Water quality has been a central theme in a redevelopment project that began with the creation of the Cardiff Bay Development Corporation in April 1987.

This article will examine the role that water quality has played in the remarkable transformation that has taken place in Cardiff and explain how monitoring technology has developed to the stage whereby any person, anywhere in the world, can view live water quality data at multiple locations in the Cardiff Bay via the YSI EcoNet web-based system.

Background
Cardiff owes much of its history to the Industrial Revolution of the 1790's, which stimulated mining in the valleys of South Wales. By the 1880's, Cardiff had transformed from one of the smallest towns in Wales to the largest and its port was handling more coal than any other port in the world.

On the eve of the First World War in 1913, coal exports reached their peak at over 13 million tonnes. However, following the Second World War, demand for coal declined and international markets were lost as other countries developed their own steel industries. Trade was increasingly lost to container ports and by the 1960's coal exports had virtually ceased.

Peter Gough from the Environment Agency was a student in Cardiff University during the 1970's and remembers the poor state of the local rivers: "The Taff was as black as coal and incapable

of supporting most aquatic life. At its worst, in the 19th century there were reports of livestock dying after drinking from the river."

By the early 1980's Cardiff Bay had become a neglected wasteland of derelict docks and mudflats. Much of Cardiff's population suffered from social exclusion with above average levels of unemployment.

The regeneration of Cardiff Bay was undertaken to create a complementary mix of housing, open space, commerce, leisure and industrial development. The project also included the construction of a barrage across the mouth of the bay to create a 200-hectare freshwater lake, fed by the rivers Taff and Ely, which would link all of the proposed developments and provide both aesthetic and recreational benefits.

Environmental considerations were extremely important in the proposed redevelopment plan and water quality protection measures were defined in the Cardiff Bay Barrage Act 1993, which stipulated that water quality objectives shall have regard to: (i) the recreational or other purposes for which use of the
water is permitted by the Development Corporation, and
(ii) the needs of the fish in the water and of migratory fish passing to or from it.

Water quality was required to meet the relevant standard as specified by the National Rivers Authority (now the Environment Agency of England and Wales). This standard was the maintenance of a minimum dissolved oxygen (DO) level of 5mg/litre. Peter Gough explains: "When the construction of a barrage was first proposed, concerns were raised for the ecological recovery of the catchment. Cardiff Bay had a huge tidal exchange which resulted in significant pollutant dispersal and a barrage would clearly prevent that and represent a risk to water quality in the future impoundment.

"One of the main concerns was the potential effect of the barrage on migratory fish such as salmon and sea trout, which were starting the process of recolonisation in the 1980s. They are very sensitive to pollution and to low DO levels in particular. A range of mitigation measures were therefore built into the proposed development plan."

Construction of the barrage took place between 1994 and 2000 at a total cost of £220million,

and in 2000 Cardiff Council took over from the Cardiff Bay Development Corporation and through the Cardiff Harbour Authority (CHA) established five main objectives:

1. Maintaining the best environmental standards
2. Improving access to and around the Bay
3. Developing water use
4. Increasing the quality and range of facilities
5. Liaising with communities, commercial businesses and other organisations

Environmental issues
The main issues of concern for the CHA are debris management, flood defence, migratory fish, algae, birds, groundwater levels, problematic species and of course water quality.

Prior to the creation of the barrage, debris (typically 1000 tonnes/annum), which was mostly derived from the two rivers that fed the bay, would have been washed into the Severn Estuary. However, CHA now employs booms to collect debris for transfer to controlled areas.

Flood control has also improved with the barrage. In the past, heavy rain in combination with heavy rivers and a Spring tide would have resulted in flooding. However, CHA is now able to closely monitor and control water levels in the bay with the barrier's sluice gates. For example, in 2001 a 1:57 year rainfall event resulted in a bay water level rise of just 20cm.

Migratory fish were referred to specifically in the requirements of the Act mentioned above, so the barrage was constructed to incorporate a fish pass to allow migratory salmon and sea trout to return to the rivers Taff and Ely to spawn. In addition, young salmon have been released into the rivers, firstly as part of an impact monitoring programme, and latterly as a mitigation measure. The bay now supports healthy populations of freshwater fish such as barbel, chub, dace, gudgeon, roach and rudd, and Peter Gough reports an improving salmon, trout and grayling population in the two main rivers and their tributaries. He says, "The fish pass incorporates a counter so we have been able to measure the success of the joint activities with the CHA. The focus on migratory fish has proved to be an elegant way to protect and report water quality because most people understand that if salmon can live in a river, the water quality must be good."

A further stipulation of the Act related to potential effects on local properties from changing groundwater levels. Groundwater surveys were therefore undertaken before the construction of the barrage and have continued ever since.

Invasive species represent a threat to the ecology of the bay and zebra mussels are currently the most significant. Capable of rapidly colonising any structure within a water body, zebra mussels can become a significant problem as they adhere to the surfaces of boats, jetties, anchors, chains, pipes etc. As filter feeders, each zebra mussel typically filters up to 2 litres/day and David Hall from CHA believes that the biomass is so large that the entire volume of the bay could pass though a zebra mussel every two weeks. As a result of this filtration, the water is very clear and David says "This means that cormorants find it easier to prey on fish that swim near the surface, so the balance of fish species has moved in favour of bottom feeders."

Water Quality
Salmon are unable to survive in low DO water and this was undoubtedly a factor in choosing DO as the main indicator of water quality. However a wide range of other water quality parameters are also monitored.

DO levels are affected by a number of different factors. For example, windy weather helps to aerate the water and cold water is able to 'hold' higher levels of DO than warm. As a result, warm windless summer days pose the greatest threat. However, pollution discharges such as combined sewer overflows can also reduce DO levels. Algae have the potential to lower DO levels following death and eutrophication, but David Hall believes that algae in Cardiff Bay, on balance, have a positive effect on DO as a result of photosynthesis.

CHA employs two methods with which to combat low DO levels. An aeration system extends across the floor of the bay and provides an opportunity to circulate and aerate the water. This system is fed by air compressors which feed over 600 diffusers through a network of 20km of pipes. However, in extremely low DO conditions, CHA is able to deploy an oxygen barge which feeds pure oxygen directly into the worst affected water.

YSI multiparameter water quality monitoring sondes have been deployed in Cardiff Bay since the beginning of barrage construction. Initially, these were strategically placed logging instruments from which data was collected manually at regular intervals, but as CHA's Steve Ellery explains: "This was labour intensive and only provided a historical view of water quality, which meant that our ability to respond to poor water quality was limited and often delayed. We therefore installed 6 YSI buoys in 2000 and began to collect data via radio."

The radio telemetry provided CHA staff with access to live data which transformed their ability to respond quickly to low DO. However, the radio systems had to contend with interference and line of sight issues, so in 2008, the buoys were connected to YSI's EcoNet system, which automatically publishes live data to a dedicated website.

A map showing the location of the YSI buoys is shown on the home page of www.ysihydrodata.com and provides any web user with access to live water quality data. This data is collected at 15 minute intervals from the buoys via GSM and stored on a secure server that hosts the web data.

Two of the buoys are fitted with water quality monitoring sondes at both 1m below the surface level and also at 1m above the floor of the bay. The remaining seven buoys have one sonde monitoring at 1m below the surface.

YSI sondes are compact, rugged battery powered instruments capable of logging data from a broad selection of sensors that have been designed specifically to withstand the most harsh aquatic environments. The sondes in Cardiff Bay are fitted with sensors for DO, pH, conductivity, salinity, temperature and turbidity, but many other sensor options are possible.

Commenting on the reliability of the sondes, Steve Ellery says: "We have been delighted with the performance of the YSI 6-series sondes because they have enabled us to demonstrate extremely high levels of compliance with the DO requirement. The initial sondes were replaced after about six/seven years and we now run eight spare sondes so that when recalibration is due we can simply swap sondes without incurring any downtime in data collection.

The ability of the monitoring network to deliver live data means that we are able to respond to low DO levels very quickly and accurately, and as a result, over the last five years our compliance performance with the 5 mg/l DO has been over 99.9% every year."

Users of the YSI EcoNet system do not always opt for live web data display but Steve Ellery has never regretted the decision to do so. He says, "If the sondes were less reliable we would not wish to display inaccurate data, but since their performance has been so good, it has been

great to be able to provide the data to anybody with an interest."

In addition to the buoy based monitoring network, CHA also takes monthly water samples from six locations for the laboratory analysis of a wide variety of parameters including phosphate, nitrate, ammonia, BOD and bacteria.

Summary
Looking back over the changes that have taken place in water quality in recent decades, Peter Gough believes that the Taff may be the only capital city river in Europe with salmon spawning within the city and says, "This is testament to what has been achieved in a relatively short period of time."

The YSI water quality monitoring network has enabled the CHA to provide live data to the public and to ensure the protection of water quality in the bay. This has ensured that the area has become an attractive environment for all forms of life including human beings.

David Hall has lived in Cardiff for the whole of his life and believes that the protection of water quality has been key to the success that the city has enjoyed in recent years. He says, "If you include the housing, pubs, restaurants, sports facilities etc., the development of the Cardiff Bay area represents a total investment of about £2 Billion.

"The overwhelming success of this area hinges on the aesthetic quality of the bay; the water is clean, wildlife is thriving and many thousands of people enjoy a wide variety of leisure activities. Prosperity has once more returned to Cardiff, and this time, it's not coal we have to thank… it's water."