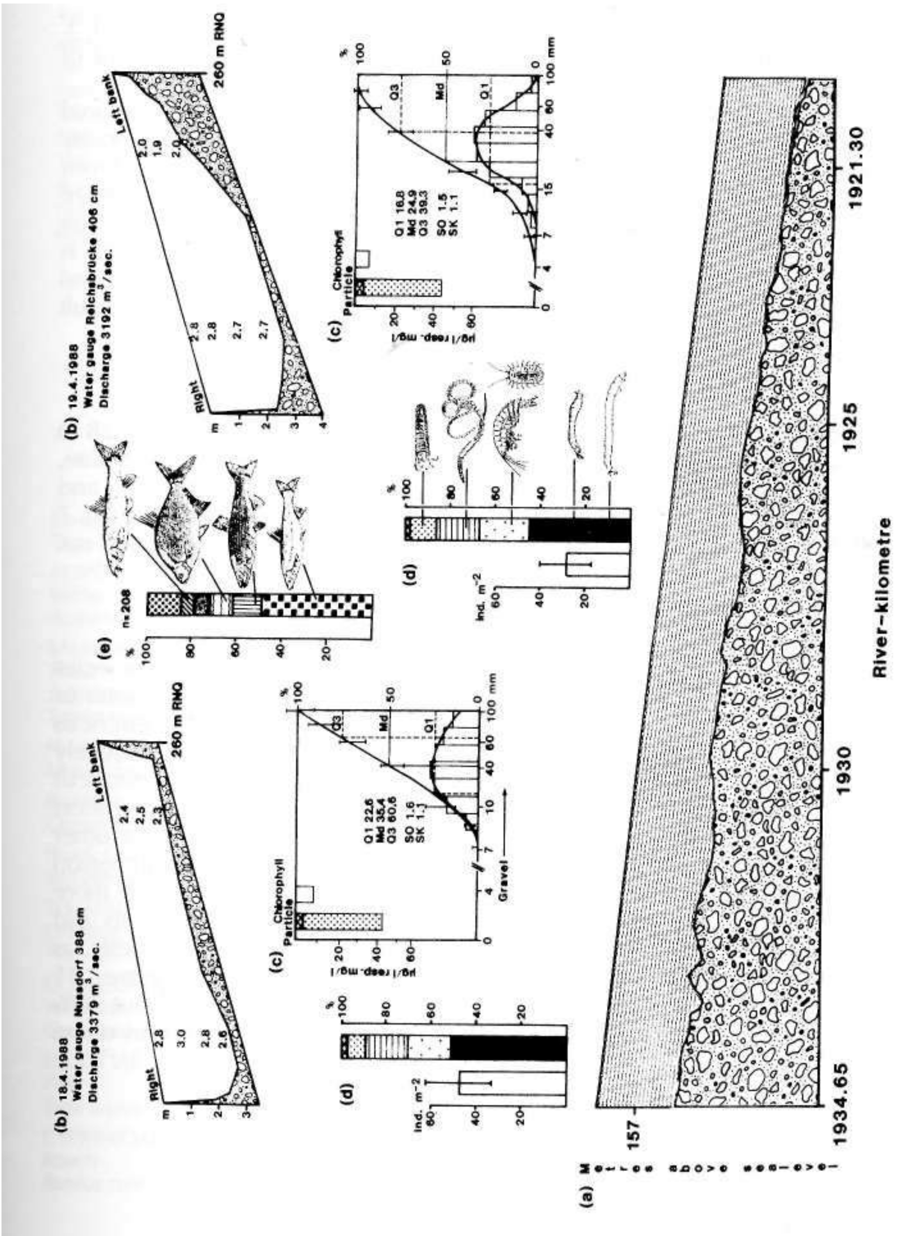
In its free-flowing regions in Austria, the Danube is a typical alpine river, characterized by a highly dynamic flow regime throughout the year due to snow-melts and regular rainy periods. The water carries a large load of mineral particles and has a temperature ranging from 0 to 20°C. From its flora and fauna the river may be classified as belonging to the hyporhithron or the epipotamon, depending on personal preference.

Physical and chemical features

A section of the Danube near Vienna represents the unimpounded free-flowing river, sampled at km 1934 and km 1921 from the river mouth (Figs 3, 4, 7). Here the river is about 260 metres wide and 2-3 metres deep. At a discharge of c. 3000 cubic metres per second, maximum water velocities in the sampled cross-sections are about 3 m sec^{-1} (Fig. 7 (b)), decreasing with depth of water to values of 0.4 to 2.1 m sec^{-1} about 10 cm above the bottom. Further changes in the velocity occur at different levels of discharge.

Because of the high turbulence of the water, materials in the water column are thoroughly mixed, with no stratification. It takes about 4 hours for water to move from the upper sampling site at km 1934 to the lower site at km 1921 (Fig. 7 (a)). The estimated load of suspended particles is c. 44 milligrams per litre of water, of which only 3-4% is due to the organic fraction. The relatively high turbidity and fast renewal time of the water are responsible for the rather low chorophyll-a content, 5-10 micrograms per litre of water (Fig. 7 (c)), although the high content of nutrients such as

FIG. 7. (*Opposite*). Summary of information on general characteristics of the free-flowing Danube in Austria, using the stretch near Vienna between km 1934.65 and km 1921.30 (from the river mouth) as an example [(a), at bottom of the text figure]. (b), cross-sections of the river (width at the regular low discharge, RNQ) and values of water velocity (m sec^{-1}) at two sampling sites. (c), content of suspended particles at two sampling sites. ▦, inorganic fraction and ▦, organic fraction (mg l^{-1}); chlorophyll-a (µg l^{-1}) in the water and grain-size distribution (frequency distribution histogram and cummulative frequency curve); $Q_{1\varnothing}$, $Md_{\varnothing}$, $Q_{3\varnothing}$, are the first, second and third quartiles (in mm), So = degree of scatter, Sk = degree of asymetry. (d), absolute and relative abundances of the major groups of macroinvertebrates at two sampling sites, showing arithmetic means of individuals, (with 95% C.L.) per square metre (n = 6): ▦, Diptera (Chironomidae, Simuliidae); □, Crustacea (Amphipoda, Isopoda); ▤, Oligochaeta, ▦, Trichoptera; ▦, miscellaneous (<5%). (e), relative abundance of fishes: ▦, nase; ▥, chub; ▤, bream; ■, white bream; ▨, barbel; ▦, miscellaneous (<5%).


(a) Metres above sea-level
157
1934.65
1930
1925
1921.30
River-kilometre
(b) 18.4.1988
Water gauge Nussdorf 388 cm
Discharge 3379 m3/sec.
(b) 19.4.1988
Water gauge Reichsbrücke 406 cm
Discharge 3192 m3/sec.
Right
Left bank
260 m RNO
(c)
Chlorophyll
Particle
µg/l resp. mg/l
Q1 22.6
Md 35.4
Q3 60.6
SO 1.6
SK 1.1
Q1 16.8
Md 24.9
Q3 39.3
SO 1.5
SK 1.1
Gravel
mm
(d)
Ind. m-2
(e)
n=208

total phosphorus (up to 600 (μg l^{-1}), soluble phosphorus (up to 460 μg l^{-1}), and inorganic nitrogen (up to 4.5 mg l^{-1}) could support larger growths of algae.

The river bed is composed of rocks, stones and gravel, with occasional patches of sand and silt, related to hydrologic variables such as velocity and depth of the water, width of the river and energy gradient. From sediment analysis, values for the degree of scatter, (So >1.5), characterize the sediments as being poorly sorted or heterogeneous; values for the degree of asymmetry, ($\log_{10}$ Sk >0.03), indicate that coarse sediment is predominant (Fig. 7 (c)). The decrease in diameter of the first, second, and third quartiles for particle sizes between the two sampling sites is the result of their different transport lengths and abrasion (Fig. 7 (c)).

Macroinvertebrates

The density of macroinvertebrates at the sampling sites ranged from 28 to 47 individuals per square metre, including Diptera (Chironomidae, Simuliidae), Oligochaeta, Crustacea (Amphipoda, Isopoda) and Trichoptera, each representing more than 10% of the total numbers (Fig. 7 (d)). So far, 54 taxa have been recorded from this stretch of river, but not much is known about the species diversity of the free-flowing river.

Fishes

Near Vienna, the fish fauna of the main river consists of 17-18 species (Table 1, columns (4) and (5)), among which the typical running-water or rheophilic fishes such as nase *{Chondrostoma nasus),* chub *(Leuciscus cephalus)* and barbel *{Barbus barbus)* are predominant. Other relatively numerous species are bream *(Abramis brama)* and dace *(Leuciscus leuciscus).* Another 13 species represent less than 5% of the total numbers (Fig. 7 (e)). This composition of fish species is also characteristic for other free-flowing sections of the Danube in Austria, as in the Wachau region further upriver (Table 1, column (1)). But the fish fauna is much more diverse where the main river is still connected with parts of its old branches, oxbows and still waters (backwaters) of the riverside forests, as represented by the area downstream from Vienna (Fig. 3). Here, 41 species have been caught (Table 1, column (5)), representing about 70% of the total number of species (57) recorded from the Austrian part of the Danube.

Table 1. A list of 57 fishes (in 15 families) recorded from the River Danube in Austria, with presence (+) and absence (–) in six sampled sections of the river, shown in columns (1) to (6). Of the listed fishes, 13 have not been recorded from any of the sampled sections. (1) Free-flowing river in the Wachau region upstream from km 2005. (2) Upstream end of the backwater zone of the Altenwörth impoundment at km 2005 (from the river mouth). (3) Downstream end of the backwater zone immediately behind the Altenwörth dam at km 1980. (4)–(6) Free-flowing river near Vienna at km 1945–1939 (4), at km 1935–1913 (5) and downstream from km 1921: Lobau, Stopfenreuther Au, Hainburger Au (6). Symbols indicate percentage of the total fish fauna: ⬤> 50%, ●< 50%, •< 30%, ·< 10% (after Jungwirth & Rehan 1986; Schiemer 1986; Schiemer et al. 1991). *, juvenile fish present near the dam.

		Altenwörth ⟷		*Vienna* ⟷		
	Wachau region above km 2005	*Upper impound. at km 2005*	*Lower impound. at km 1980*	*At km 1945 to km 1939*	*At km 1935 to km 1913*	*Downstream from km 1921*
Species, recorded from the Danube in Austria	(1)	(2)	(3)	(4)	(5)	(6)
ACIPENSERIDAE						
Sterlet						
Acipenser ruthenus L.	–	–	–	–	–	–
SALMONIDAE						
Trout						
Salmo trutta f. fario L.	•	–	–	–	+	+
Salmo trutta f. lacustris L.	–	–	–	–	–	–
Huchen						
Hucho hucho (L)	+	–	–	–	–	–
Rainbow Trout						
Oncorhynchus mykiss (Walbaum)	–	–	–	–	–	+
Brook Charr						
Salvelinus fontinalis (Mitchill)	–	–	–	–	–	–
THYMALLIDAE						
Grayling						
Thymallus thymallus (L.)	–	–	–	–	–	–
COREGONIDAE						
Whitefish						
Coregonus sp.	–	–	–	–	–	–
ESOCIDAE						
Pike						
Esox lucius L.	•	+	+*	+	+	•
CYPRINIDAE						
Roach						
Rutilus rutilus (L.)	•	●	⬤*	+	+	•

Danube Roach *Rutilus pigus virgo* (Heckel)	•	–	–	•	•	+
Pearl Roach *Rutilus frisii meidingeri* (Heckel)	–	+	–	–	–	–
Belica *Leucaspius delineatus* (Heckel)	–	–	–	–	–	–
Dace *Leuciscus leuciscus* (L.)	–	•	+	–	•	•
Chub *Leuciscus cephalus* (L.)	•	•	•	•	•	•
Orfe *Leuciscus idus* (L.)	+	•	•*	–	+	•
Minnow *Phoxinus phoxinus* (L.)	–	–	–	–	–	–
Rudd *Scardinius erythrophthalmus* (L.)	+	+	–	–	–	•
Asp *Aspius aspius* (L.)	•	•	•*	+	+	+
Tench *Tinca tinca* (L.)	–	+	–	–	–	+
Nase *Chondrostoma nasus* (L.)	●	•	•	●	●	●
Gudgeon *Gobio* [*gobio* (L.)] sp.	•	–	–	+	–	•
Whitefin Gudgeon *Gobio albipinnatus* Lukasch	–	–	–	–	–	–
Kessler's Gudgeon *Gobio kessleri* Dybowski	–	–	–	–	–	–
Danube Gudgeon *Gobio uranoscopus* (Agassiz)	–	–	–	–	–	–
Barbel *Barbus barbus* (L.)	●	●	•	●	•	•
Bleak *Alburnus alburnus* (L.)	–	–	–	•	–	–
Schneider *Alburnoides bipunctatus* (Bloch)	–	–	–	–	–	–
White Bream *Blicca bjoerkna* (L.)	+	•	•*	–	+	•
Bream *Abramis brama* (L.)	•	●	•*	•	•	•
Whiteye Bream *Abramis sapa* (Pallas)	•	+	+*	•	+	•
Blue Bream *Abramis ballerus* (L.)	•	–	–	+	–	•

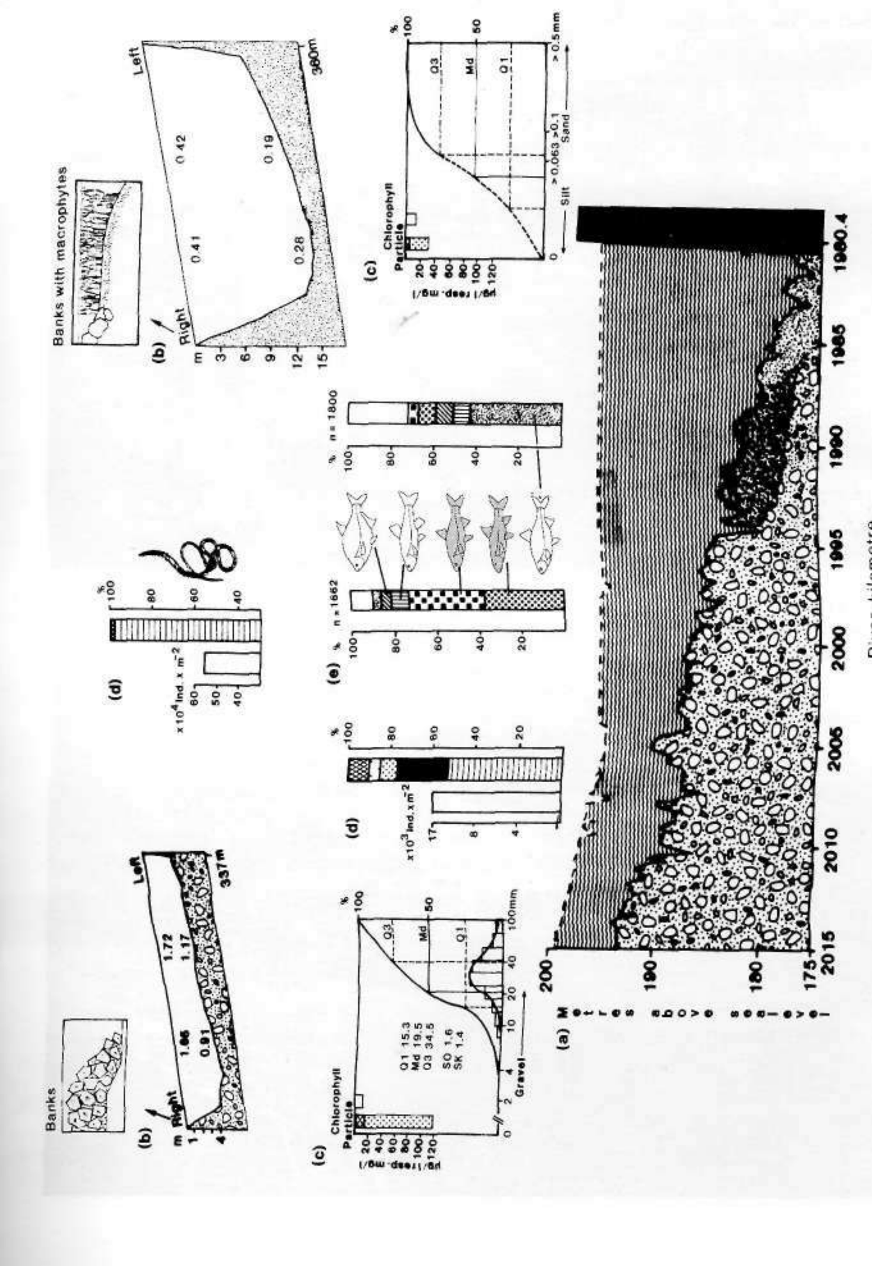
Vimba *Vimba vimba* (L.)	•	•	●*	+	+	•
Chekhon *Pelecus cultratus* (L.)	•	•	+	+	–	+
Bitterling *Rhodeus sericeus amarus* (Bloch)	–	–	–	–	–	+
Crucian Carp *Carassius carassius* (L.)	–	–	–	–	–	+
?Goldfish *Carassius auratus gibelio* (Bloch)	•	+	+*	–	–	+
Carp *Cyprinus carpio carpio* L.	+	+	+	–	+	+
Grass Carp *Ctenopharyngodon idella* (Val.)	–	–	–	–	–	+
Silver Carp *Hypophthalmichthys molitrix* (Val.)	–	–	–	–	–	+
COBITIDAE						
Stone Loach *Noemacheilus barbatulus* (L.)	–	–	–	–	–	–
Weather Loach *Misgurnus fossilis* (L.)	–	–	–	–	–	+
Spined Loach *Cobitis taenia* (L.)	–	–	–	–	–	+
SILURIDAE						
Wels *Siluris glanis* (L.)	–	+	+	–	–	+
ANGUILLIDAE						
Eel *Anguilla anguilla* (L.)	–	–	+	–	–	+
GADIDAE						
Burbot *Lota lota* (L.)	–	–	–	–	–	+
GASTEROSTEIDAE						
Three-spined Stickleback *Gasterosteus aculeatus* (L.)	–	–	–	–	–	–
PERCIDAE						
Perch *Perca fluviatilis* (L.)	–	•	+*	–	+	•
Pikeperch *Stizostedion lucioperca* (L.)	+	•	•*	+	•	+

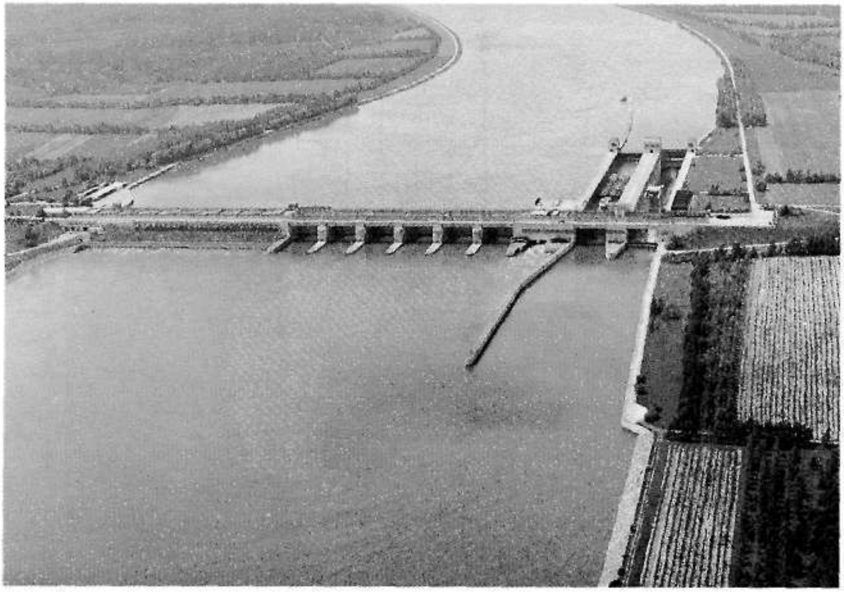
Volga Pikeperch *Stizostedion volgensis* (Gmelin)	–	–	–	–	–	–
Ruffe *Gymnocephalus cernua* (L.)	–	+	–	–	–	+
Striped Ruffe *Gymnocephalus schraetzer* (L.)	•	•	•*	•	+	+
? *Gymnocephalus baloni* (Holcik & Hensel)	–	–	–	–	–	–
Streber *Zingel streber* (Siebold)	•	•	–	–	–	+
Zingel *Zingel zingel* L.	•	●	•	+	–	+
CENTRARCHIDAE						
Pumpkinseed *Lepomis gibbosus* (L.)	–	–	–	–	–	+
GOBIIDAE						
Tubenose Goby *Proterorhinus marmoratus* (Pallas)	–	+	–	–	–	+
COTTIDAE						
Bullhead *Cottus gobio* L.	+	–	–	–	–	+
Total number of species	25	26	21	17	18	41

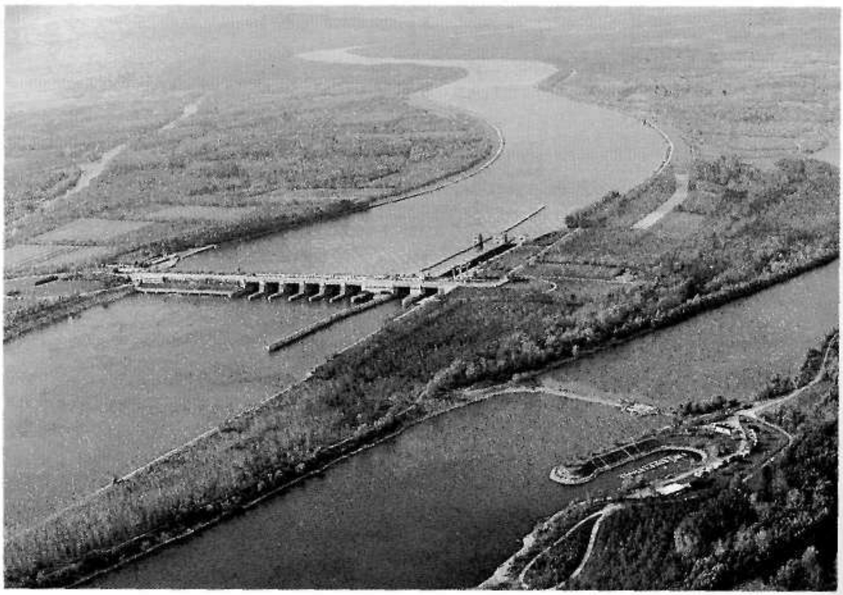
Characteristics of the impounded section of river at Altenworth (Figs 8-11)

Above the Altenworth dam we sampled a stretch of impounded river about 25 km in length, beginning with the dam of the impoundment at km 1980 (from the river mouth), where the river is 360 metres wide and 12-15 metres deep (Figs 9, 10), and ending at km 2005 upstream, near Krems, where the river is 337 metres wide and 3-4 metres deep (Fig. 8 (a and b)). The river banks have been stabilized with large cobbles or boulders about 25 cm in diameter. Near the dam, in shallow water, the cobbles are covered with aquatic macrophytes, but these do not occur further upstream at km 2005 (Fig. 8 (b)).

FIG. 8. (*Opposite*). Summary of information on the impounded Danube, using the impoundment of Altenwörth as an example. For further explanation see the legend for Fig. 7 except for the fishes: , barbel; , bream; , roach; miscellaneous (<5 %).


Banks
Banks with macrophytes
(a) Metres above sea level
(b)
(c)
(d)
(e)
Right
Left
337m
360m
Chlorophyll
Particle
Gravel
Silt
Sand
River-kilometre
n = 1662
n = 1800
2015
2010
2005
2000
1995
1990
1985
1980.4
200
190
180
175





FIGS 9–11. Aerial photographs of the River Danube at Altenwörth hydroelectric power-station (Front cover and Figs 9 and 10, by Danube Hydro Austria with permission from the Ministry of Defence) and in flood at km 2011 near Rührsdorf (Fig. 11, by G. Weisbier).

FIG. 9. (*Top left*). Altenwörth power-station, looking upstream, showing (left to right): (1) the power house (length 162 m; 9 generating units each with a rated discharge of 300 m^3 sec^{-1} and maximal flow of 2700 m^3 sec^{-1}), (2) weir system (length 193 m; 6 tainter gates with flaps 24m width and 13 m height. When discharge exceeds 2700 m^3 sec^{-1} surplus water flows over the weirs and extreme floods (Fig. 11) must be discharged safely by the spillway), (3 navigation lock system (two chambers, each with 24m clear width and 230 m usable length with double leaf vertical lift gates (upstream) and mitre gates (downstream); a tow-boat i seen in the left chamber). The lock system can also be used for flood discharge.

FIG. 10. (*Below left*). A second view of the Altenwörth barrage, looking upstream at the impounded section of river beyond the dam, showing (at distant left) the inflowing Rive Traisen and (in right foreground) an old branch of the River Danube in its original bed before the impoundment was built.

FIG. 11. (*Above*). River Danube in flood and overflowing its banks near Rührsdorf wher discharge was 9647 m^3 sec^{-1} on 4 August 1991. For comparison, a 100-year flood i estimated at 11000 m^3 sec^{-1}.

Physical and chemical characteristics

The dam produces a gradient in water velocity along the impounded section of the river, with a mean velocity of about 1.5-2.0 metres per second at the beginning of the backwater zone of the impoundment (km 2005), falling to 0.2-0.4 m sec^{-1} near the dam (Fig. 8 (b)). However, the water flow remains highly turbulent and the water column is thoroughly mixed, with no stratification even near the dam. The residence time of suspended particles in the impounded section of river is about 10 hours. Water escapes over the sill of the dam when the river is running high; at low water it continually flows through the turbines of the power-station and through the navigation locks (Fig. 9).

The gradient in water velocity leads to increased sedimentation towards the dam; the load of suspended particles decreases from 120 mg per litre at the beginning of the backwater zone to 33 mg l^{-1} near the dam. The organic fraction is about 5-10% of the total suspended particles (Fig. 8 (c)).

Due to the reduction in water velocity and consequent decrease in suspended materials, water transparency increases and the concentration of chorophyll-a also increases towards the dam (Fig. 8 (c)). But the relatively high renewal rate of the water column, combined with relatively low water temperatures (below 20°C in mid summer), prevent intensive growths of algae, and there have been no algal blooms despite the nutrient-rich conditions in the impounded section.

Due to the increase in sedimentation towards the dam, the particle size of the river bed changes from a modal size range of 18-22 mm (overall range 14-41 mm) to one of only 0.2 mm (Fig. 8 (c)). Three distinct zones can be recognized: a gravel bottom, upstream from km 1995, which is typical of the unimpounded part of the Danube in Austria, a sandy bottom between km 1995 and km 1987, and a silty bottom downstream to the dam (Fig. 8 (a)).

The silt is comprised of particles less than 63 (µm in diameter. It has an organic content consisting of 18.5 milligrams of organic carbon per gram dry weight, 1.24 mg total nitrogen per g dry wt, and 1.37 mg phosphorus per g dry wt. The water immediately above the silt, and within it to a depth of 6 centimetres, has a high oxygen content and a biochemical oxygen demand (BOD) of 0.071 milligrams of oxygen per gram and hour at 20°C.

Macroin vertebra tes

The high organic and oxygen content of the silt create an excellent substratum for certain small macroinvertebrates ("worms"), which occur at densities of about 2 million individuals per square metre. These are nearly all Oligochaeta; 95% are Tubificidae and 3% are Naididae and

Lumbriculidae. The remaining 2% consists of a polychaete worm *{Hypania invalida)* and Diptera (Chironomidae).

In the gravel zone, towards the upstream end of the impounded section of river, the macroinvertebrate fauna more closely resembles that of the free-flowing gravel section further downstream, near Vienna. However, total numbers are much greater, up to 55 000 (mean 17 000) per square metre at km 2005, due to the presence of numerous small Oligochaeta and Diptera, although other taxa comprise about 25% *oi* the total numbers (Fig. 8 (d)). 127 taxa were identified at km 2005 (Fig. 12).

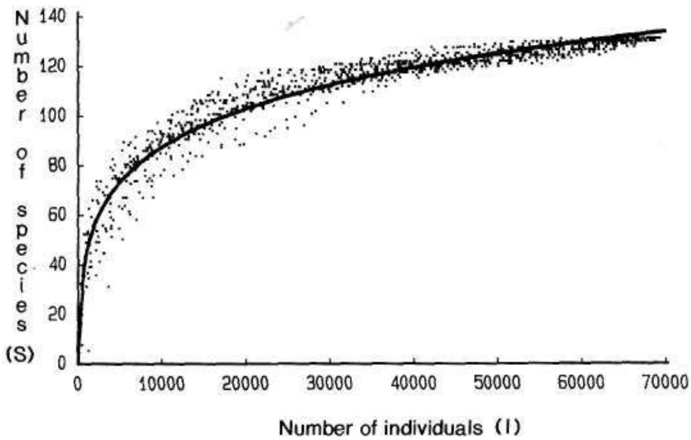


FIG. 12. Relationship between number of species and number of individuals at km 2005 (from the river mouth). (From Petto, Humpesch & Anderwald 1991).

Fishes

Rheophilic species of fish predominate at the upstream end of the impounded section, which is directly connected with the free-flowing river upstream from the backwater region of the dam. The total of 26 species found in the impounded section is similar to the total of 25 species caught in the free-flowing section upstream in the Wachau region (Table 1, columns (1) and (2)) and is higher than the 17-18 species found in the free-flowing but canal-like sections of river near Vienna, between km 1945 and km 1913. Nevertheless, the same species are generally the most numerous at all of these sites, with the notable exception of the roach *(Rutilus rutilus).* This fish is most numerous in the impounded section of river immediately above the dam (Fig. 8 (e)). At this site, juvenile fishes of most species are generally absent whereas a few do occur in the upstream part of the impounded section.

The effect of the Altenworth impoundment on the fish fauna

As shown in the preceding section, on the upstream side of the dam the natural invertebrate biota of the hyporhithron/epipotamon has been replaced by a much more specialized biocoenosis that is typical of impounded areas in general. Due to the reduced current velocity, increased water depth and accumulations of silty and muddy sediments supporting a large biomass of benthic invertebrates, the impounded section of river now conforms to a habitat more suitable for stagnophilic or still-water species of fish. However the relatively low annual mean water temperature, the lack of shoreline diversity, and low densities of planktonic organisms, have inhibited development of a typical assemblage of stagnophilic fishes. There are well-developed growths of aquatic macrophytes along the margins of the river, near the dam, especially the pondweed, *Potamogeton pectinatus,* and water-milfoil, *Myriophyllum spicatum.* These weedbeds could serve as spawning grounds and provide nurseries and feeding places for juvenile fishes of stagnophilic species. But the weedbeds are seriously affected by floods and even by high average discharges, and they provide little protection.

The original dominant rheophilic fish fauna is still present as adults, capitalising on the rich food resource of the impoundment, but they do not reproduce here to form self-perpetuating populations because there are no suitable spawning grounds. Juveniles of these rheophilic species are now only found upstream, in the free-flowing section of river above the impoundment, although a few individuals do occur in the upper part of the latter. Thus the apparent lack of a major change in the number and type of fish species in the impoundment is partly due to the fact that a suitable, unaltered section of river exists immediately upstream, from which the rheophiles can freely move into the impounded section. For this reason the Altenworth backwater region is not typical for a river where several dams are built relatively close together, as has been done on some other parts of the Danube in Austria (Fig. 2). The effects of this latter situation could not be studied in our investigation, but there may have been greater changes in the fish fauna in the impounded sections between the dams. At the very least, as no provisions were made to assist the free movement of fishes through the barriers, opportunities for mixing and exchange between the gene-pools of semi-isolated populations of local nonmigratory fishes is now greatly restricted.

Water quality in the impounded section between km 2005 and km 1980

The 127 taxa of macroinvertebrates identified at km 2005 (Fig. 12) indicate Water Quality II for the Danube at that point. This faunistic estimate of water quality agrees well with chemical and microbiological parameters used to assess quality, viz. ammonia, potassium permanganate, biochemical oxygen demand (BOD), and bacterial counts at 22°C. Long-term monitoring of these variables and orthophosphate concentrations, over the period 1957 to 1988, shows that from 1957 to 1976 the values of all variables increased considerably and water quality deteriorated, but from 1976 onwards the values all decreased except for those of ammonia (Fig. 13). Reasons for this general improvement are briefly considered in the next section.

The above water-quality variables showed no increases between km 2005 and km 1980, indicating that water quality remains unaltered in the impounded section of river.

Table 2. Summary of information on the numbers of people living in different political regions of the catchment areas of the River Danube, in 1968 and 1988. Also given are the numbers (approximate) of inhabitants connected to canalized sewage systems (CS) and wastewater treatment plants (WTP).

Political region	*Catchment area (km^2)*	*Population in 1968 (millions)*	*CS*	*WTP*	*Population in 1988 (millions)*	*CS*	*WTP*
Baden-Württemberg	7580	1.5	0.9	0.3	1.6	1.5	1.4
Bavaria	8690	7.2	4.1	2.7	7.7	6.6	6.4
Italy/Switzerland	2180	<0.1	–	–	<0.1	–	–
Total outside Austria	58450	8.7	5.0	3.0	9.3	8.1	7.8
Austria (Tyrol, Salzburg, Lower and Upper Austria, Styria)	43250	3.1	0.8	0.1	3.2	2.1	1.9
At Watergauge "Vienna-Nußdorf"	101700	11.8	5.8	3.1	12.5	10.2	9.7
Austrian part (in %)	43	26	–	–	26	–	–

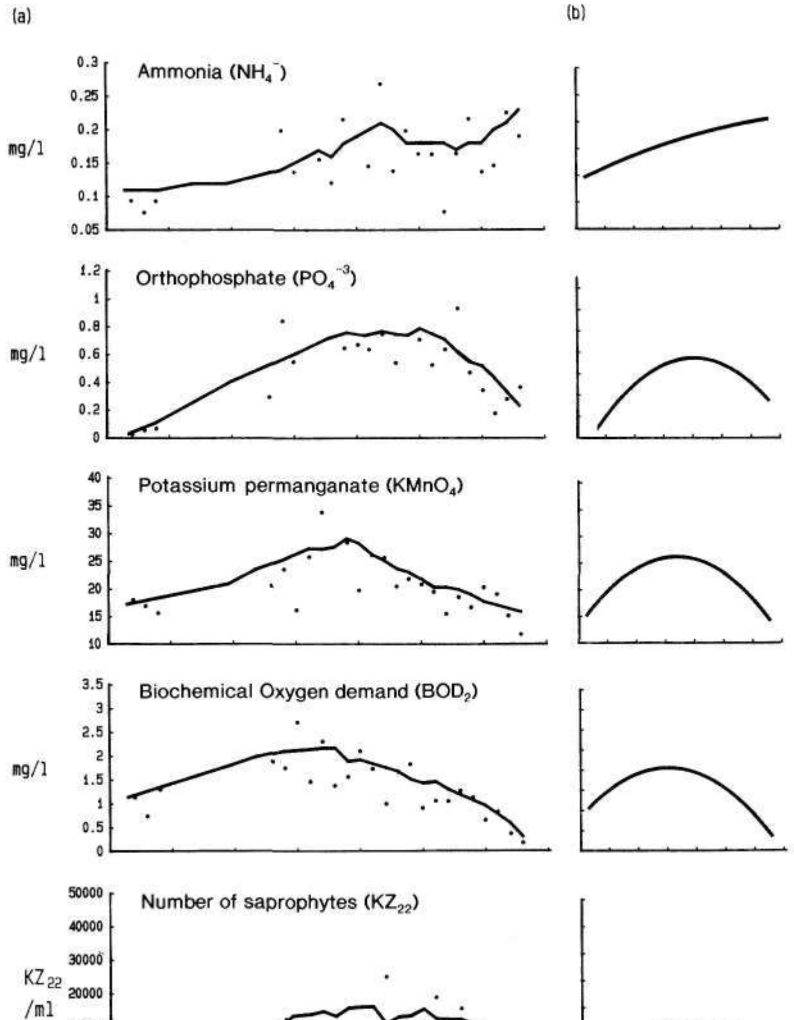


FIG. 13. Long-term development in water quality between km 1980 and 2007 (from the river mouth) in the period 1957–1988, using ammonia, orthophosphate, potassium permanganate, biochemical oxygen demand (in 2 days) and the number of saprophytes at 22°C as an example. (a), moving averages (3-year periods) of second-order polynomials; (b), polynomials of second-order. (From Petto, Fleckseder & Humpesch 1991).

Recent improvements in water quality of the Austrian Danube

For the catchment area of the Danube at Altenworth (based on the water gauge at Vienna-Nulsdorf (Fig. 5)) approximately 55% of the catchment lies in the south of Germany (Baden-Wurttemberg and Bavaria), and only 26% of the human population in the catchment actually lives in Austria (Table 2). Thus changes in the water quality of the Danube in Austria are inevitably dependant on events occurring upriver in Germany. The recent general improvement in water quality is partly due to improved treatments of sewage in both countries. In the Austrian part of the catchment, in 1968, about 25% of the population's sewage was discharged into the main river via canalized watercourses and only 3% actually passed through waste-water treatment plants. In 1988, about 70% of the sewage was treated before discharge. Similarly, in Germany the treatment of sewage increased from 30% to 85% of the population (Table 2). Furthermore, legislation has eliminated polyphosphates from washing powders and has improved the technology of cellulose production, resulting in a decrease in the phosphate and potassium permanganate contents of the riverwater, and a lower biochemical oxygen demand. On the other hand, the discharge of ammonia into recipient riverwaters is still high in Austria, as it is not yet generally oxidized during sewage treatment. However, legislation has been passed in both Germany and Austria to oxidize ammonia and reduce the nitrogen content of treated water.

Future developments on the Danube

The systematic monitoring of water levels and measurement of flows in the Danube have revealed changes in the river bed. Since the power-station on the upper parts of the River Inn, near Kirchbichl, was built in the 1940s, erosion of the river bed has occurred in the Linz basin, and the Tullner Feld (about 40 km upstream from Vienna), and subsequently also downstream from Vienna, where a substantial deepening of the bed of the Danube (c. 2 cm per year) has been observed. Mathematical models can now be used to calculate the effects of building another barrage on the Danube at Vienna (see Fig. 2). A barrage here will accelerate the scouring of material from the river bed and deepen the river downstream, whereas this process will continue to deepen the entire Vienna basin if the barrage is not built. Since the Altenworth ecosystem study has shown the overall effects of constructing a barrage and impoundment on the river, numerous schemes for reducing the scouring effect have been discussed. These include terracing the river bed, armouring the bottom, introducing ground sills, diverting discharge, adding coarse materials etc., with the aim of protecting the river and its bankside forests in the form which it has adopted since the river was first regulated in the last century.

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