Climate change – a drying up of hydropower investment?

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INTRODUCTION

Despite international efforts, increases in atmospheric concentrations of "greenhouse" gases look set to rise further, given the threefold increase in world energy demand expected over the twenty-first century (Nakicenovic et al., 1998). By 2100 global mean temperatures are forecast to rise by 1.4 to 5.8°C and will be accompanied by increases in global mean precipitation levels (IPCC, 2001). The impacts of such changes will be significant and far-reaching.

Plans to control the rise in greenhouse gas concentrations have been put forward (UNFCCC, 1997) which aim to cut or stabilise emissions relative to 1990 levels. To achieve these targets, and, in future, even more challenging targets, the energy sector will have to reduce its reliance on fossil fuels, use more renewable energy and practice greater energy efficiency.

Over the next century much new and replacement generating plant will be required to meet global demand. These new installations will have to be achieved against a backdrop of increased liberalisation of electricity supply systems, so private investment will have to be used to fund this plant build. This, in turn, means that the attitudes and perceptions of current and future investors will play a major role in whether emissions cuts are achieved.

A rising demand for electricity, likely increases in fossil-fuel prices and the need for clean emission-free generation sources all appear to be trends in favour of increasing generation from alternative sources, such hydroelectricity. Indeed, hydroelectric production, currently supplying almost a fifth of global demand, is anticipated to increase threefold over the next century (Nakicenovic et al., 1998). However, two factors may prevent this from occurring:

1. The increased involvement of private capital may not favour hydropower given that hydro capital costs are relatively high and payback periods longer than might be preferred by private investors. Further, private investors generally expect a higher financial return than the public sector, traditionally the main source of funds for hydropower development.
2. More importantly, however, is that many parts of the world are forecast to experience significant changes in climate (IPCC, 2001). Studies have indicated that variations in river flows resulting from climate change will lead to changes in hydroelectric production (Harrison and Whittington, 2001a).

In the past, hydroelectric development was often linked to a larger political and economic programme, but, in future, it will be economics more than anything else, which will govern the building of new schemes. One feature of climate change is the alteration of precipitation levels and their distribution throughout the year. Given the potential for hydro development, the considerable associated costs and the risk of change to hydrology, the authors decided to analyse the impact of climate change on the economics of hydroelectric developments.

CHANGING RIVER FLOWS

Changes in precipitation levels will be accompanied by increased evaporation rates as temperatures rise. The combination of these changes will have profound effects on soil moisture levels in river catchments. The soil moisture levels regulate the flow of moisture into rivers, with, for example, saturated soils able to absorb only limited rainfall thus increasing the likelihood of flooding. Temperature rise will also lead to changes in snow storage, as proportionately less precipitation will fall as snow. Indications are that this will increase winter river flows, cause earlier spring thaws and reduce summer low flows (Gleick, 1986). Figure 1 shows a hypothetical example of this.

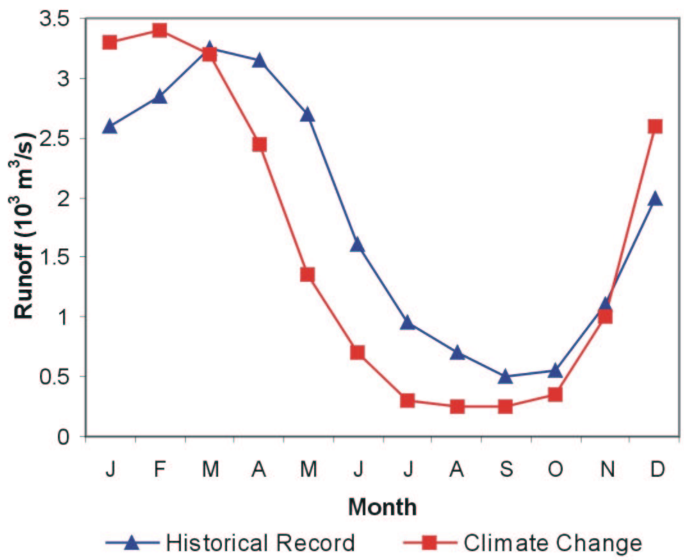

Figure 1: Hypothetical river flow patterns under current and potential climatic conditions.

Climate change impacts studies have, in general, relied on rainfall-runoff models to translate changes in precipitation and temperature into altered river flows. The changes can be based on results from General Circulation Models (GCMs) which provide information on how climatic variables may change in the future. Unfortunately, each GCM tends to predict a different change in temperature and precipitation, which results in significant and often, contradictory, differences between the resulting river flow impacts. An alternative is to examine basin sensitivity to changing climate, through the application of uniform changes in precipitation and temperature. Despite differences between the study techniques used and the climatic and hydrological characteristics of the study rivers, the following conclusions have been drawn (Arnell, 1996):

- Runoff is relatively more sensitive to precipitation change than temperature change.
- River basins tend to amplify changes in precipitation.

Evidence of Climate Impacts

A 1995 study (Reibsame et al., 1995), initiated by the US Environmental Protection Agency, examined climate impacts on several international rivers. For the Zambezi, the climate scenarios applied suggested that mean annual runoff could decline or rise by almost 20%. The most severe changes occurred for the River Nile: one scenario saw mean flows fall to less than a quarter of their historic level. Overall, it was found that river basin sensitivity increases with aridity, and this, to some degree, explains the severe fall in Nile flows.

Whilst changes in annual runoff are a useful indicator, often the seasonal changes are more profound. For example, a 1991 study (Mimikou et al., 1991) of the Mesohora basin in Greece found that a projected 20% fall in precipitation accompanied by a temperature rise of 4°C resulted in a 35% reduction in annual runoff. However, the decrease in summer flows was almost twice as large, with the fall in winter limited to 16%. This pattern is repeated in many other studies and is a result of changes in soil moisture content or seasonal snow cover. It is the seasonal aspect that has serious implications for hydroelectric generation.

HYDROELECTRIC GENERATION IMPACTS

At a given site, hydropower production is defined by the river flow, so changes in flow due to climate change will alter the energy potential. More importantly, as most hydropower schemes are designed for a particular river flow distribution, plant operation will become non-optimal under altered flow conditions. This occurs because the capability of a given hydro installation to generate electricity is set by its storage and turbine capacities, which place limits on the amount of carryover storage for generation during dry spells, and also the degree to which the installation can take advantage from higher-than-expected flows.

Several studies have examined the impact of climate change on hydropower production of which those listed in Table 1 are a representative sample. Published results suggest that the climate sensitivity of energy production is related to the storage available: in general, the greater the degree of storage the lower the sensitivity.

River	Annual Changes			
	Temperature (°C)	Rainfall (%)	River Flows (%)	Production (%)
Nile[†]	+4.7	+22	−12	−21
Indus[†]	+2.0	+20	+19	+20
Colorado[‡]	+4.0	−20	−41	−49

Table 1: Examples of potential changes in annual hydro generation resulting from changes in temperature and precipitation (Notes: [†] Reibsame et al. (1995), [‡] Nash and Gleick (1993)).

INVESTMENT

Energy production changes of the magnitude suggested in the literature will have a major impact on station revenue streams, with the sensitivity of revenue to changes in production dependent on the structure of the market in which the station is operating. For state-owned systems employing single energy tariffs, revenue will vary directly with production. Where the sales price varies with time, as in liberalised markets, a proportionately greater effect will be seen where variations in output coincide with high-demand and therefore, high-price periods. For a given power station, if energy output falls, the result will be higher unit electricity costs, a lower return on investment and also longer payback periods (if indeed the plant ever does). Essentially, the attractiveness of the scheme to potential investors would be lessened, and in the extreme case, potential schemes would not be pursued.

If potential hydro schemes are abandoned or production from existing facilities is limited by runoff changes, then alternative power stations will have to be constructed to cover the deficit. These are likely to be fossil-fuelled, given that the technology and fuel are, in general, readily available and, that their construction periods are relatively short. The impact of this is that not only would this require additional capital to be used, but it would also result in additional carbon emissions, thus exacerbating climate change (Whittington and Gundry, 1998).

Many large hydropower developments in less developed countries have been built with the intention of stimulating economic development. Often, these are internationally financed and repaid in hard currency. Reductions in revenue may make it difficult to repay the debt, putting pressure on exchange rates and stressing weak economies. Additionally, the shortfall in electricity availability will hamper Governments' development attempts (Whittington and Gundry, 1998). All of these issues will almost certainly act as disincentives for Governments to exploit their hydroelectric resources.

The authors believe that the magnitude of capital investment required for hydropower installations, together with the increased demands of private capital, make it imperative that project analysis takes account of potential climatic effects.

INVESTMENT APPRAISAL

Traditional techniques of hydropower appraisal are well established. Essentially, historic river flow data is used as an indicator of future conditions. However, given the prospect of climate change, this reliance on historic flows is not prudent. Several recent project appraisals have attempted to deal with climate change by uniformly altering river flows. Unfortunately, this practice is inadequate as it fails to take into account the tendency of catchments to amplify precipitation changes.

The authors have developed a methodology to overcome these shortcomings and have encapsulated the procedures in the form of a software model, illustrated schematically in Figure 2. The reliance on historic flows has been removed by employing a rainfall-runoff model to provide a link between climatic variables and river flows. This enables the relationship between climate and financial performance to be examined effectively.

The model's data requirements are quite extensive ranging from catchment details, to financing assumptions and time-series data. The primary data source is a time-series of historic climate data: the longer the series the better, but experience has shown that 30 years is the minimum period required if a high degree of confidence is to be placed on the results of the simulation.

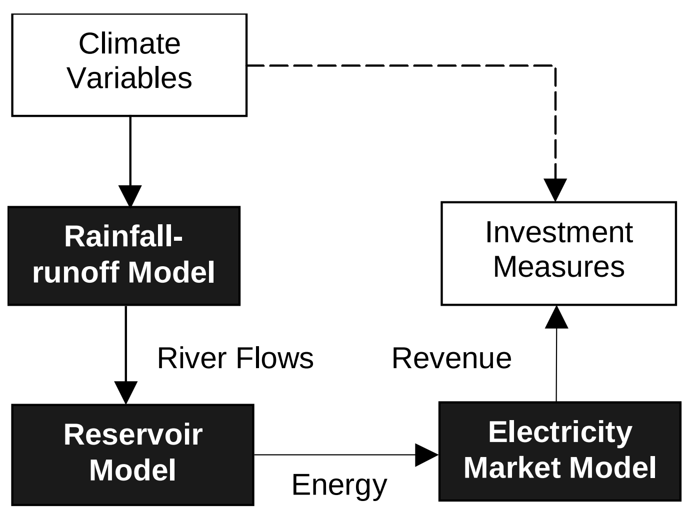

Figure 2: Schematic of new investment appraisal model.

CASE STUDY: BATOKA GORGE

The model was validated using data for the 1600 MW Batoka Gorge scheme planned for the Zambezi River upstream of Lake Kariba on the Zambia-Zimbabwe border (Figure 3). The 1993 feasibility study (BJVC, 1993) proposed a 181 m gravity arch dam with 1,680 Mm^3 of storage, but the relatively small storage (compared to Lake Kariba) means that the plant would operate as a run-of-river plant in association with Kariba to maximise firm power delivery on a system level. Annual energy production was estimated to be approximately 9,100 GWh. Basic operational and financial information was extracted from a traditional feasibility study of the scheme, and simulations indicated that the software delivered production estimates and investment measures that are comparable with figures found in the feasibility study. A series of analyses carried out by the authors show the impact of changes in climate on the financial performance of the Batoka Gorge scheme (Harrison and Whittington, 2001b; 2001c).

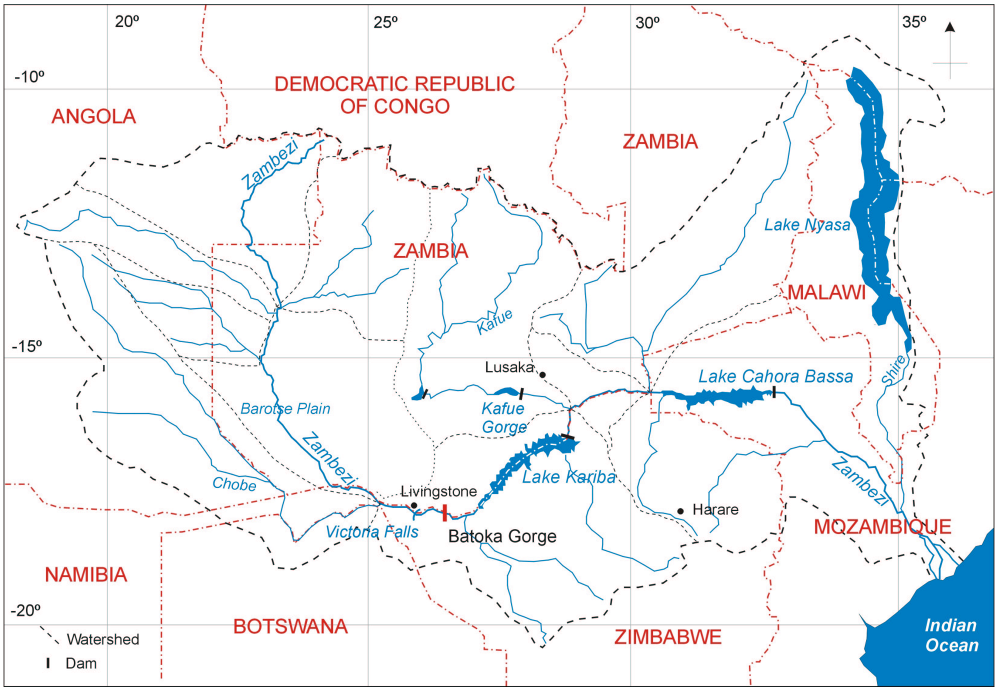

Figure 3: The Zambezi River Basin and the location of the Batoka Gorge scheme.

Scheme Sensitivity

The most simple of the three analyses was the sensitivity study, where the model was driven by historic precipitation and temperature data changed in a uniform manner to simulate climate change. Results suggest that runoff and energy production are sensitive to rainfall change, that runoff changes are significantly greater than the precipitation variation, and that, although reservoir storage is limited, production sensitivity is lower than runoff. It was also found that energy production is less sensitive to increases in flow as much of the excess flow is spilled.

The assumption of a single price for electrical production means that the investment sensitivity follows a similar pattern to production. Figure 4 shows the response of internal rate of return (IRR) and discounted payback to rainfall variations. IRR is positively related to rainfall, whilst discounted payback period shows the opposite trend (the incomplete trace indicates that the payback period extends beyond the assumed period for replacement of electromechanical equipment, in this case 30 years). The greater sensitivity to flow reductions can be seen. Although not shown in Figure 4, net present value varies in a similar manner to IRR. However, the compounding effect of revenue changes over the project lifetime means that the magnitude of the change is much greater. Over the range of precipitation changes given in Figure 4, changes in NPV range from –200% to 140%, with negative values of NPV indicating that the project will be non-viable. Overall, the results indicate that the scheme remains financially viable so long as annual average precipitation reductions are not more than around 11%.

While the sensitivity to precipitation change appears to be significant, it is useful to compare it with other non-climatic factors generally accepted as major project risks, for example, variations in construction cost or electricity sales price. Here it was found that the sensitivity of the Batoka project to precipitation changes was similar to that of electricity prices and almost twice that for construction over-runs. This implies that rainfall change in particular poses a serious risk to financial performance.

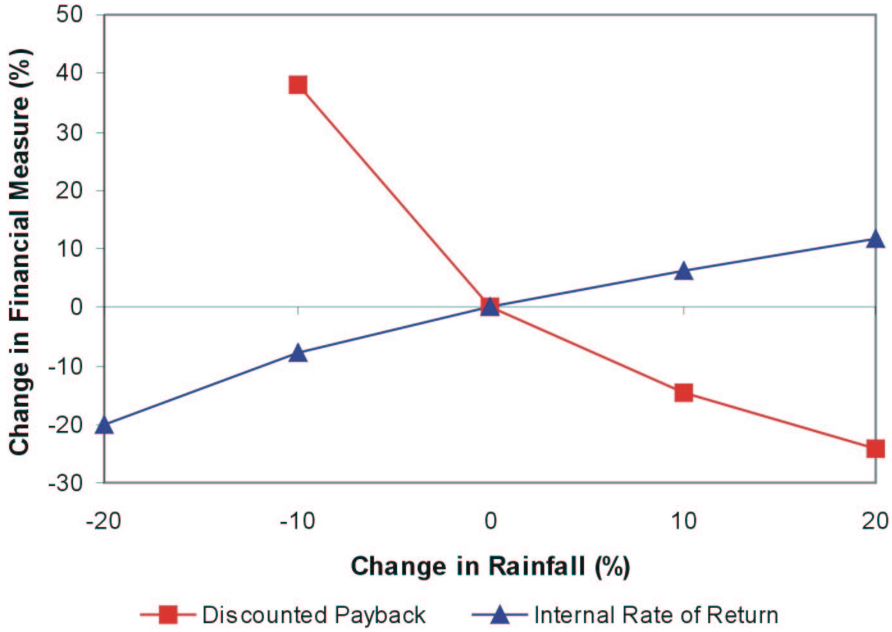

Figure 4: Sensitivity of financial measures to uniform changes in precipitation.

Climate Scenarios

In common with many sensitivity studies, there is the possibility that different variables may not be independent. The use of climate scenarios taken from the results of General Circulation Models can correct this to some extent. Here three potential future climate scenarios (Scenarios 1 to 3) have been used to drive the model. Representing conditions in the 2080s, they project temperature rises of around 5°C accompanied by precipitation reductions of 2%, 13% and 18% for Scenarios 1 to 3, respectively.

All three scenarios have major impacts, the magnitude of which is determined by the degree of precipitation change (Table 2). There are significant decreases in river flows and consequently smaller energy production levels. Such reductions in energy production have a major and detrimental impact, financially. Changes in IRR follow the production changes, and once again the impact on NPV is much greater. As can be seen in Figure 5, all scenarios indicate very large reductions in project value. The smallest change is seen with Scenario 1, where even though precipitation decreases by only 2%, the result is a 62% fall in value. The much larger precipitation decreases suggested by Scenarios 2 and 3 result in significantly negative NPV values. In these cases, and on the basis of purely financial decision-making, the scheme would be regarded as non-viable and would not proceed.

Scenario	Changes for Scenarios				
	Precipitation (%)	Temperature (°C)	River Flows (%)	Production (%)	NPV (%)
1	–2	+5.0	–10	–6	–62
2	–12	+5.3	–28	–16	–168
3	–18	+4.4	–36	–21	–220

Table 2: Summary of changes with each climate scenario.

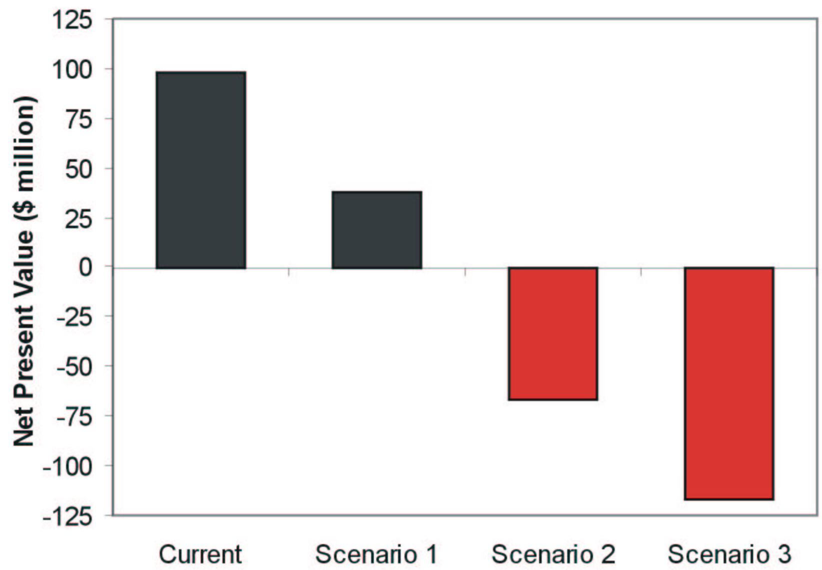

Figure 5: Scheme financial performance with climate change scenarios.

Analysing Risk

Previous research (Arnell, 1996) has noted that changes in precipitation tend not only to alter mean river flows but also their variance. The studies carried out on Batoka confirmed this and found further that monthly production and revenue variance was also altered. A preliminary study was conducted to determine whether such changes in monthly variance indicated changes in the financial risk faced by the project. Noting that synthetic river flow series are often used in water resources planning, a similar technique was applied to historic precipitation and temperature time-series. 250 statistically identical, but temporally different climate series were produced and applied to the model under current climate conditions and those indicated under the three previous scenarios.

From these simulations, the variances of the major financial measures were extracted and compared. It was found that their variance (as measured by the coefficient of variation) increases under each of the climate change scenarios, with variance increasing with the magnitude of the precipitation decrease. For example, with Scenario 3 the variance of potential returns (as measured by the IRR) increases by 64%. Other studies will be carried out in order to investigate this effect further, given that the estimation of risk is a primary issue in determining the project discount rate, itself a critical factor in determining project viability.

The Bottom Line

Although the results of the analyses are from a single scheme, they indicate that the financial performance of the scheme is sensitive to changes in precipitation patterns, implying that hydroelectric developments could become less competitive. If this were so, investment in hydropower projects would be less likely. The consequence would be that the ability to limit climate change will be reduced, firstly because hydropower is not used and secondly because increases in electrical demand will probably be met from fossil fuel burning.

CONCLUSIONS

Climatic change is expected to result from the release of significant quantities of man-made emissions of greenhouse gases. One of the key methods of limiting the extent of change is through the use of renewable energy sources, including hydropower. Unfortunately, the reliance of hydropower on climatic conditions means that the changes predicted may affect, adversely, its future viability. In particular, and given the increasing importance of private capital within the electricity industry, the economics of hydro schemes may represent a less attractive prospect to investors. As a consequence, fossil-fuelled schemes will take precedence, reducing our ability to reduce greenhouse gas emissions.

A methodology and associated model have been briefly introduced which enable quantification of changes in investment performance following from changes in climate. Results of its use on a planned scheme indicate that investment measures show significant sensitivity to changes in rainfall, implying that, hydropower will become less competitive. Therefore, investment in hydro projects is less likely to occur and our ability to control greenhouse emissions is lessened.

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REFERENCES

Arnell, N., 1996. Global Warming, River Flows and Water Resources, J. Wiley and Sons Ltd.

Batoka Joint Venture Consultants (BJVC), 1993. Batoka Gorge Hydro Electric Scheme Feasibility Study Final Report, Zambezi River Authority, Lusaka, Zambia.

Gleick, P.H., 1986. 'Methods for evaluating the regional hydrologic impacts of global climatic changes', J. Hydrology, 88, pp. 97-116.

Harrison, G.P. and Whittington, H.W., 2001a. 'The impact of climatic change on hydropower investment', Hydropower in the new millennium - Proceedings of the 4th international conference, Hydropower '01, Bergen, Norway, June 2001, pp. 257-261.

Harrison, G.P. and Whittington, H.W., 2001b. 'Vulnerability of hydropower projects to climate change', IEE Proceedings - Generation, Transmission, Distribution, (submitted).

Harrison, G.P. and Whittington, H.W., 2001c. 'Sensitivity of hydropower performance to climate change', J. Water Resources Management and Planning, ASCE (submitted).

Intergovernmental Panel on Climate Change (IPCC), 2001. Climate Change 2001: The Scientific Basis, Cambridge University Press.

Mimikou, M., Kouvopoulos, Y., Cavadias, G. and Vayianos, N., 1991. 'Regional hydrological effects of climate change', J. Hydrology, 123, pp. 119-146.

Nakicenovic, N., Grubler, A. and McDonald, A. (eds), 1998. Global Energy Perspectives, Cambridge University Press.

Nash, L.L. and Gleick, P.H., 1993. The Colorado River Basin and Climatic Change: The Sensitivity of Streamflow and Water Supply to Variations in Temperature and Precipitation, US Environmental Protection Agency, Washington, D.C.

Reibsame, W.E., Strzepek, K.M., Wescoat Jr., J.L., Perritt, R., Gaile, G.L., Jacobs, J., Leichenko, R., Magadza, C., Phien, H., Urbiztondo, B.J., Restrepo, P., Rose, W.R., Saleh, M., Ti, L.H., Tucci, C. and Yates, D., 1995. Complex River Basins. In: Strzepek, K.M. and Smith, J.B. (eds), As Climate Changes - International Impacts and Implications, Cambridge University Press, pp. 57-91.

UNFCCC, 1998. Kyoto Protocol to the United Nations Framework Convention on Climate Change, UNFCCC.

Whittington, H.W. and Gundry, S.W., 1998. 'Global climate change and hydroelectric resources', IEE Engineering Science & Technology Journal, 7 (1), pp. 29-34.