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2.7 The importance of reservoirs for water supply and power generation - An overview

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***SUMMARY:** Reservoirs have a high level of multi-functionality. They are used for water supply, energy production, flood protection, ecological services and recreation. As a multi-purpose construction and drastic intervention into nature there are a lot of aspects to be accommodated in a highly responsible manner. Due to growing populations and expanding economies, artificial reservoirs are necessary for storage and transport of water, in order to cover the continuous, anthropogenic demand for water from the non-continuous, natural water supply and to attain and preserve the fundamental human right for access to clean water. Hydropower plays an important role in regenerative power generation in base load and especially in peak load times in the electricity network. Other benefits are the high degree of saturation, the highest efficiencies and high durability combined with low utilisation servicing costs.*

The goal of human interventions into nature is to improve the foundations our society is based on. The interventions necessary for the supply, storage and distribution of water have been decisive in the development of human culture, both in earlier times and today. To cover the continuous, anthropogenic water demand from the non-continuous, natural water supply and to attain and preserve the fundamental human right for access to clean water, artificial reservoirs for storage and transport of water are necessary. This continues to be important today, as many people still do not have adequate access to acceptable hygienic water.

A further logical consequence of social development is the use of water to store energy as part of its natural cycle, which is driven by solar energy. As a limited natural resource, water became an economic good with sociological influence on society as a whole. This influence becomes apparent when considering the requirements of a reservoir. The interests of water supply, energy production, flood control, ecology and local recreation all have to be considered. This complexity and the subsequent potential for conflict has recently led to a decrease in the acceptance of large dam projects. As per the International Commission on Large Dams (ICOLD), a large dam has either a height of at least 15 m above the foundation, or a 5–15 metre retaining wall, with a minimum storage volume of 3 million m³. According to this definition there are more than 45,000 large dams world-wide (World Commission on dams p.6). This article will describe the great importance and the enormous benefit of reservoirs in relation to water supply and power generation. In this regard, *Fig. 2.7-1* shows two examples of reservoirs of varying age and design.

Historical overview

The settling of humans around 5000 years ago and, as a consequence, the increasing demand for drinking water and industrial water for agriculture, was the initial cause for the building of reservoirs to manage the naturally irregular water supply. The resulting benefit becomes

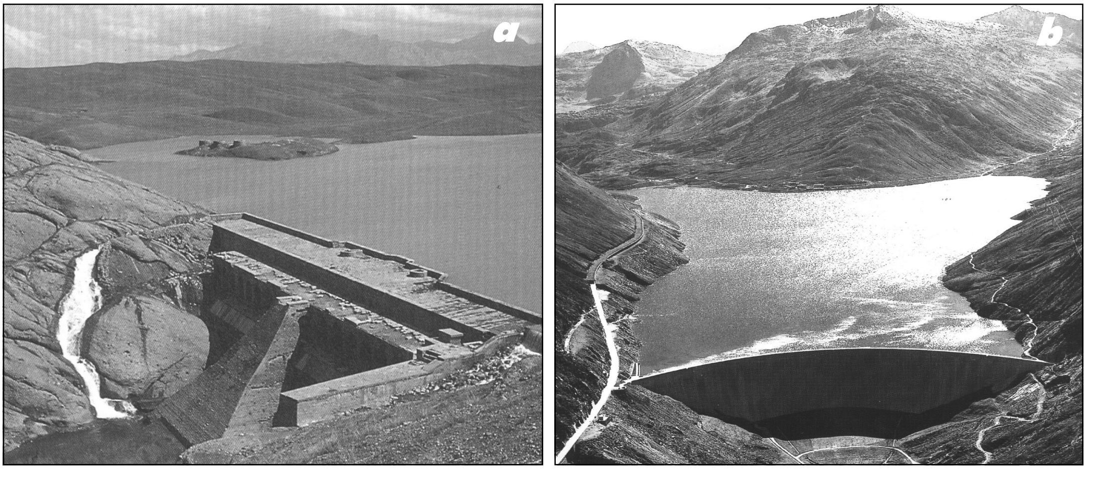

***Fig. 2.7-1:** a):* Bend-e-Fahriman (Iran) (GARBRECHT 1987). *b):* Reservoir Sta. Maria (Switzerland) (GESELLSCHAFT FÜR INGENIEURBAUKUNST 1998)

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apparent particularly in arid areas or in areas with distinct rainy and dry seasons, where the use of water is not possible without storage. The 14 m high Egyptian dam Sadd el Kafara, constructed in 2550 B.C., is considered to be one of the world's oldest reservoirs. The construction technique for this Earth-fill dam is still applied today (GARBRECHT 1987 p. 23). Thus, access to drinking water has always been the limiting factor in the development of societies and has therefore inspired civilisations to high technical achievements. An outlook to the future shows that further population growth and uncertain climate trends will probably necessitate the development and protection of freshwater.

The energy capability of water was first used in the course of further technical developments of mills, saws, and forges. The transmission of the useable power progressed from direct transfer to transfer with bars and ropes. During the Renaissance period, the scientific grounds for technical methods were finally laid out and, with the technology of electricity as an acceptor of energy, a totally new development phase for the utilisation of hydropower was started (GESELLSCHAFT FÜR INGENIEURBAUKUNST 1998). For example, in Berlin, electric power was first made available from public power stations in August 1885, after Werner von Siemens had electrical illumination installed around the Potsdamer Platz. From this time on, the use of the water wheel and its evolution into low-pressure and high-pressure turbines has played an important role in the generation of energy, in addition to non-regenerative engines for generators such as the steam engine.

The growing demand for energy due to the increasing mechanisation of the industrial countries of central Europe has been increasingly met by non-regenerative energy. *Fig. 2.7-2* shows developments over the last 250 years, and also extrapolates the possible trend into the future. The growth of the world population and the decrease in natural resources such as gas, oil, uranium and coal make the rapid development of all available renewable energy sources a life- essential requirement

Functions of reservoirs

A distinguishing feature of reservoirs is their high degree of multi-functionality. A major function is the storage of water to supply the needs of industry and agriculture. More than 50% of all reservoirs world-wide have this as their primary purpose. Roughly 30 to 40% of irrigated areas world-wide (271 million hectares) obtain their water from reservoirs. The total extraction of freshwater is estimated to be 3.800 km³/year. The total amount has doubled in the past 50 years (WORLD COMMISSION ON DAMS 2000, p.6). Growing populations and expanding economies, coupled with declining groundwater-tables and decreasing surface water quality highlight the importance of the storage of water in reservoirs. Management of water resources is needed whenever the natural supply of water decreases.

The storage capability of reservoirs serves to dampen an incoming flood wave, even without specifically controlling the shut-off valves, and is therefore an active flood protection component. The storage area absorbs large volumes of water and releases them in a time-delayed manner. This task which is considered to be the main function of flood control reservoirs only, is shown in *Fig 2.7-3*. During flood situations, this retention capacity of reservoirs also reduces the flood risk in downstream areas when the reservoir is being actively managed.

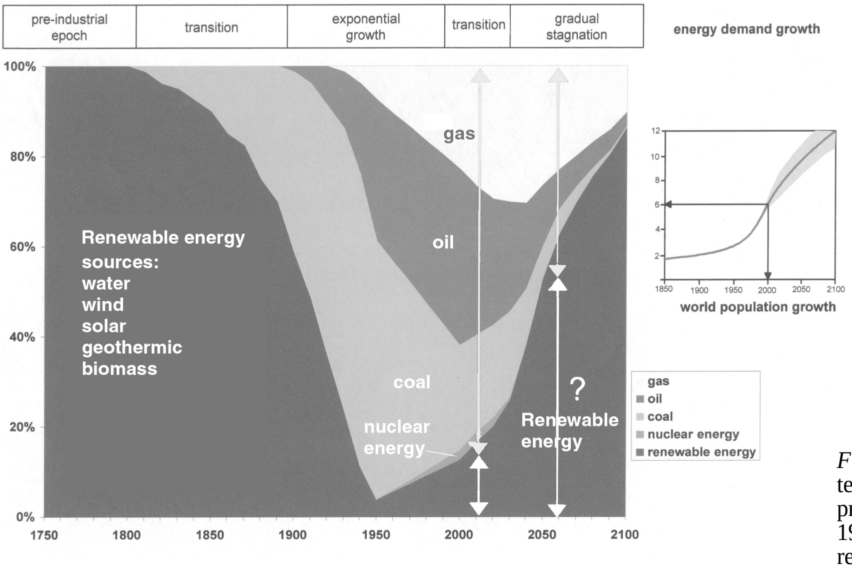

Fig. 2.7-2: Epochs of technologies of energy production. Source: ROHDE 1980 und WBGU 2003; revised: FN / IWK, 2003.

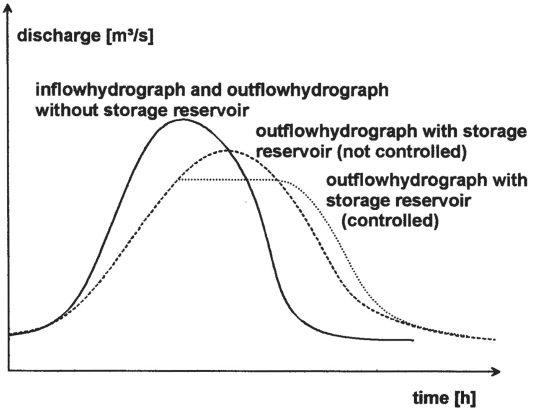

Fig. 2.7-3: Use of dams for flood protection.

Power generation and the use of reservoirs as a renewable energy source are of great importance but depend on the supply of water, the terrain relief and other conditions. 17% of electricity world-wide is generated by hydropower (see *Fig. 2.7-4*). While there is still great potential for hydropower in many countries, the maximum degree of utilisation has nearly been reached in Germany. Nevertheless politicians have to provide planning guarantees and security for investments in hydroelectric power stations, since hydropower is an investment-intensive form of energy production, due to planning and licensing procedures that can take many years. Furthermore, hydropower is the most important renewable energy source in Germany, producing more than 50% of the regenerative energy.

Hydropower has an advantage over other regenerative energy sources for many reasons. The yearly utilisation duration of hydropower demonstrates the smallest fluctuations due to the relatively constant availability of water. In this regard wind energy has more unfavourable values. Moreover, the high energy density of water in comparison to air plays an important role, because the plant's required floor space in relationship to the energy produced is rather small. The harvest coefficient, which is defined as net energy production in relation to invested energy for construction and operation of the installation, is advantageous. The long durability with relatively low maintenance costs for the installations is also an advantage (see *Fig. 2.7-5*). Furthermore, with an efficiency of approx. 80%, hydropower ranks first among all known energy sources. In view of all these aspects, the advantages of long experience with the fully developed technology of hydropower are evident.

Hydropower from reservoirs is used in diverse ways. In order to cover the peak load, to deal with fluctuations in electricity demand, and to maintain the stability of the electricity network, power stations have to be temporarily connected to and disconnected from the network. For this purpose pumped-storage power stations are of particular importance, because only they are able to startup within a few seconds and thus ensure the energy supply at times of fluctuating demand.

Furthermore, pumped-storage power stations have the ability to store surplus energy for use in the case of a regional power failure. Nowadays, fluctuations in network demand over Europe are dampened by connecting and disconnecting pumped storage power stations. But reservoirs also provide an important and reliable contribution to the base load duty of the energy supply.

Finally, reservoir projects provide an important stimulus for regional development of the infrastructure, economy and community social life. Both temporary and permanent employment opportunities are created, directly and indirectly. Big reservoirs often represent the most important basis for industrial development and export capacity in developing countries.

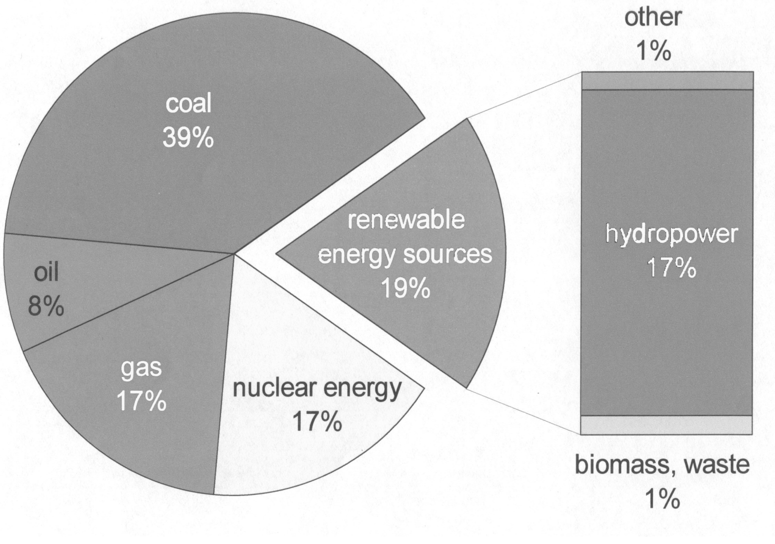

Fig. 2.7-4: World-wide power generation 2001. Source: EIA, 2003; revised: FN / IWK, 2003.

Construction and operation

The operation of a reservoir requires the integration of the realities of nature and anthropogenic requirements. The reservoir capacity is partitioned into storage lamellae (see *Fig. 2.7-6*), the size of which depends on the above variables. The dimensions of the reservoir are calculated based on mean inflow and economic considerations; the spillway dimensions take extreme flood events and safety aspects into consideration. In terms of the balancing effect of reservoirs, a differentiation is made between daily, weekly, and annual reservoirs as well as conservation storage reservoirs.

In determining the dimensions of a reservoir, long-term, continuous readings of precipitation, discharge, retention capacity of the catchment area, evaporation and infiltration, surface and soil conditions such as permeability, general climate readings and further factors are needed. Furthermore, the effects on flora and fauna, groundwater, ice conditions, suspended load, and bed load are to be taken into consideration. An important parameter for flora and fauna is the detention time t_A. As a multi-purpose construction and a drastic impact on the natural habitat, several standpoints have to be accommodated in a highly responsible manner.

The key position in a reservoir is the barrage construction. When selecting an appropriate site, a geologically and topographically well formed area has to be found, which is optimal in terms of the form of the valley, impermeability, and load capacity. The results of this research determine the type and dimensions of the barrage.

In general, there are either concrete dams or embankment dams. Concrete dams are made of quarry-stone, concrete or reinforced concrete and are built on rock. They can be subdivided into gravity dams, arch dams and counterfort-type dams. Embankment dams make fewer demands on the foundation and are less sensitive to subsidence and Earth tremors. However, they always require greater quantities of building material. They are mainly composed of sealing and guarding components. They differ according to the location of the seal in both standard dams and dams with an outer or core seal.

Operational facilities such as operating outlets, bottom outlets and spillways are integrated into the structure. *Fig. 2.7-6* shows the schematic profile of a reservoir. Great attention must be given to the dimensioning of the spillway, based on the highest assumable flood discharge, to ensure the safety of residents living downstream.

Difficulties with reservoirs

The construction and operation of a reservoir is an impact on the water regime and a fundamental modification of the ecological system, which has to be evaluated on an individual basis. Attempts are made to counteract the hereby resulting division of ecological habitats using methods such as fish ladders, bypass watercourses etc. Where this is not possible or not adequate, the ensuing ecological harm is reduced – particularly in Germany – by further ecological compensatory measures. On the other hand, the construction of a reservoir may contribute to the enhancement of the ecosystem by creation of new wetlands.

A further important aspect is the alluviation of bed load and particularly suspended load from upstream in the storage area. Through the emerging siltation the reservoir capacity and eventually the life expectancy of

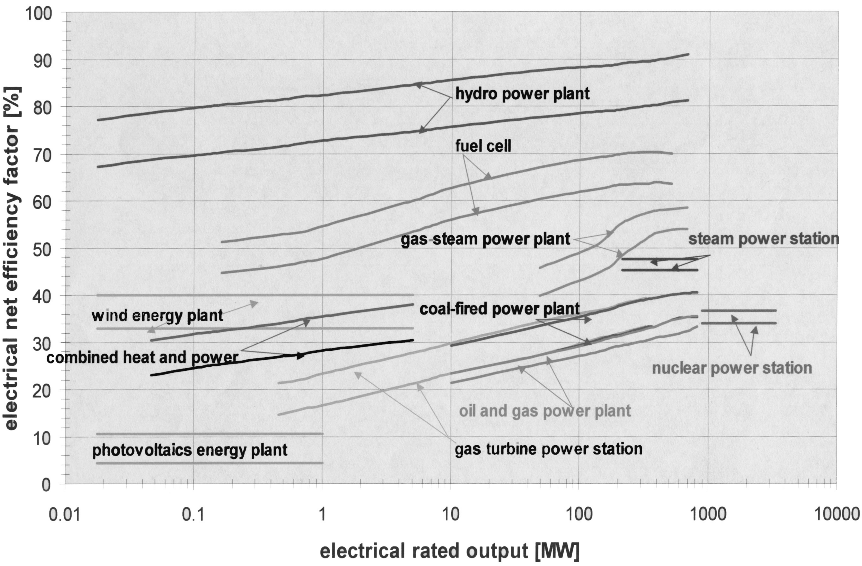

Fig. 2.7-5: Efficiency of different technologies.

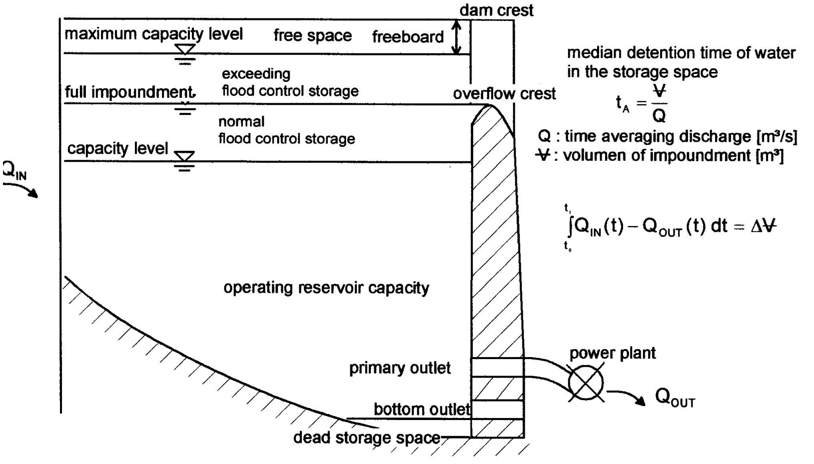

Fig. 2.7-6: Schematic illustration of a reservoir.

the construction is reduced. Cohesive elements may consolidate and make disposal very difficult. A detailed investigation of this problem has to be performed for every project and is a subject of intensive research at the respective technical institutes. However, a solution is not in sight at present.

Finally, social aspects such as the resettlement of affected households, inequitable allocation of ensuing benefits, and border disputes have to be considered while planning a reservoir. These problems are often not considered sufficiently. They are responsible for a negative image of dams in the public opinion, despite the advantages described in the preceding sections. This can be traced back to major projects that had not taken a balanced approach to the above issues. In the end it is a fact, that reservoirs are beneficial to humans in everyday life and that, without reservoirs, the useable water supply could not be adequately provided. Furthermore, approaches such as the thrifty use of energy and water or improved use of current capacities cannot solve future problems in relation to water supply and power generation.

Summary and outlook

The natural water supply that is accessible to humans does not correspond with the anthropogenic water demand. Reservoirs are necessary to achieve or assure better access to clean drinking water. Access to drinking water has always been the limiting factor in the development of societies, because the founding of cities and increase in food production are not possible without water management. Looking toward the future, continued population growth and uncertain climate trends necessitate further efforts at tapping and assuring the freshwater supply.

Hydropower, as a regenerative energy source, can and must be of significant importance in the solution of global energy and water problems. The general preference for regenerative energy sources as well as for the reduction of emissions of carbon dioxide and other harmful substances are augmented by the high degree of effectiveness, extreme durability and good harvest coefficient of hydropower. Reservoirs, built at appropriate locations, could fulfil the demands stemming from the fields of ecology and economics.

In particular, pumped storage power stations with their upper and lower reservoirs take on a special role in supplying energy during daily peak load periods. In periods of low load, energy can be stored flexibly and quickly in the upper reservoir. In peak load periods, this energy can be fed into the network equally fast.

In the face of growing populations and expanding economies, as well as the economic demands of emerging nations, reservoirs will help to solve global problems. For developed nations it is especially important to solve problems related to the use of fossil fuels and to meet the targets of the Kyoto Protocol.

The storage function of reservoirs actively contributes to flood protection. The storage area holds back high discharge volumes and releases them time-delayed. This property is often a most welcome by-product of their original and planned functions. The construction and operation of reservoirs constitutes an impact on the water regime and a modification of the ecological system, which has to be evaluated on an individual basis. As a multi-purpose construction there are several ecological and economical points of view to be accommodated with the utmost sense of responsibility. Particularly in Germany, compensatory measures are used to fulfil environmental requirements. Moreover, the construction of a reservoir may result in an ecological amelioration through the creation of additional and valuable wetlands♦

In conclusion a citation from Nelson Mandela: »*The problem is not the dams, it is the hunger, the thirst and the darkness in the housing areas*«.