ENERGY FROM HYDROPOWER
INNOVATIVE AND REGENERATIVE

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1 Introduction

The growing energy demand worldwide on the one hand and the emerging ecological awareness on the other are leading to an increased demand for regenerative energy. As a continuously available base-load energy supply option, hydropower is a significant regenerative energy source. The paper at hand lists three examples of hydropower plants which meet the economic requirements and current environmental boundary conditions. Special attention is paid to the interdisciplinary interaction of energy policies, energy prices and ecological components. If these boundary conditions had not changed profoundly within the last 5 years, none of these projects would have been realised.

Studies to determine new locations for small hydropower plants have explored innovative avenues, with due consideration of ecological and economic aspects. There is, however, a strong need for updating the methods for determining and establishing supra-regional master plans which take into account present, and as far as predictable, future developments. The hydropower plants that are currently being realised or about to be realised are predominantly based on old studies, with economic data (investment costs and revenue) having been updated, but without addressing the general actual issue in view of energy demand, ecology and globalisation.

2 Small-scale hydropower plants

2.1 Background and strategic approach

The EU Directive on the promotion of electricity produced from renewable energy sources in the internal electricity market (2001/77/EC) obliges Austria to increase its production from renewable energy resources by more than 100% from the year 2010 onward. Parallel to this Directive, the EU Water Framework Directive (WFD) postulates a good ecological status and potential for all water bodies. That is why a regional planning tool is required to undertake the following tasks:

- Depiction of the regional scope of action, which takes into account both objectives
- Compilation of data for small-scale hydropower plants with regard to ecology and energy.

The implementation of the requirements is effected through a framework plan. When elaborating the framework plan the following relevant data are incorporated:

Basic data – energy aspects:

- Hydrology: gauge levels from hydrological yearbooks
- Topography: catchment area sizes and potential head conditions
- Existing facilities: surveys using questionnaires and water registers

Basic data – ecological aspects:

- General information (e.g. protected areas)
- Linear information such as morphological structure, distribution of sensitive species along a river stretch
- Selective information such as biological quality of rivers and streams

2.2 Development of hydropower potential through the construction of new plants

The study (ILF 2004, Widmann Thonhauser, Moritz 2005) investigated 4200 km of exploited and unexploited river stretches. The ecological data were used to establish criteria for a supra-regional assessment of the ecological viability of potential new projects and to define minimum requirements for environmental flow (residual flow, fish passes). These minimum requirements were used to ascertain the hydropower potential. Four categories were established to assess the ecological compatibility of the construction of a hydropower plant:

Category 1: justifiable
Category 2: possibly justifiable
Category 3: generally not justifiable
Category 4: not justifiable / exclusion criteria

Table 1 lists the rating matrix of the ecological criteria for the construction of new hydropower plants.

An energy-oriented assessment of unexploited portions of rivers was performed by means of an economic analysis. According to Gordon (1983), the investment costs (I) were determined from the head (H) and the capacity (P). The constant C was derived from existing hydropower plants in Lower Austria (Fig. 1).

$$I = \left(P / H^{03} \right) \times C [€]$$

Evaluation criteria	Justifiable	Possibly justifiable	Generally not justifiable (exclusion criteria in red)
Supraregional sensitivity	low	medium	high
Prevention of further deterioration of morphological structure			all river stretches of quality class 1 and/or with no significant structural measures
Existing water diversion or reservoir	no water diversion or reservoir	---	existing water diversion section or reservoir
Water quality	Quality class < II	Quality class = II	Quality class > II
Protection area	outside protection area	Natura 2000, Landscape Protection Area Nature Park	**Nature Reserve Natural Monument (National Park)** Protected Spawning Ground
WFD reference and intercalibration sites		Location upstream	**WFD reference and intercalibration site**
Special fauna feature: freshwater pearl mussel		Lainsitz, Kamp and Krems River Basins	**Existing population according to MOOG et al. 1993 and current survey data according to STUNDNER**
Tributary to River Danube permitting fish migration		River Mouth Sections for River Danube Tributaries: Stream order: 1-3: 1 km	River Mouth Sections for River Danube Tributaries: Stream order 6 and larger: 10 km Stream order 4-5: 5 km
LIFE Project Area („Lebensraum Huchen" – Danube salmon habitat)			Designated LIFE project areas at Melk, Mank and Pielach rivers
Mean average low flow ($MJNQ_T$)	> 100 l/s	50 - 100 l/s	< 50 l/s

Table 1: Rating matrix (ILF 2004, Widmann, Thonhauser, Moritz 2005).

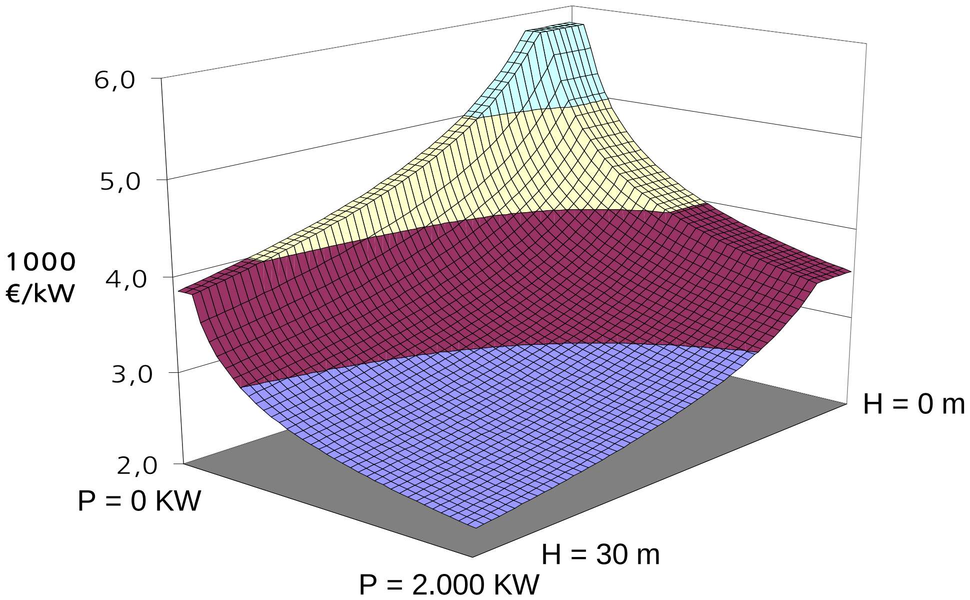

Figure 1: Specific investment costs [€/kW].

The hydropower plants were categorised according to energy-oriented criteria using the factor Investment Costs (I) versus Internal Rate of Return (R).

Category 1: I/R < 1.0	economically useable
Category 2: 1.0 < I/R < 1.2	possibly economically useable
Category 3: I/R > 1.2	not useable

The revenue is influenced significantly by the attainable energy prices (tariffs). An assumed tariff reduction to 75% of the estimated value results in a doubling of the not useable river stretches. A tariff increase has the opposite effect.

Superimposing the energy-oriented analysis on the ecological criteria results in the potential of the to date unexploited river portions (Table 2). 27% of the river stretches unexploited to date are useable in a techno-economic regard and are located in areas justifiable or possibly justifiable from an ecological viewpoint, permitting the development of approx. 50% of the overall additional potential.

Potential	Energy aspects		
Ecological aspects	**Useable**	**Possibly useable**	Not useable
Justifiable	**3%**	**5%**	3%
Possibly justifiable	**7%**	**12%**	22%
In general not justifiable	13%	10%	20%
Not justifiable / exclusion criterion	1%	3%	3%

Table 2: Interaction matrix of the potential along river stretches not exploited to date.

2.3 Revitalisation and rehabilitation of existing plants

The province of Lower Austria has 306 small-scale hydropower plants with a capacity of 72 MW. They generate some 408 GWh/a of electricity. 424 km of river stretches are being used for this purpose. This amounts to about 11% of the investigated river sections. The assessment of the existing plants was done in an analogous manner, using selected energy and ecological criteria, and shows that there is potential in the revitalisation and rehabilitation of existing plants (ILF 2004, Widmann, Thonhauser, Moritz 2005).

In addition, shutting down plants with a low annual production and relatively high utilization of river stretches was investigated, applying the same criteria. From an ecological viewpoint it makes sense to shut down plants with an overall annual production of 56 GWh/a, this corresponds to 13% of the current annual production, which would make it possible to restore 176 km or 44% of the rivers to their original state.

2.4 Overall potential

By consolidating the potential of constructing new plants and revitalising existing ones, lower and upper limit values for additional energy production were obtained (Table 3). The existing plants have a capacity of 408 GWh/a. The increase of potential thus ranges from 11% to 90%.

	Lower limit	Upper limit
New construction	35 GWh/a	297 GWh/a
Revitalisation/rehabilitation of existing plants	9 GWh/a	73 GWh/a
Total	44 GWh/a	370 GWh/a

Table 3: Summary: potential of new construction and revitalisation

2.5 Summary and outlook

Essential results of the study are:

- Evaluation and assessment of the existing small-scale hydropower plants
- Evaluation of ecologically justifiable development potential in existing plants that is of interest with regard to energy production
- Evaluation of ecologically justifiable development potential in undeveloped river stretches that is of interest with regard to energy production
- General recommendations for implementation

The structure of the master plan makes it possible to adapt the compiled knowledge to future modifications. The master plan for making use of hydropower potential by means of small-scale hydropower plants is therefore an efficient instrument for

- documenting the actual situation
- assessing steering measures and concrete projects
- documenting the implementation.

3 Feldkirch-Hochwuhr Hydropower Plant

3.1 Project description

The project for the rehabilitation of the city of Feldkirch’s old diversion power plant on the Ill River in Vorarlberg was the reason for analysing the overall situation and developing an interdisciplinary solution taking account of flood protection (the Ill river floods Feldkirch approximately every 2 years), the power generation needed especially for Feldkirch and the upgrade of the river bank along the affected section in terms of architectural aspects. The project of ILF Consulting Engineers that won a design competition permits an economical rehabilitation of the existing structures, and at the same time significantly increases the Feldkirch municipal works’ own energy generation, ensures continuous residual flow in the river stretch through the city, eliminates migration barriers and significantly improves flood protection of the town (Fig. 2). The Hochwuhr hydropower plant has been supplying 4,000 households with electricity since 2003. With a head of 9.5m, a design flow of 50 m^3/s and an installed capacity of 4 MW, the goal is an annual production of 17.4 million kWh (Fritzer, Widmann, 2001, Schöberl, Fritzer, Mathis 2003, Mathis, 2006).

Figure 2: View of the completed run-of-river plant.

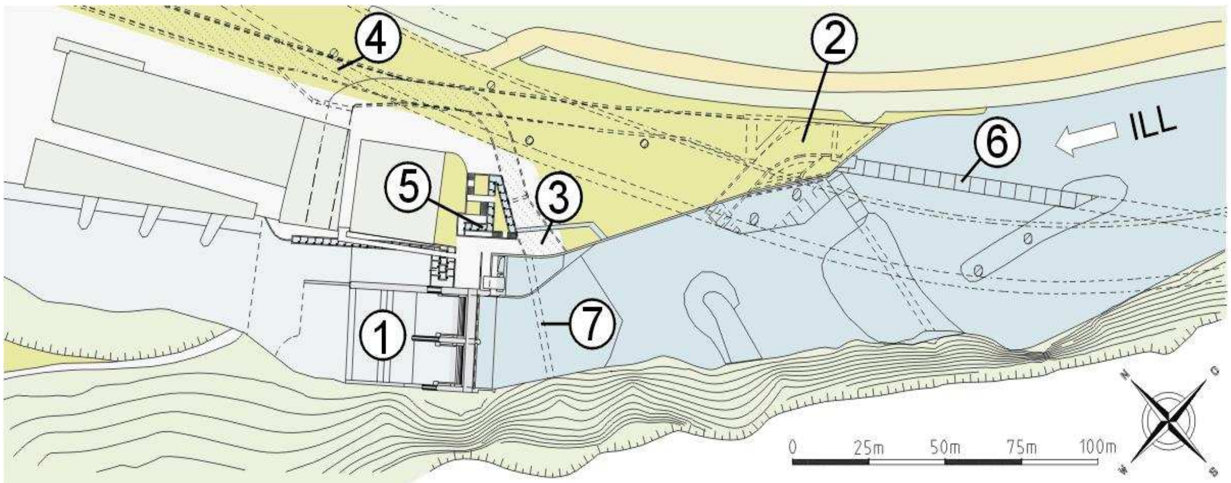

Figure 3: Layout (legend: 1 = KW Hochwuhr; 2 = old intake of the headwater channel; 3 = new intake; 4 = rehabilitated headwater channel; 5 = fish pass; 6 = lateral weir; 7 = "Hochwuhr").

The layout with the most important components is depicted in Fig. 3; Fig. 4 and Fig. 5 show representative sections through the powerhouse and the weir.

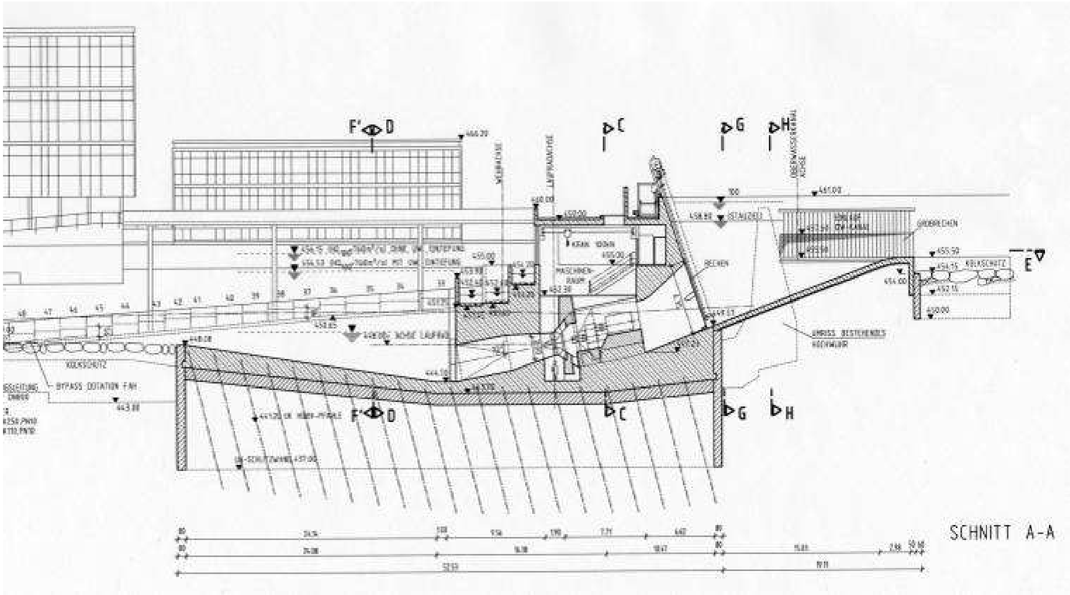

Figure 4: Section through the powerhouse.

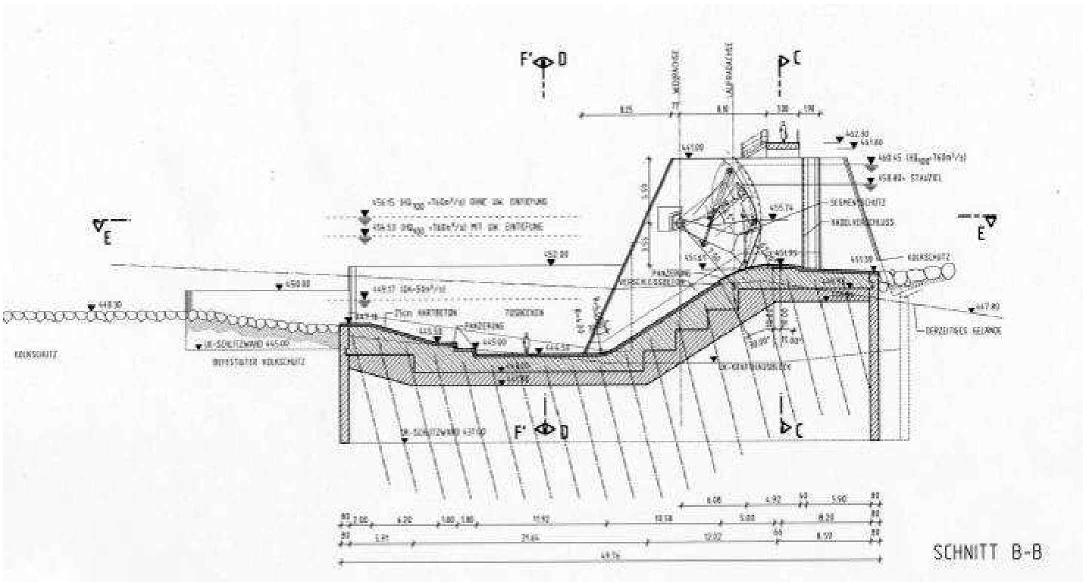

Figure 5: Section through the weir structure.

3.2 Economic feasibility studies

The decision to build the Feldkirch power plant was taken in 1999, based on investment costs of 10.50 million €. The IRR was calculated to be 5.51% (Cash flow in Fig. 6).

Unexpected difficulties during the underground works in 2002 (unforeseen geological and geotechnical behaviour of the ground/rock mass) resulted in cost increases totalling 14.50 million € until the completion in 2006, which significantly reduced the profitability (IRR 3.20%) (Cash flow in Fig. 7). After the cost forecast was presented based on the actually encountered underground conditions, it was briefly considered to discontinue the construction project despite the already effected advance investment of 1.5 million €. However, in the end, the decision to continue the project was a political one.

Due to a 54% increase of electricity costs from 1999 to 2006, the power plant currently has a significantly higher profitability (IRR 7.49%) as compared to the time of investment (Cash flow in Fig. 8).

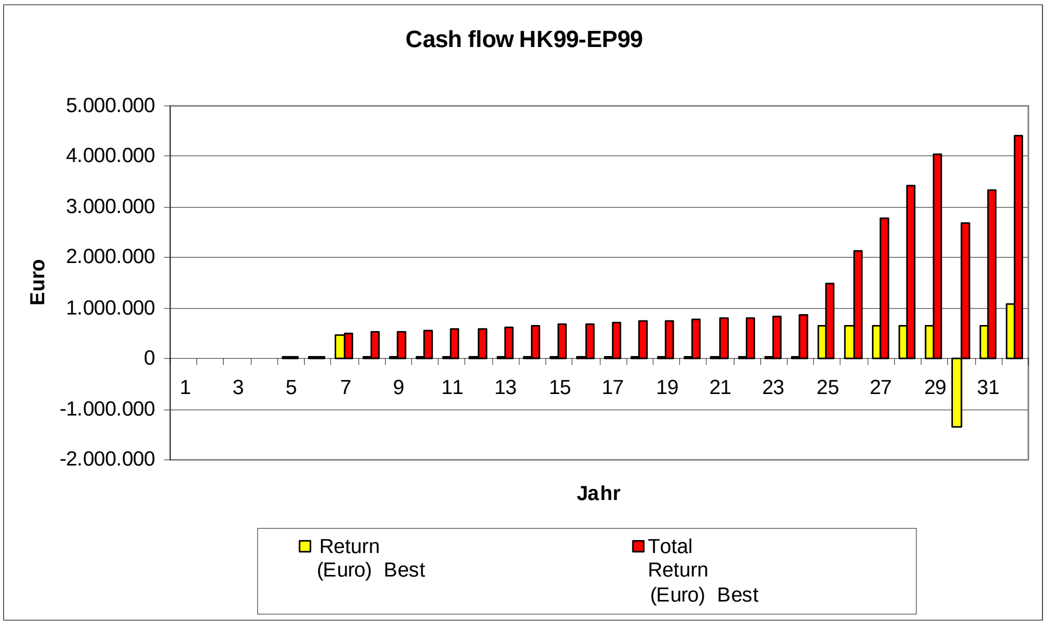

Figure 6: Cash-flow calculation 1999. Expected investment costs 10.50 million €.

This development can be attributed to the worldwide shortage in the energy market and clearly shows that it makes sense to adopt a progressive investment policy in the field of hydropower.

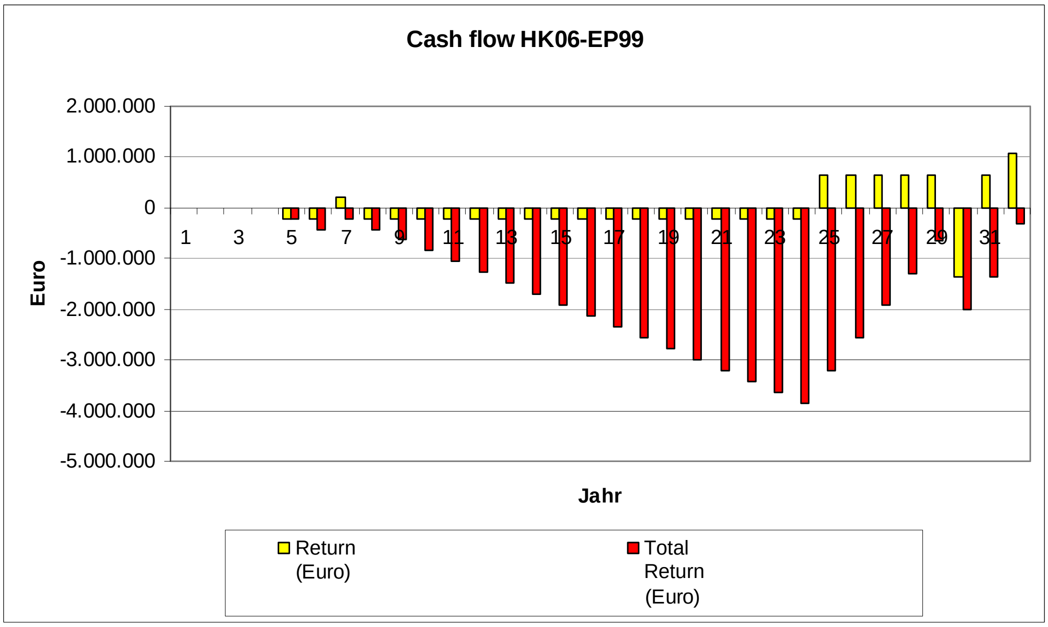

Figure 7: Cash flow calculation 2002: Expected investment costs 14.50 million €; Energy price as in 1999.

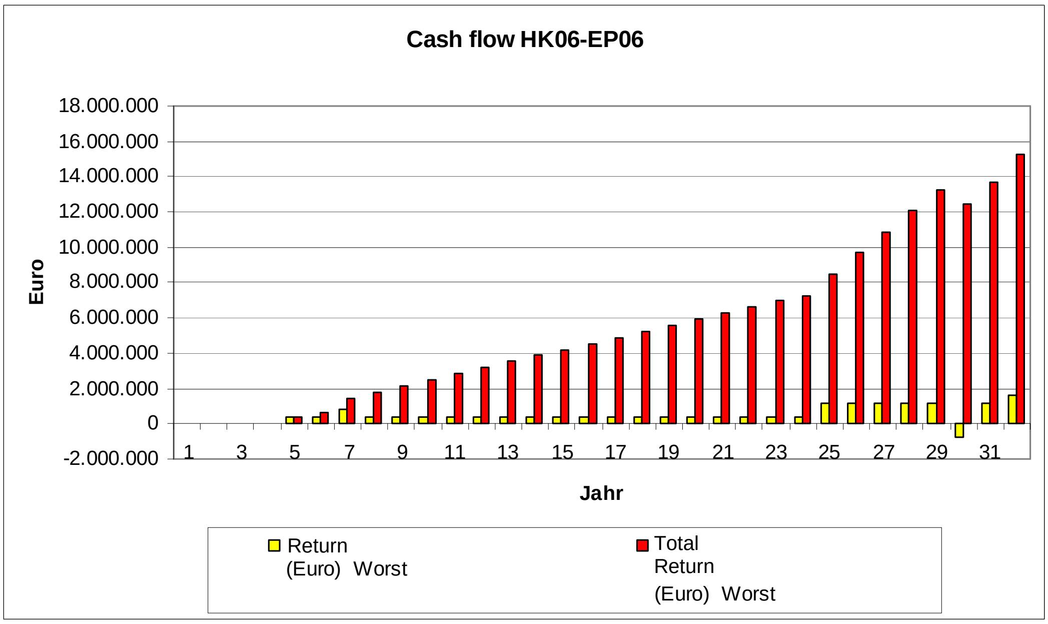

Figure 8: Final cash flow calculation 2006. Investment costs 14.50 million €; electricity costs as in 2006.

4 Sir Adam Beck Niagara Power Generating Complex

Figure 9: Sir Adam Beck Power Generating Complex: SAB 1 and 2.

4.1 Project description

The Niagara River is a river straddling the Canadian-United States International Border. Its overall length is 53 km with an average flow of 6000 m³/sec. Ontario Power Generation (OPG) will further increase the capacity of the existing Sir Adam Beck (SAB) power plant (Fig. 9) by implementing the third stage of the construction programme. An additional 500 m³/s of water is to be withdrawn from the Niagara River and conveyed to the existing powerhouse through a new tunnel (Diversion Tunnel) to be built (Fig. 10 and 11), facilitating an increase of 1.6 billion kilowatt hours in average annual energy generation.

Figure 10: Niagara Tunnel Project: Bird's eye view (Delmar, Charalambu, Gschnitzer, Everdell 2006).

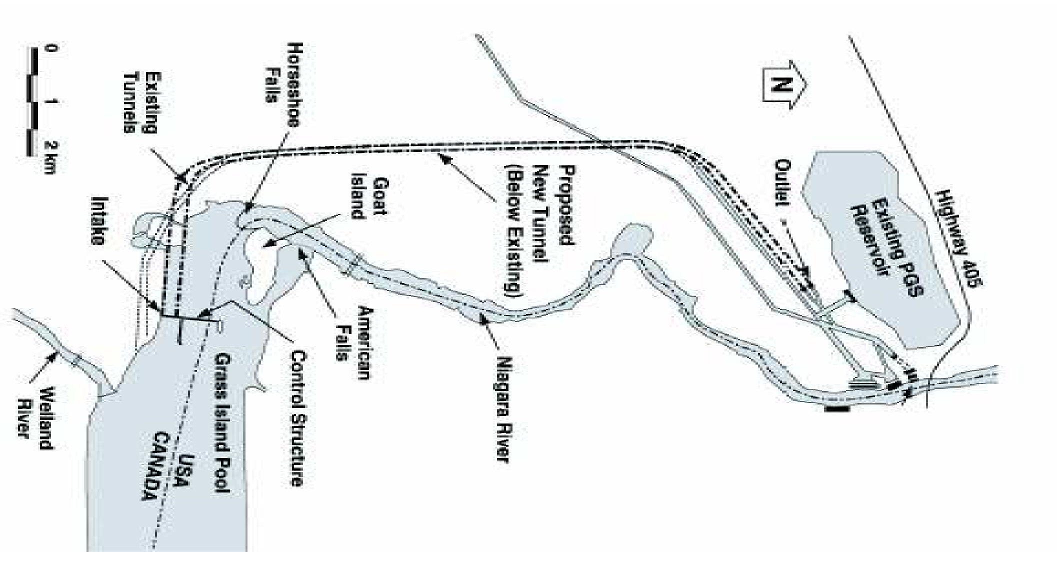

Figure 11: Niagara Tunnel Project: Location plan

On 18.08.2005 OPG awarded the Design and Build Contract to the STRABAG company on the basis of an alternative design elaborated by ILF. The contract encompasses the construction of a 10.4 km water tunnel (Fig. 11 and 12) with intake and outlet structures. The construction costs total some 420 million €. The project was initiated on 01.09.2005 and is meant to be designed and built within 4 years. The tunnel will be driven using a hard rock TBM with a diameter of 14.44 m (Fig. 13). During excavation, a temporary lining comprising shotcrete, rock bolts and wire mesh will be installed. The final lining with a thickness of 0.6 to 0.7 m will consist of non-reinforced concrete. For the structure to sustain operating water pressures of up to 15 bar, the final lining will be pre-tensioned by interface grouting.

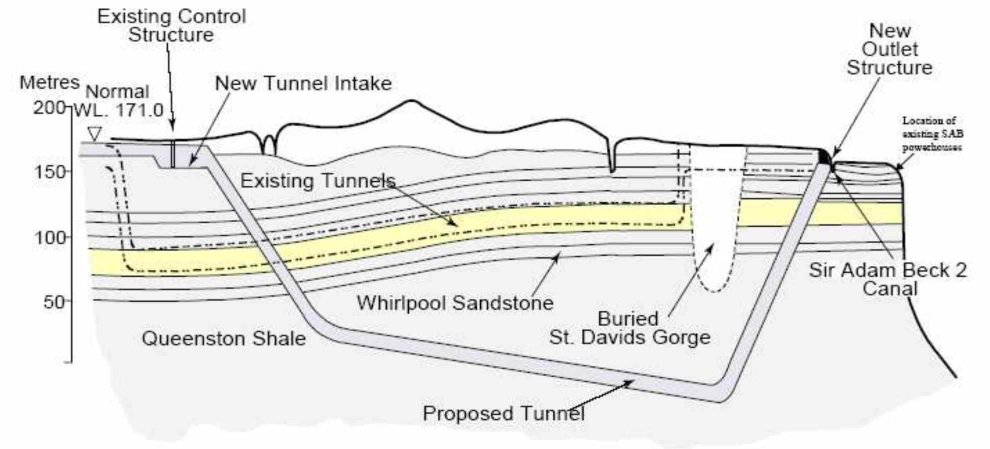

Figure 12: Niagara Tunnel Project: Longitudinal section

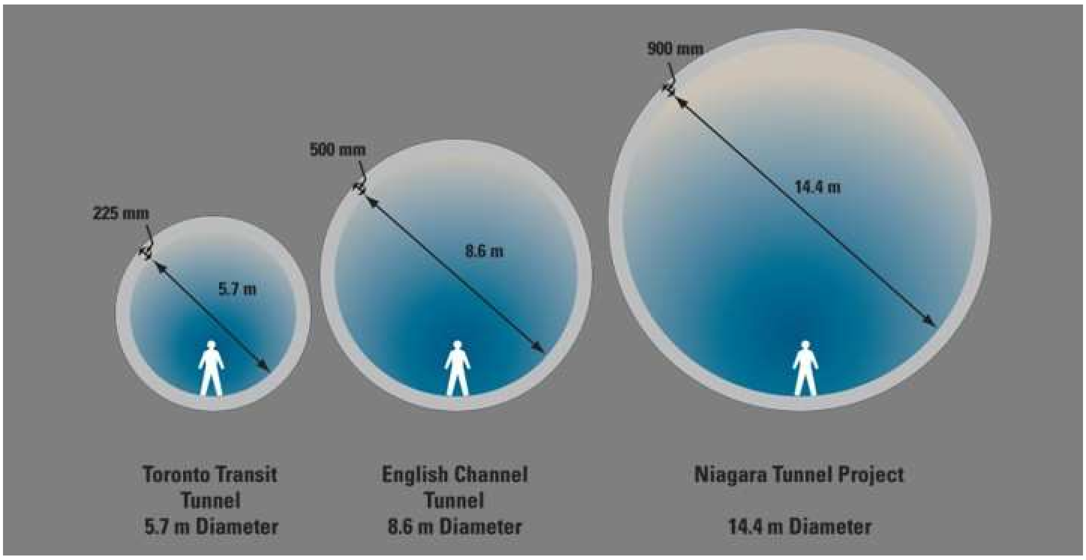

Figure 13: Cross section of the Niagara Tunnel (right) as compared to the cross section of the Toronto Metro (left) and Channel Tunnel (centre).

4.2 Economic Background

The hydropower potential of the Niagara River is utilised by Canada and the USA as laid down in the bilateral Niagara Diversion Treaty of 1950. Canada erected the Sir Adam Beck (SAB) Niagara Power Generating Complex in 1922 and 1954.

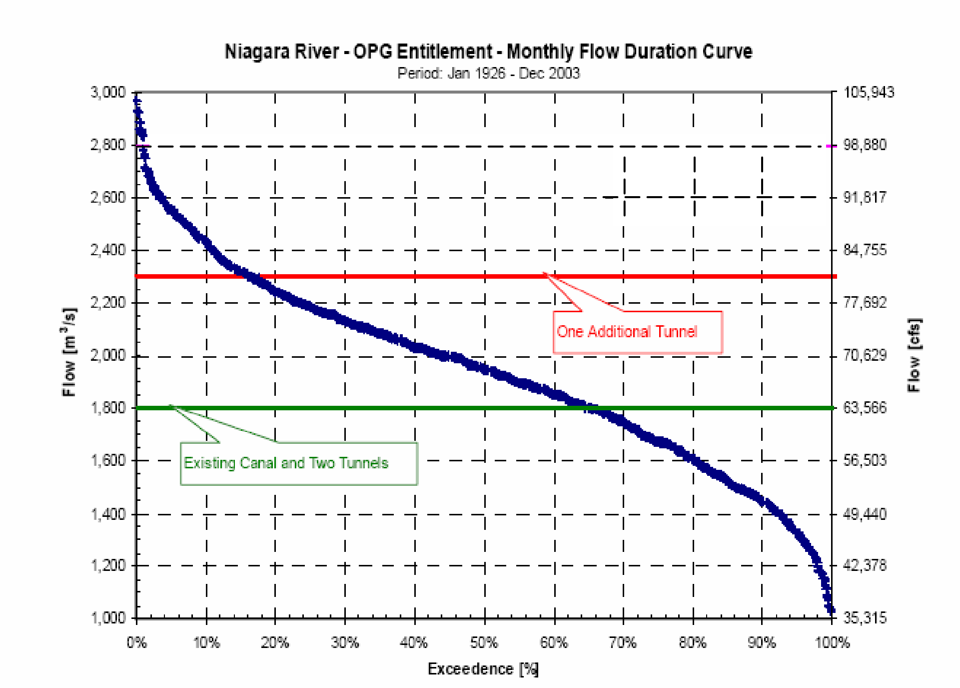

Figure 14: Water utilisation by Canada.

The decisive boundary condition for achieving a flow of 500 m³/sec is the roughness of the inner lining, in addition to the specified diameter. In order to give the company entrusted with the construction an incentive to achieve as little roughness as possible, a bonus–malus system was contractually stipulated, which recompenses any deviations from the contractually agreed flow rate. Furthermore, for any reduction of the construction period and thus earlier start-up appropriate additional compensation was agreed.

	In service Since	**Diversion Capacity [m³/sec]**	**Station Capacity [MW]**	**Annual Energy [GWh]**
SAB 1	1992	625	487	2700
SAB2	1954	1200	1472	9200
SAB PGS	1958	-	122	100
Current Totals		1825	2081	11800
Niagara Tunnel	**2009**	**500**	**-**	**1600**
Future Totals		2325	2081	13400

Table 4: Characteristic values of the SAB Niagara Power Generating Complex (Delmar et al. 2006).

Acknowledgment: The author wants to thank OPG for the permission to publish details on the Niagara Power Generation Complex.

5 Summary

On account of the worldwide growing energy demand renewable energy sources play an increasingly important role. Energy generated from hydropower which, in contrast to wind energy, ensures base-load supply, comprises an important component of the diversification of energy resources. The interdisciplinary study of existing energy resources permits ecologically sustainable resources to be systematically developed in future in order to join the worldwide efforts for environmentally friendly and sustainable construction. Due to the significant increase in energy prices since 1999, previously unprofitable projects can be implemented with a high degree of profitability.

New studies on the erection of new hydropower projects are needed. Most of the power plant projects currently being designed and built are based on more than 20-year-old studies. The technical, economic and ecological boundary conditions have changed significantly when one takes into account the globalisation of the energy market. That is why it is necessary to elaborate power plant studies which address these changed conditions in order to achieve the best possible efficiency and effectiveness when implementing new hydropower projects.

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