Water management at Dinorwig pumped-storage power station.

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SYNOPSIS. Optimum operation of the Dinorwig pumped-storage scheme requires a constant volume of water within its closed reservoir system. Heavy rainfall and the subsequent floods can cause additional or 'excess water' to spill into the closed reservoir system. Whilst the reservoirs are designed to cope safely with the rainfall and subsequent floods in the case of extremely rare events, optimum operation of the pumped-storage scheme can be vulnerable on an annual (or even more frequent) basis to rainfall and the subsequent floods.

This paper describes how 'excess water' is currently managed and then describes a computer model of the system, which was constructed on behalf of the power station operators. The model links hydrology, hydraulics and power station operation. The aim of the model was to increase understanding of the link between upstream catchment conditions, current operational conditions/rules, 'excess water', and downstream catchment conditions, on a day-to-day basis. (rather than extreme event basis). The model was then used to simulate the system with modified upstream conditions and modified operational conditions/rules.

Overall the work has increased understanding of water management at Dinorwig and assessed commercial and environmental implications of different water management strategies.

Translations: Afon = River, Nant = Stream, Llyn = Lake

INTRODUCTION

A *pure* pumped-storage scheme consists of two reservoirs, an upper and a lower one. Inputs are the natural streams that flow into the reservoirs and direct rainfall. Outputs are evaporation, controlled release (e.g. compensation flow) and uncontrolled release (e.g. flow over a spillway) Water falling from the upper reservoir drives turbines in order to generate

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electrical energy. The water is collected in the lower reservoir and is later pumped back to the upper reservoir. Generating is usually carried out when electricity has high value to the electricity network and pumping when the cost of electrical energy is lower. Thus pumped-storage can provide both economic generating capacity and special support services to the national electricity system. The lower lake of a pumped-storage scheme minimizes the effect of the generating/pumping cycle on the natural river system.
In a *pure* pumped-storage scheme the *total* volume of water in the reservoir system i.e. upper lake, lower lake, shafts and tunnels, must remain constant. This constant volume of water is simply moved between the upper and lower reservoirs during the generating/pumping cycle. If there is more water in the reservoir system than required then, there is said to be positive 'excess water'. If there is less water in the reservoir system than required then there is said to be negative 'excess water' (Jog, 1989).

Both positive and negative 'excess water' can have an economic impact on the optimum operation of a pumped-storage power station.

CASE STUDY: DINORWIG PUMPED-STORAGE POWER STATION

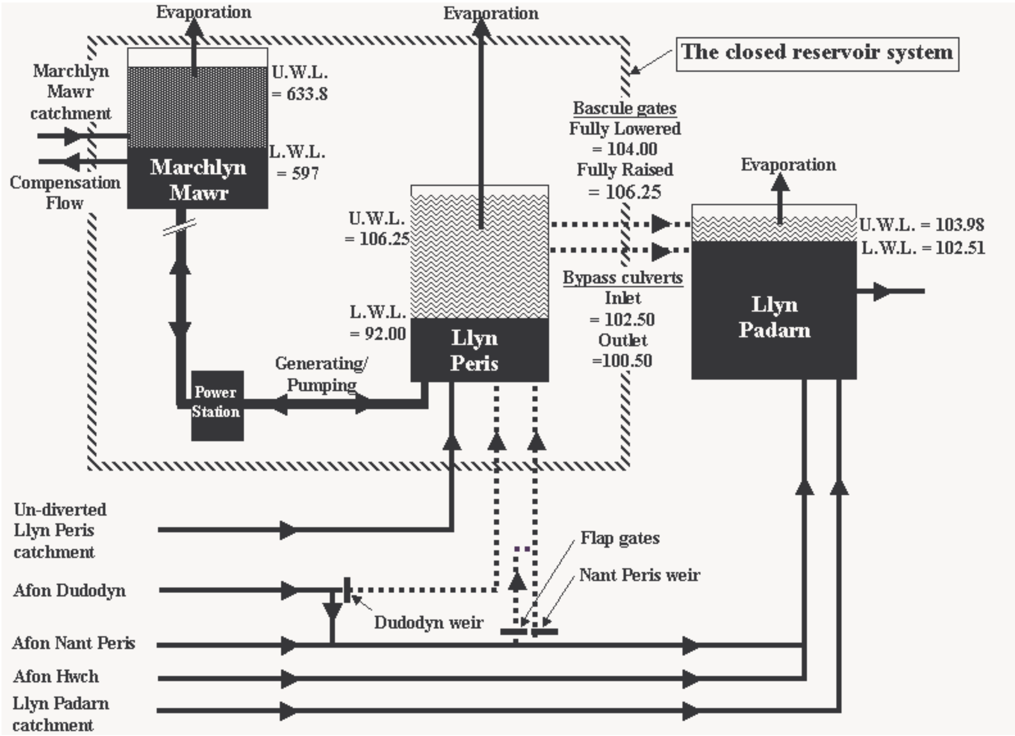
Dinorwig pumped-storage power station, in North Wales, is currently owned and operated by First Hydro Company. First Hydro Company also own and operate Ffestiniog pumped-storage power station. Dinorwig has a generating capacity of 1728 MW (First Hydro Company, 2005). The major constructions to form Dinorwig power station were:
- a dam at Marchlyn Mawr (the upper reservoir) to enlarge an existing lake,
- a dam at Llyn Peris (the lower reservoir) to enlarge an existing lake,
- a shaft and tunnels between Marchlyn Mawr and Llyn Peris to allow flow in either direction
- an underground complex containing the power station.

Downstream of the power station system is a natural lake, Llyn Padarn.

Prior to the construction of the Dinorwig scheme the Afon Hwch, Afon Nant Peris and Afon Dudodyn flowed into Llyn Peris. To reduce the natural inflows into Llyn Peris and hence the build up of 'excess water' in the reservoir system, the following changes were made when the scheme was built:
- Diversion of the Afon Hwch so it now flows into Llyn Padarn. All flow is diverted.
- Diverting the Afon Nant Peris so that it now flows through a Diversion Tunnel into Llyn Padarn. Under low flow conditions all flow in the Afon Nant Peris is diverted. Under high flow conditions spill into Llyn Peris still occurs.
- Diverting the Afon Dudodyn into Afon Nant Peris (upstream of the Diversion Tunnel) using a diversion pipe. Under low flow conditions all

flow in the Afon Dudodyn is diverted. Under high flow conditions spill into Llyn Peris occurs.

Figure 1 shows Dinorwig scheme, including the remaining inputs and outputs to the closed reservoir system, after catchment diversion. Also shown in Figure 1 is Llyn Padarn. The pumped-storage operation results in the level of Llyn Peris only rising higher than Llyn Padarn for a short window each day, if at all.



All Elevations in Metres above Ordnance Datum (mAOD)

U.W.L = Upper working level
L.W.L = Lower working level

Figure 1. Dinorwig pumped-storage power station.

Although the catchment diversions described above exclude the majority of otherwise natural ‘excess water' there will still be a residual inflow into the reservoir system, especially at times of high river flow. Three Bypass culverts and three Bascule gates were therefore incorporated into the lower dam to discharge ‘excess water’ from Llyn Peris into Llyn Padarn. The Bypass Culverts are either open or closed. The Bascule Gates have six possible positions from fully-lowered to fully-raised.

For a release of ‘excess water’ to take place:
Llyn Peris level > Level of the Bypass culverts/Bascule gates
AND Llyn Peris level > Llyn Padarn level
AND Llyn Padarn level < a level specified by the Environment Agency

These three conditions constrain when ‘excess water’ can be released from the reservoir system. Figure 2 shows typical operational data, from the power station, for October 2004. There were only 8 opportunities to discharge ‘excess water’ in the 31 day period, and the amount of water that could be discharged on each occasion will have been constrained either by the power station generating schedule or Llyn Padarn level.

In 2002, First Hydro Company commissioned an Engineering Doctorate (Engineering and Physical Sciences Research Council, 2005) study to increase their understanding of ‘excess water’ on an operational basis (rather than extreme event basis, which is already covered under Section 10 of the Reservoirs Act)

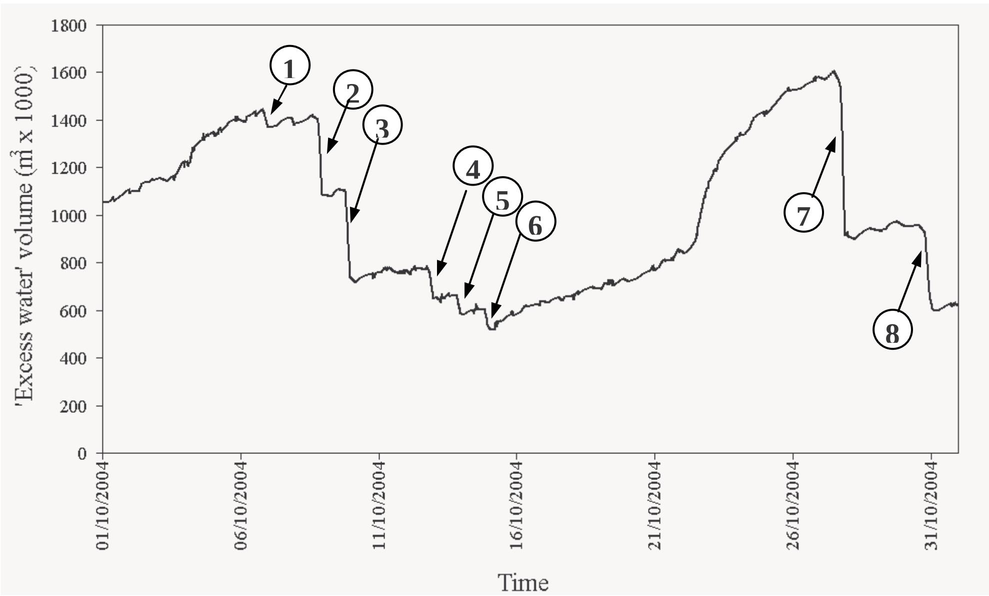


Figure 2. ‘Excess water’ volume, October 2004

ENGINEERING DOCTORATE PROJECT

The Engineering Doctorate project looked at the Dinorwig scheme on a catchment basis, including both upstream and downstream catchments.

An extensive database of existing hydrological data (rainfall, automatic weather station data, river flow and lake levels) was compiled using data supplied by First Hydro, the Environment Agency, the Environmental

Change Network (ECN) and the Met Office [through British Atmospheric Data Centre, (BADC)].

Data from the automatic weather station allowed open water and catchment evaporation to be estimated, an example of which is shown in Figure 3.

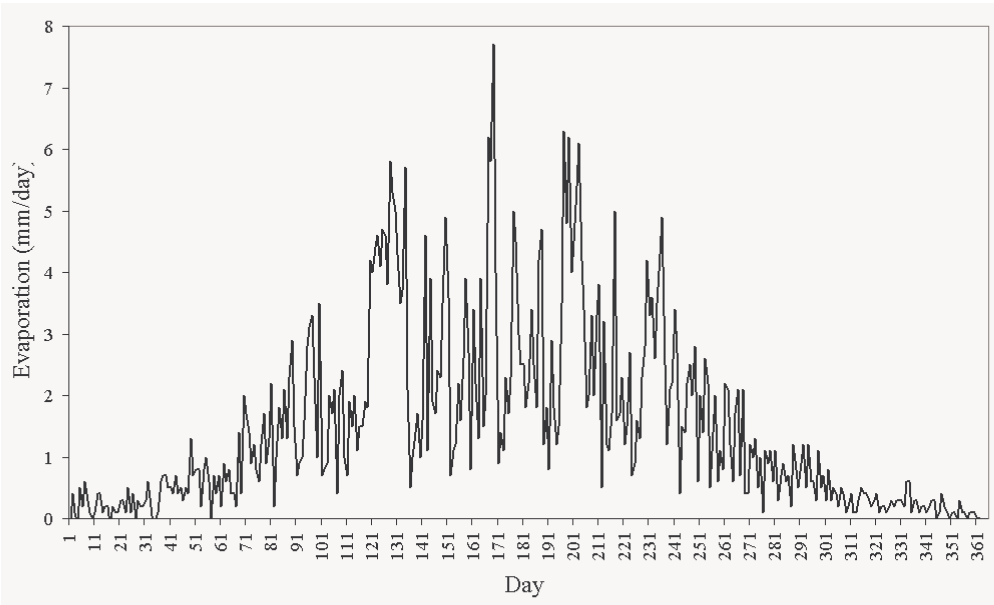


Figure 3. Estimated open water evaporation at Dinorwig, 2000

Data from the rain gauges was first used to construct a spatial rainfall model. This spatial rainfall model was then used as one of the inputs to a hydrological model of each of the catchments upstream and downstream of Dinorwig power station. The hydrological model chosen for this application was the ISIS Probability Distributed Moisture (PDM) model. (Wallingford Software, 2005b). Where flow data, with a natural flow regime, were available, each hydrological model was calibrated and validated against the gauged flow data. Where flow data were not available the hydrological model parameters were estimated from those used in the gauged catchments. Figure 4 shows an example of the flow predicted by the model and that recorded by the Environment Agency at the Nant Peris gauging station.

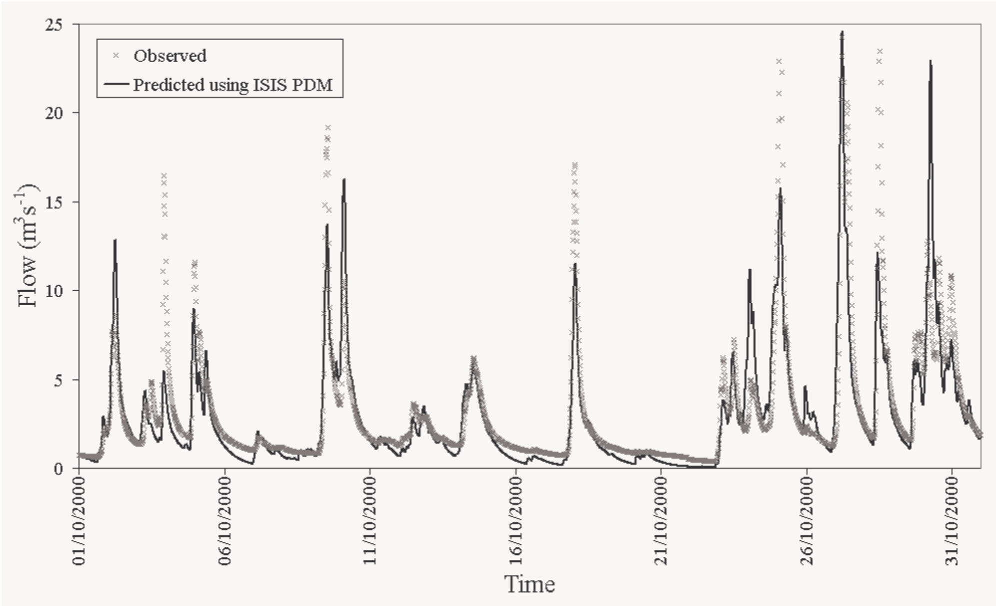


Figure 4. Nant Peris flow at Nant Peris gauging station, October 2000

The catchment flows predicted by each catchment model were then used as the inputs to a hydraulic model. The hydraulic modelling software chosen for this application was ISIS. (Wallingford Software, 2005b). The hydraulic model was designed to simulate both the physical system (including reservoirs, lakes, rivers, diversion structures and discharge structures) and the Power Station operation.

A wide range of data sources was used to construct the hydraulic model. These included Design Reports, As-Constructed Drawings and Topographical Surveys.

To operate the hydraulic model an initial Llyn Padarn level, an initial 'excess water' volume and a generating schedule for the entire simulation period are specified. The hydraulic model will then predict 'excess water' volume and Llyn Padarn level at each time step, based on the volume of water spilling into and released out of the closed reservoir system. The model will automatically open/close the Discharge culverts and lower/raise the Bascule gates according to the operational rules.

The hydraulic model was calibrated against historic 'excess water data' and Llyn Padarn level data. This calibration process highlighted that both the existing Llyn Padarn level–area and level-discharge relationships were inadequate. The Llyn Padarn level-area relationship was improved using NextMap Digital Terrain Model data. (Intermap, 2005) and the Llyn Padarn Level-Discharge relationship was improved by installing flow monitoring instrumentation at the discharge point. Through this work it was possible to improve the performance of the model.

Figures 5a and 5b show the results of a model simulation for October 2000. This was the wettest period on record. Also shown on Figures 5a and 5b is the observed data. Figures 6a and 6b shows the results of a model simulation for the July 2003. This was the driest period on record.

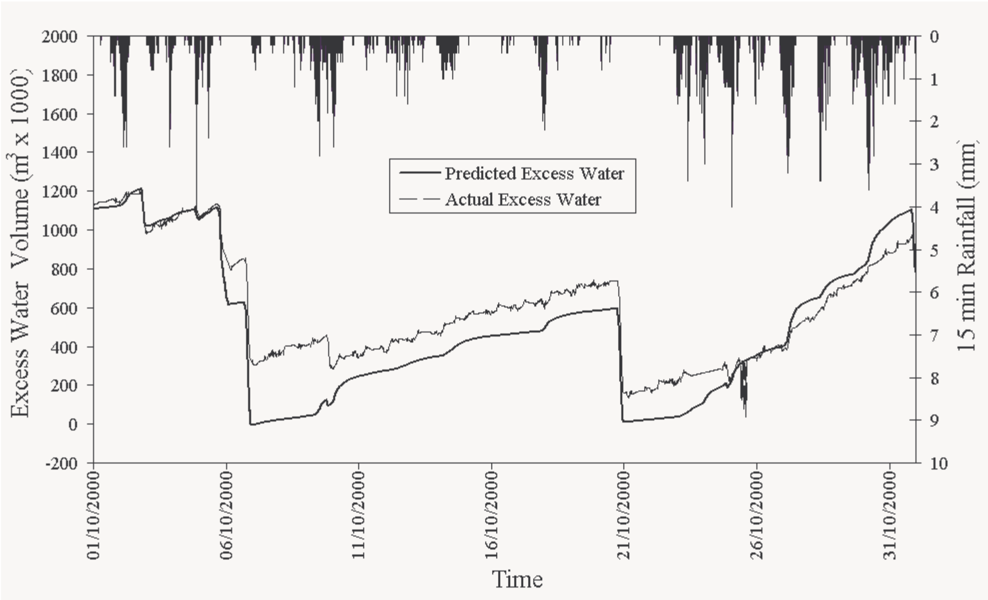


Figure 5a. Results for October 2000. 'Excess water' volume

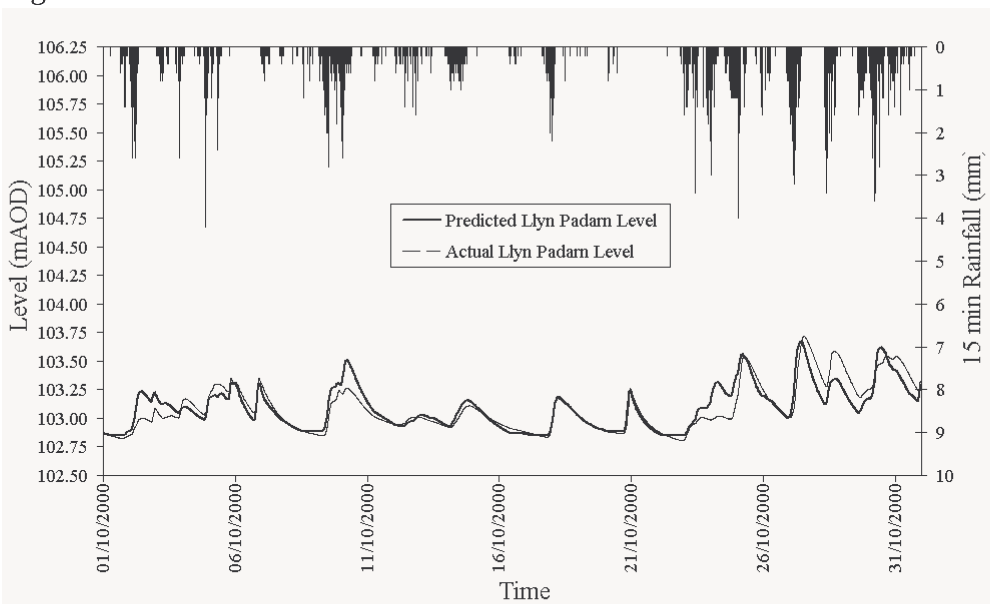


Figure 5b. Results for October 2000. 'Llyn Padarn' level

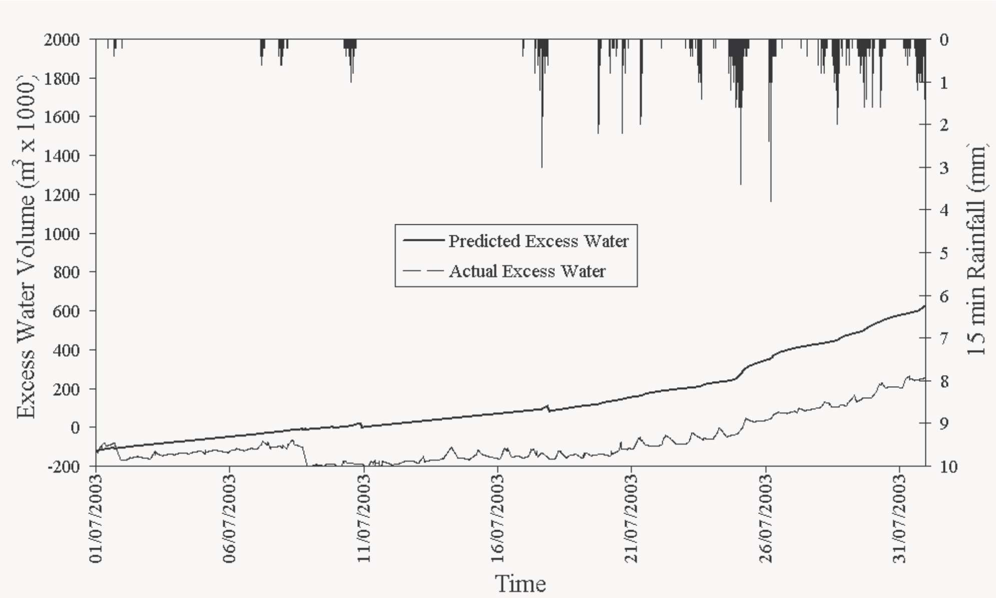


Figure 6a. Results for July 2003. ‘Excess water’ volume

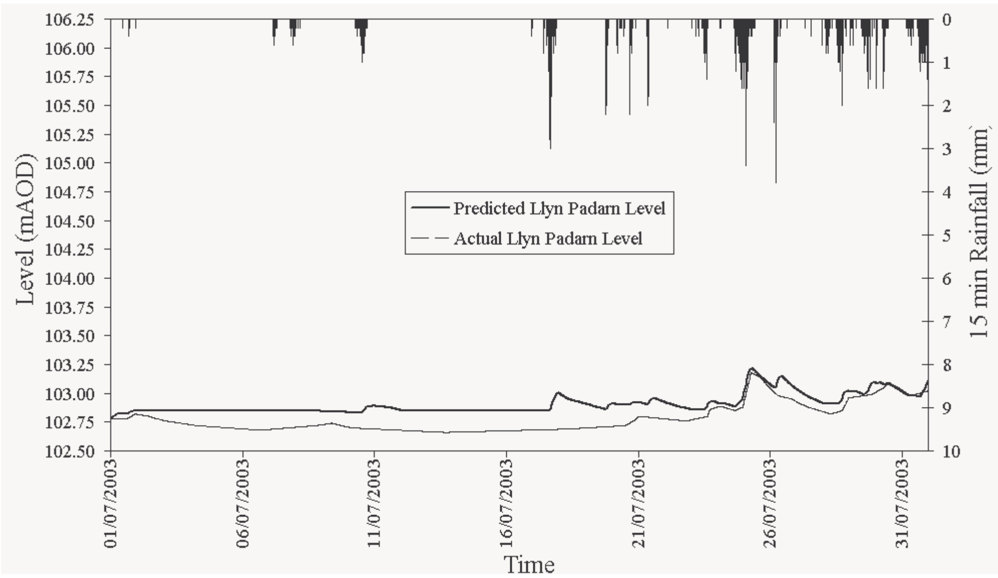


Figure 6b. Results for July 2003. ‘Llyn Padarn’ level

Figures 5a/5b and 6a/6b showed the model performed reasonably well, when tested during both the wettest and driest periods on record. Further model refinements are planned as additional information becomes available. In the simulations presented it is important to note that any error in predicted ‘excess water’ will accumulate over the simulation period and that any errors in Llyn Padarn level may also result in ‘excess water’ been released incorrectly.

It is also possible to use the model to quantify the different sources of ‘excess water’ in the power station system. Figure 7 shows that during October 2000 most of the ‘excess water’ came from the direct catchment of Llyn Peris, a smaller proportion came from the direct catchment of Marchlyn Mawr and an even smaller proportion came from spill at the diversion structures. This information can be used to inform investment decisions about future catchment diversion schemes.

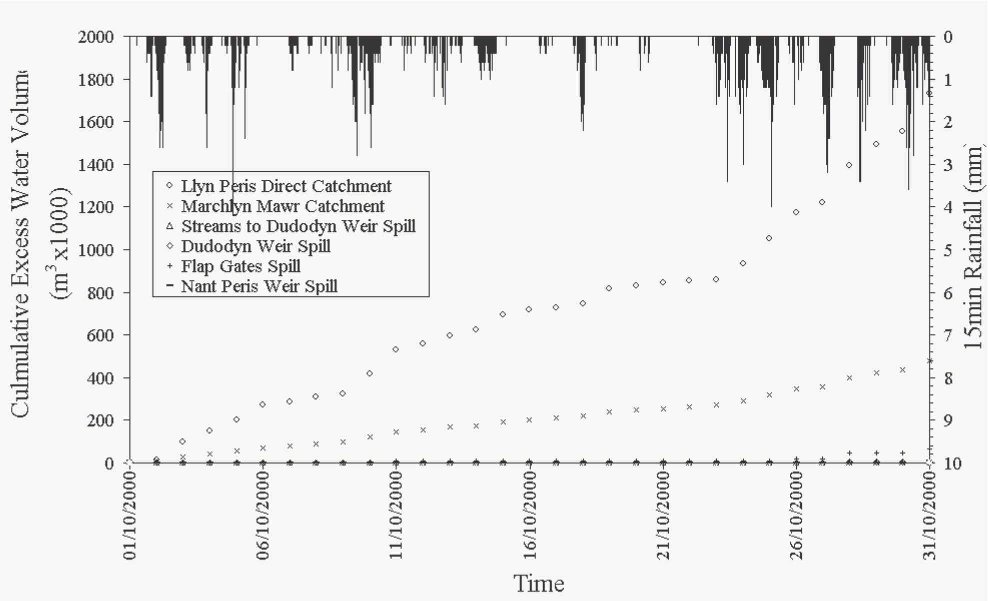


Figure 7. October 2000: Sources of ‘Excess water’

Having shown the model to perform well against historic events, the model was then used to explore how the Dinorwig system performed under different operating rules.

Having developed and proved the model concept First Hydro now also have the option to implement the model as a real-time flood forecasting system. One possible software system is Floodworks (Wallingford Software, 2005a) which would use the existing ISIS PDM/ISIS model as the basis for a real-time flood forecasting system. Such as system has already been implemented at Dolgarrog Hydroelectric power station, also in North Wales. (Kalken & Billcliff, 2004).
Implementing a complete FloodWorks model was considered beyond the scope of this work therefore a simple ‘excess water’ forecasting tool has also been developed, in MS Excel/Visual Basic for applications (VBA) based on the principles of the ISIS PDM/ISIS model. The software is designed to forecast ‘excess water’ up to 120 hours ahead, based on an

anticipated generating schedule and current catchment conditions. The software allows Control room operators to trial different Culvert openings and Gate positions to ensure that the operational rules are not broken. First Hydro can also trial different generating schedules to see the impact on ‘excess water’. Using MS Excel as the interface for the software makes it accessible to Control Room staff at the power station, without the need for detailed training in hydrology and hydraulics. It is also very easy to link this software to First Hydro’s existing plant databases. This software is currently undergoing testing within First Hydro Company.

FUTURE WORK

It is now proposed that the existing model will be tested against future rainfall scenarios. It is proposed that a ‘Weather generator’ will be used to simulate the likely rainfall *patterns* that could be expected in 2020 and 2050, under Low and High emission scenarios. This will allow an assessment to be made of likely impact of climate change on the sustainable operation of the power station.

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