Defra Reservoir Safety research contract

Guidance Note on Real time monitoring of dams for early detection of internal erosion

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Jacobs Ref B2220300

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Executive Summary

This Guidance Note sets out the issues that need to be evaluated when considering implementation of real time monitoring, as a means of early detection of internal erosion.

The Note first provides a review of current practice in real time monitoring, both in relation to dams and in other industries. It then provides commentary on the types of sensors that may be used, followed by commentary on issues regarding physical installation. It concludes with a section on use of real time data.

An indication is given of the whole life costs of real time monitoring, to allow evaluation of whether the costs are proportionate to the benefits achieved.

The cost of real time monitoring for early detection of internal erosion is likely to be significantly less for dam owners who already have real time monitoring for other purposes, than for owners without this facility.

Acknowledgments

This Guide was prepared by the following:

Individual	Role	
Alan J Brown	Project Manager and Panel AR Dam Engineer	Jacobs
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Paul Harrison/ Chris Branigan	Issues regarding physical installation	Jacobs

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This Guide was reviewed by the Defra Reservoir Safety Advisory Group comprising Peter Mason (chair), Chris Collier, Kenny Dempster, Paul Ditchfield (Defra), Ian Hope, Andy Hughes, Mark Morris and Neil Williams.

1 General

1.1 Aims and use of Guidance Note

The purpose of this Guidance Note is to

> *"To facilitate the take up of real time monitoring of dams for early detection of internal erosion, where the cost is proportionate, by carrying out a feasibility report into relevant recent/ ongoing developments in other industries "*

1.2 Relationship to other Guidance

This report should be read in conjunction with the "Guidance on Early Detection of Internal Erosion", produced in parallel with this report.

1.3 Definitions

Key terms are defined in Table 1.1, whilst the various components of a system for real time monitoring are illustrated in Figure 1.1 and Figure 1.2.

Table 1.1 Key terms in relation to real time monitoring

Term	Definition (as Glossary in ICOLD Bulletin No 118, 2000, with some modifications)
Alert system	A system which automatically warns an operator or user if any unusual activity is detected by the monitoring system
Automatic monitoring system (AMS)	A complete monitoring system which includes three components: • Automatic data acquisition system (ADAS); • Data transmission system (DTS) and • Data processing system (DPS).
Datalogger	A microprocessor based programmable device which energises, measures and stores (or records) the output of an instrument. Usually operated as a standalone unit with data uploads to a PC or laptop computer at specified intervals
Real time monitoring	Where a) readings of an indicator are taken at a frequency greater than that of surveillance visits, for example every hour or more frequently. b) the readings are then automatically checked for any change from normal behaviour, with an alarm triggered where behaviour varied from previous experience
SCADA	Supervision, Control And Data Acquisition
Sensor	A device designed to detect, measure or record physical phenomena. On energising manually or automatically, it converts a variable input into a signal suitable for measurements

Figure 1.1 Components of systems for real time monitoring (standalone)

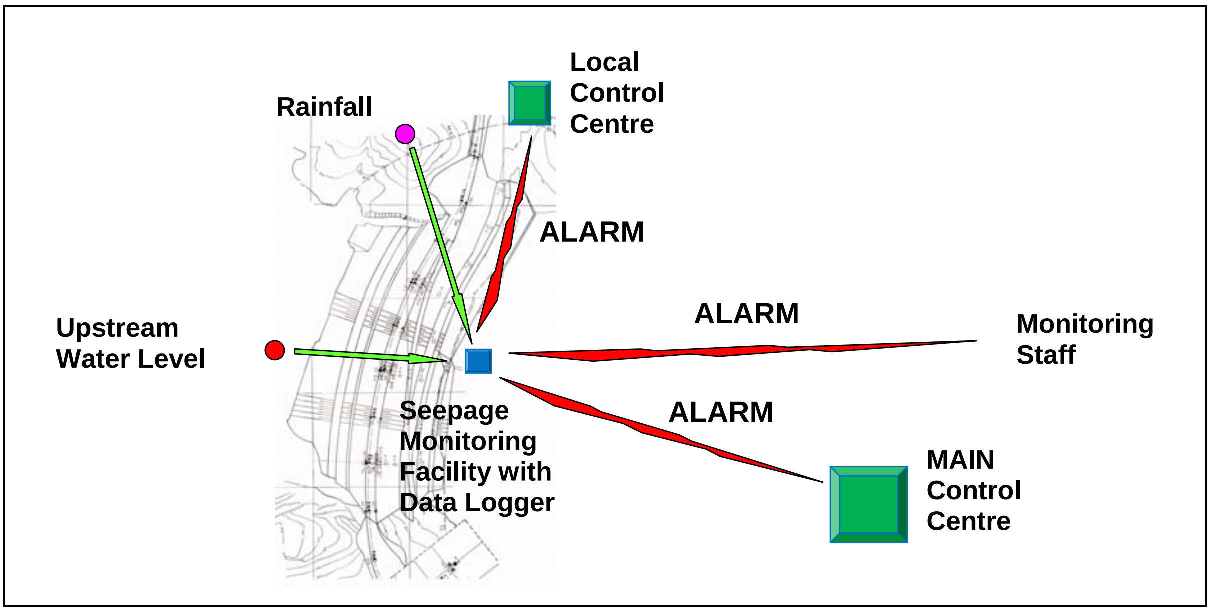
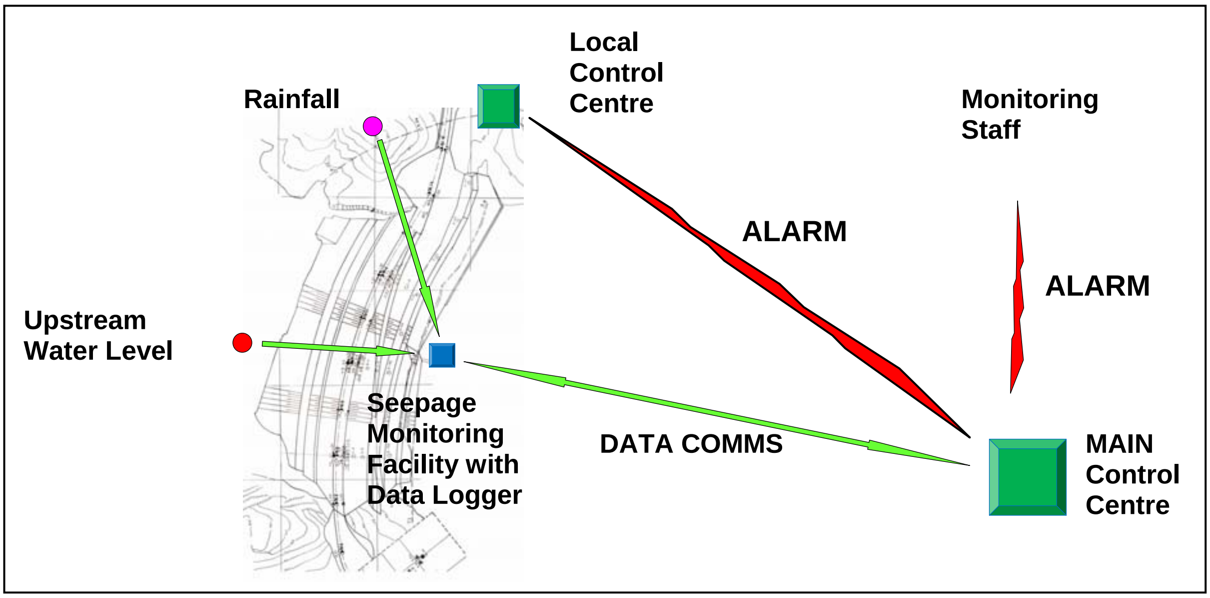


Figure 1.2 Automatic Monitoring Facility enabled for Remote Data Handling and Alarms



1.4 The role for real time monitoring of dams

There is evidence that although in some situations internal erosion may continue at a slow rate for years, in other situations the rate of deterioration can be rapid (or accelerate after a long stable period) and lead to rapid failure. Internal erosion in the vicinity of appurtenant works appear to be particularly vulnerable to this rapid deterioration.

Thus although surveillance (visual inspection) should always be the primary tool for assessing the condition of a dam, in some circumstances real time monitoring of key indicators may be a proportionate part of the dam safety management process. This applies where the nature of the soils and/or detailing of interfaces between the embankment and structures is such that internal erosion could progress rapidly to failure (“progressive internal erosion”) and the consequences of failure include significant risk to people downstream

It may also be appropriate in some circumstances to provide quantitative readings at frequent intervals due to fast changes in local environmental conditions, such as

a) reservoir levels in pumped storage schemes
b) where the structure is very sensitive to temperature variations, which occur over a daily cycle
c) where there is concern over leakage at high reservoir levels, as floods pass through the reservoir. This may be monitored as part of an investigation, as it is likely that physical works would be carried out if this was considered to be an issue.

A third scenario where real time monitoring may be useful is to understand how seepage, or other indicators react to rainfall or other changes, and thus to better understand the behaviour of a dam. In this case it would be similar to real time monitoring to provide early detection of progressive internal erosion, but without an alarm.

It is implicit in real time monitoring for early detection of internal erosion that the primary objective is to increase the time available between an erosion incident developing from the point that it is detectable, to the point of failure of the dam and consequent release of the reservoir. Thus to be of value all parameters which are measured in real time must have corresponding trigger levels and a data processing system which automatically triggers an alarm when a trigger is exceeded. These trigger levels must also be meaningful in terms of providing warning.

It should be noted that

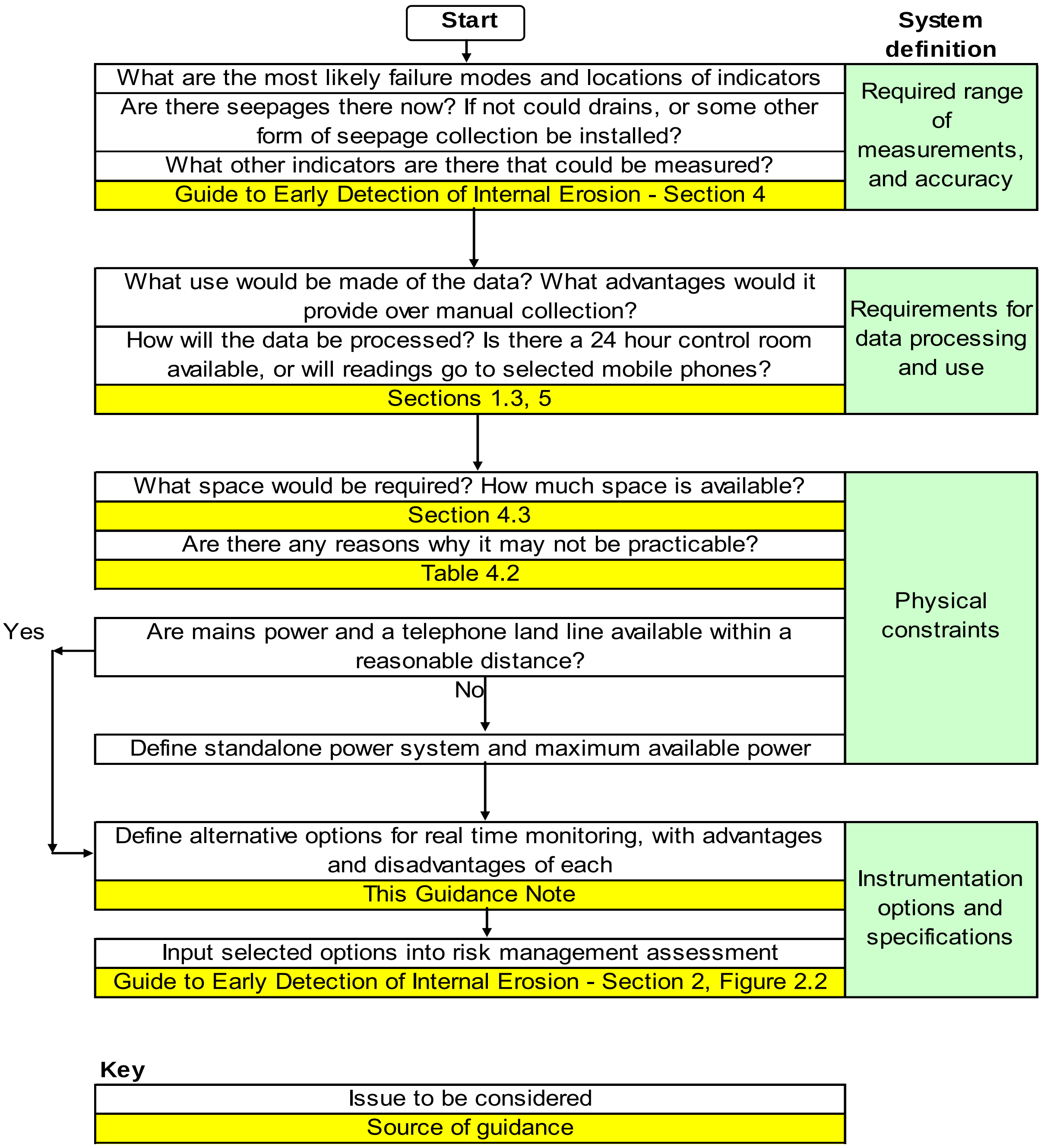
a) real time monitoring does not replace surveillance, but complements it
b) it is suggested that a risk based approach is adopted to decide when real time measurement would be worthwhile, based on the cost of real time monitoring relative to the reduction in risk that it achieves

Where real time monitoring is being considered as a candidate risk reduction works then the thought process to evaluate the practicalities and costs are set out in Figure 1.3. The indicators of internal erosion which are most likely to be practicable to monitor in real time are seepages (and associated suspended fines) emerging on the downstream face of the dam. It is these that this guide concentrates on, although providing comment on other indicators which could be monitored.

1.5 Structure of Guide

The report is structured into the following parts
Chapter 1 : Sets out the aims of the guidance
Chapter 2 : Current practice in real time monitoring
Chapter 3 : Instrumentation hardware
Chapter 4 : Physical installation
Chapter 5 : Use of data

Figure 1.3 Process to determine viability of real time monitoring for early detection of internal erosion



2 Current practice relevant to real time monitoring of dams and associated structures

2.1 Introduction

This section summarises current practice relevant to real time monitoring of both dams, and structures through the dams of which pipes and culverts pose the largest risk of internal erosion. It is based on literature review and interviews with a number of dam owners (both their dam safety managers and other technical disciplines).

2.2 UK Dams

An assessment of current UK practice was undertaken by holding face to face discussions with four major owners of reservoirs in the United Kingdom who between them they own and operate around 400 earth embankment dams. The discussions followed the format of a pre-prepared questionnaire developed to capture their practice and experience with regard to surveillance and monitoring of indicators which may give early detection of internal erosion. One of the companies has recently installed real time monitoring equipment at two dams which relays flow data to their control centre and has trigger levels when intervention is undertaken. Another has a single similar installation.

It was generally acknowledged that the majority of earth embankment dams leak to some degree and that on approximately 50% of dams the leakage is monitored.

One of the companies which undertakes a high proportion of various types of monitoring has experienced a number of internal erosion related incidents, none of which were predicted from the monitoring. Indeed the incidents have occurred in unexpected places and have developed in a very short timescale, without predictive indications or warning. This has reinforced their view that surveillance, rather than monitoring is the most reliable form of detection of progressive internal erosion.

Owners described their experiences with traditional and contemporary approaches to identification of leakages and internal erosion. Investigation techniques employed have included temperature probes set into embankments to identify leakage paths and geophysical techniques whereby electrodes are used to establish magnetic fields which indicate where water flow paths are present. One owner has installed a real time monitoring system on a permanent installation of temperature probes.

2.2.1 Surveillance and monitoring of seepage

Surveillance for significant consequence dams is primarily visual at intervals varying between every 48 hours (including weekends and bank holidays) up to once per week. This surveillance is carried out by trained operatives who observe many features of the dam and also the leakage monitoring locations.

Leakage monitoring is undertaken in a variety of ways. Very small flows or seepage may be by visual observation. Where the leakage can be captured at a discharge point flows may be timed into a measuring jug or similar to enable the rate to be determined and recorded for long term trend analysis. One company reported the use of a can with a slot down the side which permits a rate to be determined from calibration marks alongside the slot. Where leakage measurement facilities are installed they are read at intervals normally prescribed by the last Inspecting

Engineer. Typically this is once per week and results are normally plotted graphically with inclusion of rainfall and reservoir level.

2.2.2 Instrumentation

For the more significant leaks the most common form of measurement was confirmed as being by the installation of a V-notch measuring facility. This may be a metal weir plate set within a channel or small brick/concrete chamber; or a prefabricated metal box made to British Standard details.

Reservoir owners reported that in some cases installation of a V-notch facility, which includes some limited flow retention, has resulted in sediment accumulation from flows which were previously reported to be clear. This demonstrates that internal erosion is actually taking place. Periodic measurement of the retained fines can be undertaken to determine the rate of erosion and whether it is constant over an extended period or increasing.

In addition to flow, discoloration and transmission of suspended solids is an indicator of internal erosion. Turbidity meters are available to measure the degree of material in suspension but none of the reservoir owners are presently using them.

2.2.3 Remote and real time monitoring

The technology is available to monitor dam leakage flow and turbidity at pre-determined intervals throughout the day and transmit the results to a control centre where alarms can be activated if pre-set trigger levels are exceeded. Although most of the major reservoir owners utilise remote real time monitoring for many other aspects of their business they do not presently use it generally for monitoring internal erosion.

Three of the reservoir owners use real time monitoring of leakage on a small number of their reservoirs. This mostly involves the monitoring of flow over V-notch weirs. A number of owners use remote monitoring with readings sent to a local datalogger, to avoid the need for entry into confined spaces.

The reasons given for deciding to undertake real time monitoring included

a) risk management, where seepage flows were high and the source not fully understood
b) the time savings that can be made when frequent visits to remote sites are necessary.

2.3 International practice for dams

ICOLD Bulletin No 118 (2000) describes automated dam monitoring systems. This bulletin describes eight reason why an automated system may be adopted, including

- “to improve the quality and reliability of a classic monitoring system”, and
- “to provide operators with quality measurements taken at a high frequency”.

This Bulletin provides some useful information relevant to those considering adoption of a real time monitoring system. It includes in Appendix D twelve case histories of major dams with automated data monitoring systems, as summarised in Table 2.1.

Other specific examples of real time monitoring include those given in Stewart et al (2000), where the case histories of WAC Bennett Dam and Coursier Dam are presented “to highlight the exceptional value of automated monitoring as an effective risk management measures for potential internal erosion and piping failure modes in embankment dams". At WAC Bennett Dam real time monitoring comprised V-notch flow, turbidity and video cameras at the V notch chambers, whilst at Coursier Dam real time monitoring was of weirs and piezometers.

Table 2.1 Summary of case histories of automated dam monitoring

(from ICOLD Bulletin 118)

Dam	**Dam height, type**	**Number of instruments**		**Remarks**
		Total	**Automated**	
Piedra del Aguila dam, Argentina	170m, concrete gravity	2000		
Durlassboden, Austria	83m, earth fill	454	64	Store one value per day. Developing neural networks to improve data processing
WAC Bennett, Canada	183m, earthfill	594	129	Alarm system has 3 levels of alarm
Laparan, France	Concrete arch			Monitoring is generally automated because of difficult access in winter, need to follow behaviour trends or to reduce time taking manual readings
AEM, Italy. Four dams	51- 136m, concrete gravity	13	9	
Kaore, Japan	108m, arch			
Imha, Korea	73m, rockfill	178	109	Ongoing problems of noise on data transmission
Tarnita, Romania	97m, concrete arch		209	Automated because of concern over magnitude of irreversible displacements under thermal movements
Nok-AMS, Switzerland				Describes "modular" system applied to portfolio of 17 dams
Clarence Cannon, USA	60m, embankment			Instrumented because of various geotechnical issues that emerged during construction
Deadwood, USA	55m, concrete arch			Early warning system installed because of concern over planar feature in dam foundation. Various programming glitches during system implementation
Six dams, Spain	20 to 86m		3 to 54	

2.4 Other water supply infrastructure

2.4.1 General

The years since the privatisation of the UK water industry in 1990 have seen dramatic changes to many facets in the way that water services are undertaken. Water companies are regulated to control price increases and the response has been to pursue efficiencies. This has coincided with a period when new technology has become available which has been applied to many aspects of the water business. Advances in instrumentation and the transmission of real time data via mobile phone technology have enabled the transformation.

2.4.2 Water Treatment Works Monitoring

Historically water treatment was a labour intensive process requiring manpower, in some cases 24 hours per day, to control the plant and operate valves, pumps and other equipment. Now the monitoring is undertaken by instrumentation and computers control the whole process and operate the equipment without manual intervention. Key information from a water company's installations is transmitted by telemetry to control centres where the plant performance can be reviewed if required. Alarms alert the control manager to abnormal situations where manual intervention could be activated. Normal attendance at the water treatment site may only be for a short period several times per week to undertake basic surveillance and maintenance tasks.

The water treatment parameters which are measured and subject to real time monitoring include flow, turbidity, water level and temperature, all of which could be relevant to monitoring of internal erosion. The instruments, installations and data handling are now reliable and commonplace within the water industry. A small water treatment works may utilise around 100 real time signals to a control centre whereas a large works may require around 400. Control centres are capable of managing many thousands of real time signals. Reservoir owners employ in-house technical expertise which could be utilised in establishing real time monitoring of reservoir embankment internal erosion indicators.

2.4.3 Other real time monitoring of water and wastewater

Wastewater treatment works employ similar instruments and real time monitoring to control works remotely and monitor discharges to watercourses.

Water companies monitor flows in principal supply and distribution mains and transmit real time information to a control centre where resources are managed.

Insertion probes are used in distribution mains to measure colour and turbidity and transmit the results using mobile phone technology.

Turbidity at raw water intakes is measured and when pre-set high levels are attained the flow is isolated.

2.4.4 Turbidity monitoring in relation to water treatment

Turbidity in water supply has two distinct trigger levels. Levels of turbidity greater than 5 NTU (nephelometric turbidity units) are discernible to consumers and therefore this becomes a natural upper limit of acceptability for drinking water. The second trigger level is around 1 NTU which is a quoted upper limit for efficient disinfection of water using disinfectants such as chlorine.

It is therefore one of the main physical parameters that is used to indicate water quality for water supply purposes. Maximum limits on turbidity are included in national and international regulations. The World Health Organisation has produced *Guidelines for Drinking Water Quality* (latest edition 2006), which quotes a maximum guide level of 5 NTU acceptable to consumers but also a treatment level of less than 1 NTU for successful disinfection.

The European Community regulations on water quality sets a treatment standard of less than 1 NTU and requires that the water at consumers' taps must have a turbidity which is acceptable to the consumers without stating a level.

In the UK the EC Directive has been interpreted and incorporated into statute in the Water Supply (Water Regulations) 2000 for England and Wales with similar regulations for Scotland and Northern Ireland. This states that the turbidity level leaving a water treatment plant must be less than 1 NTU and the maximum level at a consumer's tap is 4 NTU.

In the United States the US Environmental Protection Agency sets the following turbidity standards:

5 NTU for surface waters used as drinking water without filtration
1 NTU for slow sand or diatomaceous earth filtered water
0.5 NTU for conventional or direct filtration

In the UK, on-line turbidity measurement is therefore undertaken as a matter of course on the outlet to the majority of water treatment works. This is to enable demonstration of compliance with the regulations and as an early warning of possible problems within the treatment process. Trigger levels for alarms will typically be set at 0.1 NTU. Occasionally, where there is a history of high turbidity in the treated water, there may be shut down controls initiated automatically on high turbidity readings.

A selection of consumers' taps are sampled for turbidity compliance at least annually for all water supply zones.

A few surface water sources of high quality (springs), may not require treatment other than disinfection. Such sources are frequently monitored for turbidity compliance on a permanent basis and will often have an automatic shut-down control system on high turbidity. An example is Idlecombe Spring on the Isle of Wight which is an excellent water of reliable quantity for most of the year but at periods of exceptional rainfall may exhibit raised turbidity levels for short periods. A sluice valve is automatically controlled by the turbidity meter so that any water with a raised turbidity level is diverted to the stream.

Cryptosporidium oocysts are a particular problem in water supply because of their resistance to even high concentrations of chlorine. However, they can be removed by any process that limits particles down to the size of 4 μm or smaller. Conventional water treatment processes well operated and maintained will normally provide sufficient barrier to oocysts. The primary element in conventional treatment process assuring removal of small particles is the filters. Continuous on-line turbidity measurement on the outlet to all filters is used as an indicator of the condition and operation of the filters and therefore the efficiency of crypto oocyst removal.

The Bouchier Report (DETR, 1998) states: "5.4.1 Investigation of waterborne outbreaks has shown that often there was a significant increase in turbidity at the time that the contaminated water was estimated to have entered supply." This report recommends that "5.4.3 For all sites at which Cryptosporidium might be a high risk, as determined by the risk assessment, monitoring should include continuous turbidity measurement on the outlet of each filter and on the final water using instruments capable of detecting changes of less than 0.1 NTU."

2.5 Other industries

2.5.1 Company X

Company X undertake remote real time monitoring of approximately 450 assets. Parameters monitored include water levels, weir operation, flows through conduits, sluice operations and gate positions. Alarms are incorporated where appropriate, with relevant personnel being notified directly by mobile telephone if a trigger level is reached. A 'reach out' facility, in which remote operation can be undertaken, is also available at a limited number of sites.

The real time monitoring system is internet based and has been in operation for three years. All software has been developed by Company X.

In general, remote readings are recorded at 30 second intervals, being averaged to provide a reading over 5-minute intervals. In order to conserve batteries, stored information is only transmitted to the central server every 24 hours. 90% of the information is relayed by mobile telephone technology, with the remaining 10% being transmitted by land line.

Data from the last ten years, including information obtained both manually and remotely, can be retrieved upon request. There are no limits to the number of persons who can access the database at any one time.

Each monitoring instrument is inspected every 6 months by a specialist sub-contractor, and a pro-active replacement policy is adopted. Problems associated with the system include the susceptibility to vandal damage and the rapid rate at which current technology becomes obsolete.

A combined monitoring instrument for turbidity, temperature, dissolved oxygen, blue-green algae and pH has been developed but not yet implemented.

The business justification for the real time system includes time savings, legal defence and compliance with the requirements of the Water Framework Directive/Water Act.

2.5.2 Hydroelectric power

Practice is similar to the water industry, in that key plant (the turbines and generators) is linked to real time monitoring and control because of the need to respond to rapid changes in load, whilst the dam safety monitoring regime is based around weekly (or similar) visits and readings.

2.5.3 Environmental monitoring by Environment Agency

The Environment Agency is responsible for overseeing monitoring of water and air quality, some of which is real time. Documents relevant to this project include those shown in Table 2.2.

In addition the Environment Agency maintains a network of flow gauging stations, and in some cases "automatic water quality and flow rate monitoring stations" (AFMS). The latter may typically take hourly readings of predetermined parameters, which could include one or more of ammonia, conductivity, dissolved oxygen, nitrate and turbidity

Table 2.2 Guides and publications produced by the Environment Agency relevant to real time monitoring of dams

Year	Title	Remarks
	Monitoring Certification Scheme (MCERTS) www.mcerts.net	A scheme for self certification of monitoring of discharges, which includes guidance notes on various aspects of the monitoring. It includes the two documents listed below
2004	Technical Guidance Note (Monitoring). M18 Monitoring of discharges to water and sewer	50 pages. Appendix includes requirements for monitoring frequency under several different pieces of legislation, that under the Waste Incineration Directive requiring continuous sampling of pH, flow and temperature.
	Certification of continuous water monitoring equipment	Performance standards and conformity testing procedures have been published for automatic wastewater samplers, on-line analysers covering turbidity, pH meters, ammonia, chemical oxygen demand, total organic carbon, dissolved oxygen, total phosphorus, nitrate and total oxidised nitrogen (TON) analysers, and flowmeters.
	Waste management	
2003	Guidance on monitoring of landfill leachate, groundwater and surface water. LFTGN02	283 pages. Comprehensive and useful guide to monitoring related to landfills; produced to assist waste management industry. Readers are expected to be familiar with the Landfill Regulations (England and Wales) 2002. The majority of measurements are not real time.
2000	Guidance on the assessment and monitoring of natural attenuation of contaminants in groundwater. R&D Publication 95.	Prepared by Enviros Aspinwall and LGC plc for Environment Agency staff who assess third party proposals for use of monitored natural attenuation as part of a remedial strategy for dealing with polluted groundwaters. Monitoring to confirm performance of the designed system is not real time, although it recognises that the water quality will vary with time.

2.5.4 Landfills and Leachate

Landfill site are required to measure the volume of leachate pumped away from the site. This is either measured by volume where tankers are employed or metered where pipes are discharged. Very few landfill sites operate ‘real time’ leachate monitoring systems and few, if any, correlate seepage with rainfall.

2.6 Strategy for procurement and maintenance

A key issue in regard to the practicality of real time monitoring will be the approach to maintenance, calibration and replacement of the equipment, and also use of the data. This is illustrated in Table 2.3. This is likely to be a major constraint for companies without in-house ICA skills, in terms of cost and likely reliability.

Table 2.3 Range of variation in strategy for maintenance, replacement and use of real time equipment

	Water Company – Real time monitoring installed at water treatment works	**Company X**
Equipment installation	In-house staff	External contractor
Maintenance		
Maintenance cleaning: frequency and by whom	Twice a week by plant engineers who visit each WTW regularly	All carried out by external contractor six monthly, and under call-out where problem identified
ICA check i.e. check that it still works correctly	By Instrument technician (the company employs 50 specialist ICA staff)	
Recalibration	Periodically; often in the laboratory at the WTW	
Instrument replacement	On failure, or when technology superseded	Ten years
Replacement of batteries in power pack	Not relevant	Routinely as part of six monthly check
Alarm management		
Alarm sent to	24 hour control centre, manned by in-house staff	Mobile phone of Duty Engineer
24 hour control centre for receipt of alarms from public		Contracted out to local County Ambulance Control centre

2.7 Summary from review of current practice

In general real time monitoring is only currently adopted in the following situations

a) where loadings or other key environmental constraints are changing relatively rapidly and actions need to be taken in response to these changes. This applies, for example to both water treatment and hydroelectric power plants where settings of machinery need to be adjusted.

b) To provide a record of environmental compliance, for example at discharges from treatment plants

c) At larger dams internationally, with many instruments, to provide improved monitoring

For dams in UK early detection of internal erosion is generally dependent on visual surveillance visits, carried out at frequencies between every 48 hours and weekly, or less frequently for low consequence dams. Monitoring of seepage flows is generally weekly, by manual readings, although the timescale for plotting and analysis of these readings is variable. The focus is on detection of new seepages, rather than detection of changes in magnitudes of seepage, or the quantity of suspended solids contained in existing seepages. Where real time monitoring is installed at a dam, this is usually in response to specific risk management or time constraints.

3 Instrumentation – Hardware

3.1 Introduction

Whilst the capture of any seepage is probably the most difficult element of seepage monitoring for existing dams, particularly older dams, the installation and interrogation of sensors to measure the parameters that may affect it, is relatively common practice. The remote access and 'near real time' data presentation facilities that are now available with the latest generation of communication systems can enable early detection of changes in the performance of a dam structure.

It is noted that the influence of 'non – seepage' flows, such as runoff from rainfall and groundwater can reduce the effectiveness of manual monitoring systems due to their infrequent nature. Apparent seepage flows can change significantly over a short time scale and these changes may not be detected by site staff. Where an investigation is carried out because of concern over internal erosion it is suggested that consideration be given to an automated system to determine changes in seepage flows and to measure the effect of external influences on seepage.

3.2 Sensors

3.2.1 General

In many cases where the seepage is already being monitored, the measuring devices rely on physical visits to the measuring locations. Water levels behind weirs are typically read using either simple scales or a mechanical 'hook gauge', with the computation of flow often being carried out at a later date. Suspended particles may be trapped in the stilling chambers located behind weir plates.

Where an existing SCADA system is in place, it could be configured to accept input from additional remote sensors and perform the necessary computations. Alternatively, if a stand alone, automated seepage monitoring system is to be installed, dedicated sensors may need to be added, even if they are already included in an existing SCADA system.

3.2.2 Reservoir water level

As seepage of the stored water through an embankment, its foundation or its abutments is driven by pressure generated by the upstream water level, part of any seepage monitoring regime should, in most cases, include measurement of the upstream water level.

There are many systems and devices available to remotely detect water levels for such applications. Selection of the most appropriate device is dependant upon the automated regime that is to be installed (or that already exists) and the physical nature of the project.

The accuracy of most sensors is increased if they are installed in a stilling tube or chamber. This reduces the effects of water surface movement on measurements since changes in water level are only influenced by flow to and from the base of the tube, thereby removing the effects of turbulence and wind. It also affords protection from waterborne debris and human intervention.

Float based measuring devices. These are suitable for use only where a structure is available or can be created, onto or into which a vertical stilling tube can be fixed. The length of the tube must extend from the measurement elevation, over the full range of the water level and at least 1m below. The vertical movement of a float within the tube is then detected using a shaft based sensing device and converted into an absolute elevation.

Pressure transducer based devices. These are not dependant upon a vertical installation and can be positioned in any suitable location upstream of the dam. They do, however, provide the best quality output when installed within a stilling tube or chamber, which need not be vertical. Transducers are selected for their characteristics, particularly, power requirements, output and sensitivity within the range of expected water levels. These sensors must be of the 'vented' type so that changes in atmospheric pressure do not distort the water level readings. The input and output features of any transducer must match those of the system data logger. Connecting cables must be provided with suitable protection but can normally be run over long distances. Where ever possible these devices are installed such that they can be retrieved at a later date for maintenance, re-calibration or replacement.

Ultrasonic based devices. These sensors are common within the fresh and foul water treatment industries and commonly form a sizable percentage of the sensors linked to associated SCADA systems. One of their main advantages is that they are 'contact-less', relying on the rebound time of a sonic pulse focused vertically down from a fixed point onto the water surface. These devices are best employed where the water surface is mainly flat consequently they are best used where a stilling tube or chamber can be created. They are comparatively expensive devices and can be relatively 'power hungry' but where a suitable power supply is available, provide an accessible water level monitoring solution.

Radar based devises. These are very similar to the above but operate using a radar frequency rather than ultra sonic. They tend to be more expensive and were developed for use in industrial applications with particularly harsh environments.

3.2.3 Rainfall

Seepage is generally not directly affected by rainfall. However, the flow of water registered by a seepage measuring system can be greatly affected by rainfall. It is vital that these effects are eliminated from seepage data, particularly where automated alarms are to be established. Initially, analysis of the affects of rainfall on seepage volumes should be studied in order that they can be eliminated from potential alarm triggering events.

The most suitable and cost effective automatic devices for the measurement of rainfall are the 'Tipping Bucket' rain gauges. These employ a very simple, contact-less 'bucket' to measure the volume of rain entering a standard funnel. When the calibrated bucket reaches a known volume, it automatically 'tips' releasing the water and re-setting the device. They are configured to generate a pulse output for each known volume of rainfall, usually equivalent to 0.1 or 0.2 millimetres. They are easily linked to most data logging systems where the data can be included in trigger activation criteria.

In the event that investigation and monitoring concludes that rain has little or no effect upon the seepage volumes, the rain gauge could be eliminated from a monitoring regime.

3.2.4 Flows

Once seepage water has been routed along a particular path and, where possible, external influences eliminated, the measurement of the volume is essential. This will form the main data source from which potential internal erosion will be assessed and alarms would be triggered.

Weirs are the most common form of measurement used for this application. The seepage flow enters an enlarged chamber on its route to drainage. There, it is forced to 'still' where any turbulence is removed or significantly reduced. It is then allowed to drain from the chamber over a calibrated weir. The level of the water behind the weir plate is proportional to the flow over the weir. Weirs are generally a 'V' shape with angles commonly ranging from 30 to 90 degrees. Where larger flows are encountered and water elevations limited, weirs can also have a level base and vertical sides (square weir) or have a level base with sloping side (Thompson weir). V notch weirs should, wherever possible, be constructed using guidance from BS 3680 Part 4a: 1981.

Various sensor types are available to automatically measure the level of water behind the weir plate. Commonly, these include:

Magnetostrictive devices, where a float containing a magnet passes along a vertically mounted sealed sensor tube. The position of the float along the tube is very accurately determined by a pulse passed down the inside of a special sensor tube within the external tube. They require a 24 V AC supply and provide a contact-less, 4-20mA output. They come as a sealed stainless steel construction, with many sensor ranges.

Electrical pressure transducers, where the level of water is registered by a short range pressure transducer located in the base of the stilling chamber. Many types of pressure sensor are available with a wide variety of input and output options. Selection of the most appropriate sensor for an application must be carried out on an individual project basis. Vibrating Wire (VW) and 4-20mA outputs are the most common with the VW requiring a special interface for some loggers. These sensors must be of the 'vented' type so that changes in atmospheric pressure do not distort the readings. For accurate and reliable data a stilling tube is also required.

Float based sensors generally convert the level of a float into an electronic signal by registering the rotation of a shaft from which the float and its counterbalance are suspended. Vibrating Wire sensors are also available where the sensor registers changes in the buoyancy of a cylinder rather than movement.

Flow meters. Some seepage systems utilise sumps and pumps rather than gravity based drainage systems. Volumes of water that are pumped from the sumps can be monitored using flowmeters fitted in-line with the discharge pipe-work.

Doppler flow meters. These are used in open channels to measure flow and level of water using a single device. An ultrasonic signal is transmitted from the sensor located in the base of the channel. It is aimed into the oncoming flow. The frequency shift of the signal rebounding from waterborne particles or bubbles, indicates the velocity of the flow. Computation based upon depth and channel dimensions provides reliable flow volumes. This methods is generally used for larger flows.

3.2.5 Turbidity

It appears that generally the term Turbidity tends to refer to low concentrations of solids in a liquid, whilst the term Suspended Solids tends to be used where higher levels of material are suspended in a liquid. Turbidity measurements are covered by BS6068-2.13:2000.

The automatic measurement of Turbidity and Suspended Solids in seepage water from dams is rarely used in the UK. In North America, automated sensors are becoming more common in seepage monitoring, partly due to the remote location of some dams and partly due to the availability of more reliable sensors.

Since the filtering effect of materials through which seepage water often passes, the sensitivity of the sensors must be considered. However, the possible influence of particles carried by water from other influences, such as rain passing through or over the dam body, must also be addressed.

Normal and ‘Self Cleaning’ Turbidity sensors are available to operate in the 0 – 50 NTU range. These are usually mounted vertically in a stilling chamber and linked to a local data logger and power source. Installation remote from the data logger is also possible since a 4-20mA output option is available. A number of sensors could be linked into one data logger and power source.

3.2.6 Temperature

The measurement of temperature in relation to seepage can be divided to two configurations. Firstly, the installation of networks of sensors within the body of the dam during construction; secondly, the installation of sensors close to the surface, post construction.

Generally, thermistors or thermocouples are employed as point measurement sensors since they are accurate, stable and inexpensive. They can be easily linked to most data logging systems and cabling is generally inexpensive.

Sensors must also be installed in the upstream water in order that a relationship can be established between the upstream water temperature and the temperature of any seepage water.

Fibre optic based systems have also been developed for this type of application and have provided some encouraging field data. However, due to the cost of the readout equipment this technology is not considered appropriate for inclusion in this study.

3.2.7 Power demands

The power demand will vary significantly with instrument type, with an indication of typical demands given in Table 3.1.

Table 3.1 Indicative capital cost and power consumption of instrument sensors

Parameter	Typical Instrument Types	Instrument capital cost for supply (2007)	Instrument Power consumption	Comments
Pore Pressure;	Vibrating Wire Piezometer	about £500	negligible	
Temperature	Resistance; Thermocouple; Thermistor	about £50	negligible.	
Water Level	Ultrasonic; Float; Hydrostatic Pressure	about £1000 about £500	up to about 3W negligible	
Precipitation	Tipping Bucket	about £300	negligible	Requires a heater with power consumption about 20W if it is necessary to correctly measure precipitation falling as snow.
Flow	Ultrasonic Head over Weir; Ultrasonic Doppler; Pressure Head; Magnetostrictive Float	about £2000 about £500 about £800	about 3W negligible about 2W	24 Volts required
Turbidity	Optical	about £1000	about 1W	
Closed Circuit Television	Fixed Camera; Remotely Controlled Camera	about £1000	about 5W (fixed camera)	Not effective during hours of darkness.
Data Converter and Recorder	Data Logger (including software)	£500 to £15,000	See Remarks	Data logger power consumption ranges from negligible (for single instrument with local data collection) up to about 20W (for multiple instruments with remote data transmission).

3.3 Data loggers

Automatic data loggers are available in many forms. In their basic forms, they are configured to interrogate sensors at specific intervals and store the resulting readings. They are available to accommodate single sensors through to many hundreds of sensors.

More sophisticated devices can be programmed to perform mathematical functions based upon the gathered data and execute output routines that include the automatic transmission of data and alarm triggering functions. These devices normally function as ‘near real time’ data handling devices.

A generic, multi-channel, stand alone data logger normally comprises some or all of the following components:-

- CPU, providing instrument excitation and the monitoring control, data storage capacity, computation with trigger activation facilities and communication interface.

- Sensor interface(s), allowing instruments employing differing or specific excitation and interrogation requirements to be connected to a single data logger.
- Power supply(s), providing both running and backup power for logger operation and communication equipment. Some loggers can operate from a single sealed battery for considerable periods, others require an external power source to trickle charge a battery. Communication devices are generally ‘power hungry’ and require an external source. Power supply options include; mains charger, solar panel, large lead-acid accumulator, small scale wind turbine.
- Communication device(s), enabling programming, interrogation and data retrieval using PC or other suitable device

Trigger levels for an automated system would need to be established and presented as an algorithm (including water level) or based upon acceptable levels in a lookup table that could be included in the data logging device.

3.4 Communication / Telemetry

Data can be downloaded from stand alone data loggers using Notebook PC’s, PDA’s or purpose built devices using cable, IR or Bluetooth facilities. During investigation phases, remote access to the data may not be required and these local options may suffice.

However, automatic data loggers require communication systems if they are to activate remote alarms and /or supply data to monitoring stations. Options for communication links are shown in Table 3.2.

3.5 Monitoring stations and alarms

Where a remote monitoring station is to be established, a PC would normally be dedicated to communication with logger(s) and management of incoming data. Generally the software used to programme and interrogate the data loggers includes various communication options for automatically gathering or receiving data from remote stations.

Various data management and presentation software packages are readily available for use with a wide variety of hardware. Alternatively, the data, normally in an ASCII text format could be incorporated into a local SCADA database for computation, presentation and analysis.

Remote data logging systems can be configured to activate physical local alarms or generate electronic messages when a measured or computed parameter passes an established threshold. For example, a warning light or audible signal could be triggered local to the logger or at a nearby control building. Alternatively, SMS or e-mail messages could be despatched to key personnel.

Alarms can also be triggered by monitoring station systems or associated SCADA systems. Most software allows for alarm status displays and the initialisation of a user specific routine when a trigger has be enactivated

Table 3.2 Alternative forms of data transmission

System	Solution for All Users	Alternative Solution for Major Users Only	Comments
Manual Downloading	The data is stored on a data logger at the dam and the dam is visited periodically, data is downloaded and the collected data taken to a central location for analysis.	As for All Users	Low tech solution. Major disadvantage that any problems with the dam, or the monitoring system, would not be found until after the following visit. Labour intensive. Capital cost up to £2k, operating costs dependant upon labour rates.
Land line (PSTN or Private Data Cable)	Each dam is connected to the Public Switched Telephone Network (PSTN), data is collected on a data logger at the dam and transmitted to be analysed centrally by a service provider who sends alarms and information to the user by e-mail, web, text or voice message.	Each dam is connected either to the Public Switched Telephone Network (PSTN), or to the user's own telemetry system, data is collected on a data logger at the dam and transmitted to be analysed centrally by the user's own computer system centre to initiate alarms, etc.	Very reliable solution utilising well established technology. Preferred solution for "critical" dams. Capital costs dependant upon the length of the required telephone type cable between the dam and the existing local PSTN system, operating costs up to £200 p.a.
Mobile phone (GPRS Data System)	Each dam is linked to the General Packet Radio System (GPRS) using cellular telephone technology, data is collected on a data logger at the dam and transmitted to be analysed centrally by a service provider who sends alarms and information to the user by e-mail, web, text or voice message.	As for All Users, but the data is collected and analysed centrally by the user's own computer system centre to initiate alarms, etc.	Reliable solution utilising established mobile telephone technology. Not suitable for areas with no cellular telephone coverage. Network provider contract and SIM card required. Capital cost up to £500, operating costs up to £100 p.a.
Radio System	Only appropriate for Major Users.	Each dam is linked by radio to the user's system centre, data is collected on a data logger at the dam and transmitted and analysed centrally by the user's own computer system centre to initiate alarms, etc.	Reliable solution utilising established radio technology. Geography may limit use in some areas. Frequency allocation and radio transmission licenses required. Technology limits this solution to Major Users who already have an established radio network. Marginal costs on an established system are negligible.
LEO Satellite System	Each dam is linked to the Low Earth Orbit (LEO) satellite system, data is collected on a data logger at the dam and transmitted to be analysed centrally by a service provider who sends alarms and information to the user by e-mail, web, text or voice message.	As for All Users	The only solution for remote locations outside the mobile telephone coverage areas. Contract required for satellite links resulting in higher operating costs. Satellite communications can be adversely affected by rain, snow, etc. Capital cost up to £3k, operating costs up to £300 p.a.

3.6 Life span of equipment

Monitoring equipment for use in the civil, structural, geotechnical and environmental industries is generally intended to have a medium to long life span. Piezometers, for example are intended to operate for periods grater than 25 years.

Sensors used for seepage monitoring are generally accessible and could, in the event of failure, be repaired, replaced or upgraded. In general, the simpler the sensor (e.g. few moving parts, few electronic components, contact-less) the less likely it will be to fail.

Many data logging components are designed for harsh, remote environments. Care must be taken when sourcing equipment that the supplier fully understands the intended application. Equipment should be sourced based upon its intended use and life span required. Budgets must reflect the probability that more robust equipment will usually have a higher cost.

Additionally, the technology is still developing rapidly, such that some equipment may become obsolete and/or the manufacturers go out of business, such that spares are difficult to obtain. It is therefore suggested that for planning purposes it should be assumed that electrical equipment has a life span of ten years. Nevertheless much equipment should have a lifespan in excess of this, provided the initial purchase is of high quality robust simple equipment.

3.7 Sourcing and Installing Equipment

It is strongly recommended that equipment be supplied by specialist organisations and installed by experienced personnel. Calls for quotations should be based upon both specialist engineering input and a site specific survey with particular attention to the precise requirements of any monitoring regime.

It is recommended that specialist advice be sought where it is not already available. Independent instrumentation specialist services are available to assist with the design and sourcing of equipment and services. Most instrumentation companies also offer a technical support service, as part of their general operations.

Some of the major instrumentation suppliers include:-

- Soil Instruments Ltd, www.soil.co.uk
- MGS Geosense (representing RST, Canada) www.mgs.co.uk
- Sol Data / Gage Technique International Ltd (representing Slope Indicator, USA) www.soldata-ltd.co.uk
- Geotechnical Instruments Ltd www.geotechnical.co.uk

In terms of engineering advice panel engineers under the Reservoirs Act 1975 are listed on the Defra website (www2.defra.gov.uk/db/panel/default.asp) whilst geotechnical instrumentation falls under the umbrella of the Association of Geotechnical and Geo-environmental Specialists, AGS (www.ags.org.uk). The following are suggested internet search criteria for ‘Yahoo’ or ‘Google’ to help locate independent specialist services to assist and advise on appropriate selection and best positioning of sensors, together with sourcing guidance:-

- *Geotechnical Instrumentation Specialist*
- *Structural Instrumentation Specialist*
- *Independent Instrumentation Specialist*

4 Issues regarding physical installation at dams

4.1 Introduction

This section provides comment and guidance on the practicalities of physical installation of real time monitoring relevant to early detection of internal erosion at dams in the United Kingdom. It is structured as follows

a) measurement of reference parameters such as reservoir level and rainfall, required where seepage varies with these parameters and trigger levels are to be used to provide automatic alarms
b) measurement of seepage and associated suspended solids at V notches, the application likely to have most widespread application in United Kingdom
c) other options where installation of a V notch is not possible
d) other issues

4.2 Reference parameters

The technology for continuous measurement of water level and rainfall is now well established. A particular issue to note in relation to water level is the range and accuracy of the sensor. Where high accuracy is required then it may be necessary to have several sensors at varying elevations up the upstream face. A separate senor would normally be installed to measure the depth of overflow over the spillway.

Sensors can be installed in the reservoir bed but this is expensive as it requires either emptying the reservoir, or use of divers. Alternatively probes can be installed by suspension from the reservoir surface, but it is generally difficult to ensure reliable location on the reservoir bed, and there is a vulnerability to the sensor being displaced in the long term.

4.3 V notch chambers

4.3.1 Measurement of seepage flow

To provide accurate measurement, V-notch weirs should where possible be designed and installed in accordance with BS 3680 Part 4a: 1981. In practice some deviation is often acceptable, as it is changes in flows that is of most interest, rather than absolute magnitudes.

The v-notch plate is bolted to the sides of the chamber and is hence designed to be easily removed. When the plate has reached the end of its asset life, a new V-notch arrangement can therefore be installed in the existing chamber. Maximum longevity of the measuring facility can be achieved by ensuring that the weir plate in the vicinity of the notch is formed from a corrosion-resistant material such as stainless steel. It is expected that a stainless steel weir plate will have a typical asset life of 20-25 years.

Level recording sensors should be installed at the specified distance upstream of the V-notch plate, and positioned to enable easy access for future maintenance and repairs.

4.3.2 Measurement of suspended sediment

Turbidity monitoring instruments capable of providing real time monitoring can be incorporated into leakage reception chambers. They should be located in a zone where air bubbles are unlikely to be trapped in the water but where solids remain suspended.

It is suggested that a sensitive instrument capable of recording turbidity in the range 0.1 to 10FTU would be required for the monitoring of dam leakage. The limit of visual detection is 5FTU.

Maintenance of the instruments will depend upon the environment in which the sensor is installed; cleaning of the sensors may be required at up to 1-2 week intervals, although this would be extended where the more expensive, 'self cleaning' devices are installed.

Whilst not relevant to the real time monitoring issue, an alternative means of assessing the quantity of suspended fines is to collect the fines which settle out in the V notch chamber. In this situation it would be necessary to detail the chamber to avoid sediment from other sources, such as surface runoff and the atmosphere. Where space allows it locating the V notch chamber in a drawoff tunnel should eliminate these effects.

However, as shown in Table 4.1 the slow settlement rate of clay and fine silts is such that it is unlikely that these finer particles would settle out in chambers of practicable dimensions. Thus where any eroded particles are likely to be clay or fine silt detection should be through turbidity measurement, rather than reliance on collection of fines which settle out in the V notch chamber. Nevertheless collection of suspended fines is still considered a useful check on data from real time monitoring.

Table 4.1 Typical settlement velocities of particles in suspension

Particle type	Terminal/ settlement velocity (mm/s)	Maximum seepage flow (litre/ min) rate for sedimentation of fines to occur
Clay	0.001	0.06
Fine silt	0.01	0.6
Medium silt	0.1	6
Coarse silt	1	60

Note 1. Assuming maximum horizontal velocity equal to settlement velocity, and 1m^2 cross section

4.3.3 Locations for V Notch installations

(a) General

Embankment leakage may originate from numerous locations within the dam and its appurtenant structures. Some of the practical factors that need to be taken into account when deciding the practicality of a V notch arrangement are set out in

Table 4.2. Appendix A includes a table that outlines the feasibility of installing V notches and associated real time monitoring at a sample of 10 different reservoir sites, whilst Appendix B includes extended commentary of the practicality at two of the sites in Appendix A . This limited sample suggests that at many of dams in the United Kingdom real time monitoring is physically possible. The decision on adoption of real time monitoring should be based on proportionate cost in relation to the reduction in risk achieved.

The construction of the V-notch measuring chamber will depend to a large extent upon the location of the monitoring point, i.e. upon the dam face or within the draw-off tunnel. Typical forms include brickwork chambers, reinforced concrete chambers, galvanised mild steel boxes or stainless steel boxes.

(b) Embankment

Leakage from the embankment may be observed at any position on the downstream dam face, along the mitres or from the adjacent abutments.

Leakage flows from different areas should preferably be kept separate and monitored individually. However, they may be combined to give a total leakage flow. The construction of multiple v-notch chambers may therefore be required, depending upon the nature of the measurement required.

Where a new chamber must be constructed to incorporate a weir plate, consideration should be given to minimising the depth of excavation required; however, to a large extent this will depend upon the position and alignment of the leakage point/drain in question.

For reliable leakage measurement it is necessary to ensure that the leakage flow is not affected by additional external sources such as rainfall, overflow, compensation or other discharges.

Weir locations within spillway channels and stilling basins should be avoided, as the measuring facilities may impede spill flows or may become drowned out at regular intervals.

(c) Pipes and culverts

Leakage flows may be observed through the lining of the draw-off tunnel, or along the outside of tunnels, culverts and pipework situated through the embankment.

Within tunnels the leakage may be monitored at the point of egress, or intercepted and piped to a measuring facility normally located at the downstream end of the system.

Care should be taken to ensure that the position of the measuring weir arrangement does not interfere with the hydraulic operation of the scour system or impede any other flows conveyed through the tunnel system.

Table 4.2 Practical constraints on location of V notch chamber

Issue	Comment	Possible solutions
Downstream submergence	The proximity of a downstream reservoir causes a) the point of leakage to be completely submerged, or b) prevents free discharge from a V-notch weir.	'a' is insurmountable, whilst the latter may possibly be overcome by altering the drainage pipework arrangement and raising the level of the measuring weir chamber.
Ochre deposits	Leakage water, particularly that originating from behind tunnel linings, may contain significant deposits of ochre, which obstruct the V notch	Frequent cleaning will be required, and could be aided by installing washouts on any drawoff pipework in the tunnel. However, manual readings could be taken at the same time as cleaning, negating some of the benefits of automation of flow monitoring
Space for V notch	Obstructions within the confines of a tunnel, such as the arrangement of the draw-off pipework or access walkways, may not allow the V-notch to be installed in accordance with the dimensional parameters specified by BS 3680: Part 4A: 1981.	a) Re-alignment of pipework or access metalwork may be feasible, although this is likely to be expensive b) Accept reduction in monitoring accuracy
Position of leakage	Ideally measured near the point of egress.	The flows may be directed to an alternative location where the V- notch weir chamber can be more easily constructed, maintained and monitored.
Other sources of water	Draw-off tunnels may be used to directly convey stream compensation/supply flows, or water seeping from leaking pipework or valves may obscure seepage flows	Extend discharge points to downstream of V notch
Power and communications links	Ideally site V notch chamber to minimise distance (and thus cost) from existing links	Use free standing system, using batteries and solar power and mobile phone or other technology for telemetry.
Access for cleaning V notch chamber	If the design includes periodic collection of accumulated sediment in the V notch chamber, the layout needs provision to divert incoming flows, and also dewater the chamber without disturbing silt.	a) Install a piped or channelled diversion system around the chamber to enable flows to be discharged at a suitable downstream location b) Draining of water from the chamber could be achieved by the provision of a drain valve at a convenient position, near to the base of the walls, or by low rate pumping.
Vandalism	Equipment that is accessible to the public is vulnerable to vandalism	Locate chamber and equipment in secure enclosed areas. Where this is not possible use high quality locks, as certified by the Loss Prevention Certification Board

4.3.4 Health and Safety Considerations

Manual recording of leakage flows within draw-off tunnels, valve shafts and other deep chambers will generally necessitate the reservoir operatives entering an area designated a confined space. Remote real time monitoring may therefore significantly reduce the requirement to enter these potentially hazardous areas for leakage monitoring purposes; however, this will not reduce the frequency of confined space entry required for routine structural inspections or checks on other apparatus.

Similarly, the recording of external leakage flows may require entry into steep channels conveying water, or access across slippery inverts. Again, these hazards could be eliminated or significantly reduced by the introduction of remote monitoring.

When installing remote sensors and electrical equipment within the confines of a tunnel, it is essential that the correct IP electrical protection rating for the local environment is used.

4.3.5 Examples of V notch installation

(a) Basic V notch

Figure 4.1 shows a typical example of a V-notch chamber and seepage recorder that could be installed within the downstream face of a reservoir embankment.

A trash grid is provided to filter out large suspended solids that may accumulate in the vicinity of the V-notch plate and the recording sensor. This grid, and the upstream section of the chamber, will therefore require periodic cleaning. A baffle plate is often provided at the same location to still water entering the section of chamber immediately upstream of the V notch.

(b) System to allow collection and measurement of suspended silt

Figure 4.2 shows a possible arrangement for a combined settlement and measurement facility suitable for a single, low rate leakage flow.

This is similar to the basic flow measurement chamber described in Section 5.2.5, but with the introduction of a piped diversion system, with associated control valves, to facilitate draining the chamber to collect and weigh sediment which has settled out.

Multiple chambers and diversion arrangements may be required if it is necessary to monitor more than one individual flow.

Figure 4.1: Typical Arrangement of a Real Time Monitoring Facility

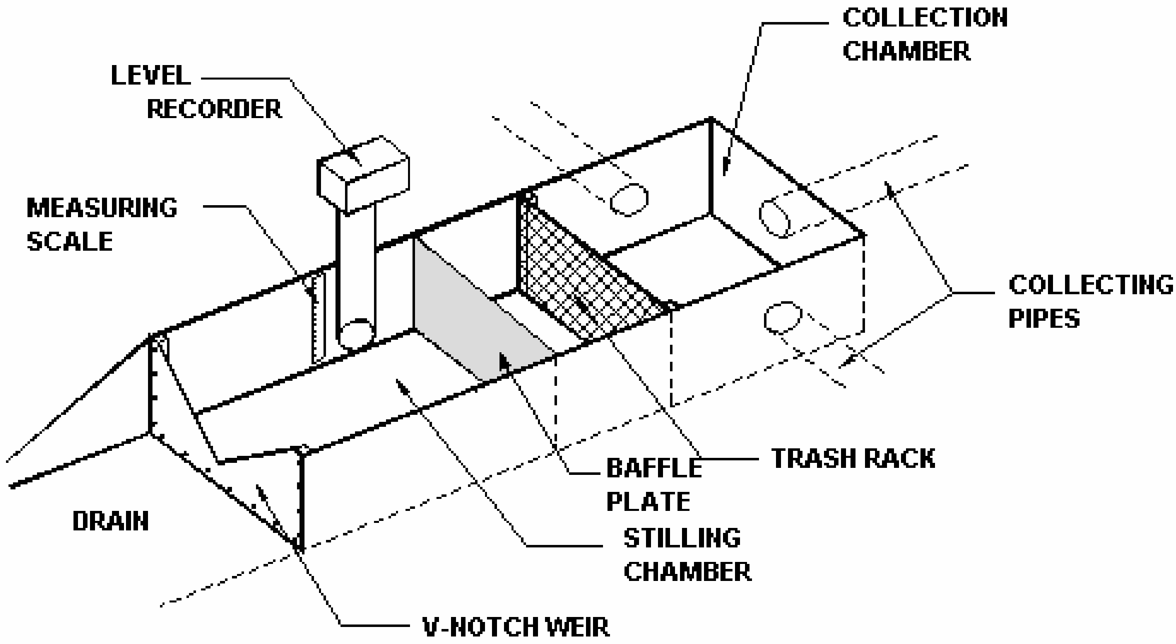
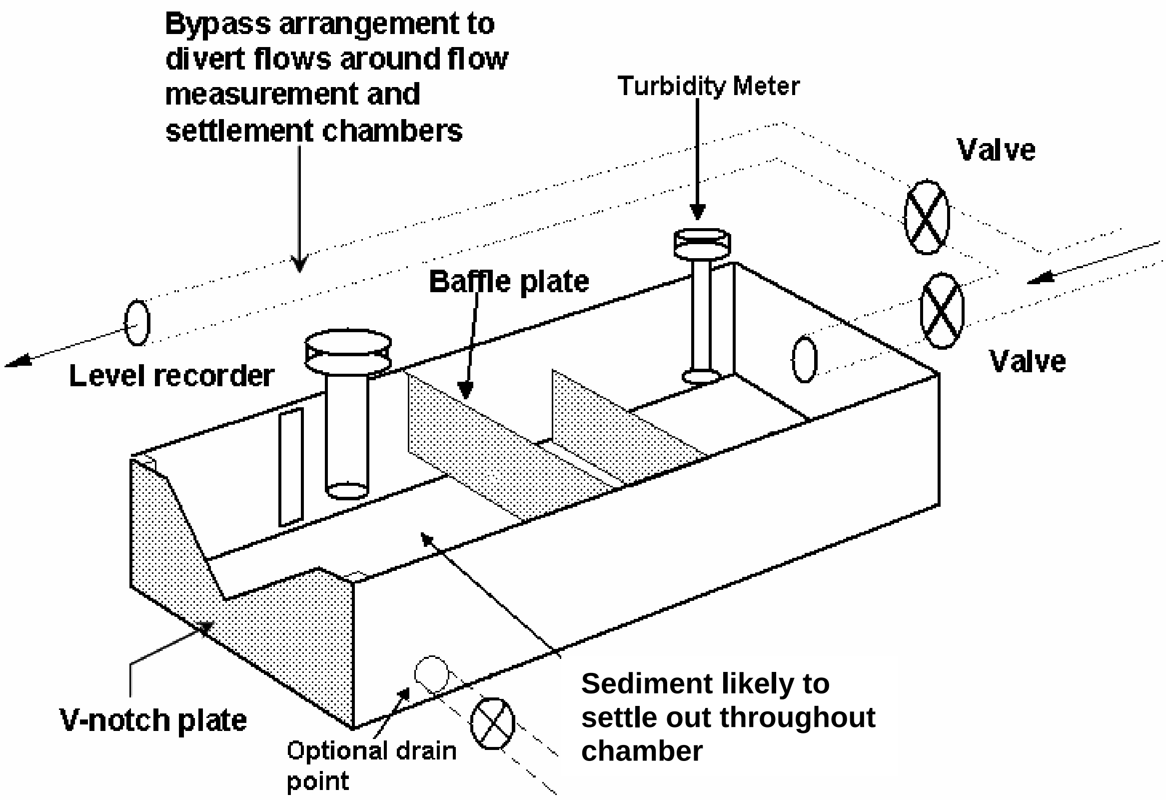


Figure 4.2: V-notch Chamber Incorporating Settlement Facility and Bypass Arrangement



4.4 Other Options in addition to V notch installation

4.4.1 Piezometer installation

Piezometers are used to detect fluctuations in pore water pressure within the dam. They may therefore provide some indication of a potential leakage path.

Various types of piezometer are available. Hydraulic piezometers are normally installed in dams during construction but have a limitation in that the tubing cannot be installed at a level greater than 5m above the piezometric level. Due to the higher level of maintenance required (de-airing) and the size of the terminal structures required, these piezometers have generally been superseded by electric piezometers for most dam monitoring applications, despite their limitations. For instance electric piezometers are not generally considered suitable for use in locations where their surrounding soils would remain partially saturated for long periods. For both types, as the tip is permanently buried, the instrument cannot be repaired if a malfunction occurs.

In relation to real time monitoring only electric piezometers provide a direct reading suitable for remote reading and real time monitoring purposes. However, most other types of piezometer can be adapted for real time monitoring, for example

- Automated systems have now been developed to upgrade the terminal panels of Hydraulic piezometers to allow automatic monitoring in parallel with manual systems, where required.
- The standpipe piezometers installed in many smaller dams can be upgraded for automatic monitoring by using either a removable electrical piezometer fitted with a packer for rapidly responding, real-time logging or a removable self contained logger for storage of frequent readings for later retrieval.

4.4.2 Temperature measurement.

This technique detects the location of leakage by recording temperature differences at depth within the reservoir embankment (either through probes or fibre optics). As the changes due to localised seepage are small compared to seasonal temperature changes the results require expert interpretation. The method can therefore be used to collect real time data, but is not easily adapted to provide alarms of changes in seepage associated with progressive internal erosion. The high cost of the readout equipment for fibre optic based systems should also be noted.

4.5 Power supply

For most remote monitoring installations using small numbers of common sensors, the provision of a sizeable lead/acid battery will produce adequate power for up to 6 months, without the need for re-charging. However, if remote communications are to be included charging facilities will be required. Data loggers are usually fitted with backup power to ensure the storage of data in the event that the operating supply has been exhausted.

The various options for power supply are summarised in Table 4.3. The technology for re-chargeable battery packs in combination with solar power is providing much improved reliability for power, and in appropriate circumstances will last 6-12 months.

Table 4.3 Alternative forms of power supply

Power System	Description	Comments
Rechargeable or Replaceable Batteries	The instrumentation, data collection and/or transmission systems are powered by one or more rechargeable or replaceable batteries. Each dam is visited regularly and the batteries are replaced with recharged or new batteries.	Low tech solution. Disadvantages are the labour and materials requirements for replacing batteries and the possibility of loss of data due to premature battery failure. Suitable for electrical loadings up to around 30mW. Not suitable for dams with large numbers of instruments, or for dams with instruments having high electrical power requirements, such as rain gauges, some water quality analysers, etc.. Labour intensive. Capital cost up to £500, operating costs dependant upon labour rates.
Mains Electricity Supply	Each dam is connected to the mains electricity supply. Small rechargeable batteries would be provided to cover for short periods of mains power supply failure.	Very reliable solution. Suitable for all electrical loadings. Preferred solution for “critical” dams. Capital costs dependant upon the distance between the dam and the existing mains power supply. Operating costs up to £100 p.a.
Solar Panel	Each dam is provided with a solar panel array linked to rechargeable batteries to cover the night-time and periods of low sunlight.	Reliable solution utilising established technology. Suitable for electrical loadings up to around 20W. Not suitable for dams with instruments having high electrical power requirements, such as rain gauges, some water quality analysers, etc. Solar panel may require protection against environmental damage or vandalism. Capital cost up to £6k, operating costs negligible.
Wind	Each dam is provided with a pole or mast mounted wind turbine linked to rechargeable batteries to cover periods of low wind speed.	Reliable solution utilising established technology. Suitable for electrical loadings up to around 40W.Higher power output than solar panels, but may not be suitable for dams with instruments having high electrical power requirements such as some water quality analysers. Applicability dependant upon wind profiles in the local environment. May require planning approval. Wind turbine may be subject to environmental damage or vandalism. Capital cost up to £10k, operating costs negligible.

Where power is available but no communication link is installed, it may be feasible to install a data logger to record flows over a period of time. Whilst not strictly a real time measurement system, this option may provide a greater frequency of monitoring information compared with the periodic records obtained by the visiting Plant Engineer.

4.6 Procurement and Costs

The method of procuring a real time monitoring system will depend upon the owner of the asset.

Large utility companies are likely to procure services either through their capital programme contractors and/or through in-house resources. Framework suppliers may be used for the provision of instrumentation.

For dam owners who currently do not carry out any real time monitoring it will be necessary to employ consultants to design installations and contractors to procure, install and commission the equipment, as well as maintain it. In this situation there is a real risk of the equipment falling into disrepair due to lack of calibration and maintenance.

An indicative overall cash cost over a forty year period is given in Table 4.4. These could be discounted to provide the present value cost for use in an "as low as reasonably practicable analysis". Clearly the numbers will vary significantly, depending on site access, what parameters are measured and what economies of scale may be possible where there are installations at many dams.

Table 4.4 Indicative whole life cost of real time monitoring

Item	Budget cash cost for simple V notch chamber, over 40 years	
Civil works for first installation	£10k	Will vary widely depending on access and site constraints
Procure monitoring equipment, outstation, battery pack and communications link	£5k	
Install and commission equipment	£10k	Includes engineering fees
Maintenance of monitoring equipment, including regular replacement of batteries	£40k	Allow £500/ year for six monthly maintenance visits, plus £500/year average for call-outs
Replace sensors and other monitoring equipment every 10 years	£15k	3 sets of replacements
Total	£80k (2k/ year)	

Notes
1. The above excludes the cost of the central data processing system and manpower costs associated with false alarms and data management.
2. It is an indicative cost, for a site with straightforward access and installation.
3. Cost would be lower where installed at a site with existing, or multiple devices, where cost would be spread over several instruments

5 Use of real time data

5.1 General

A key part of planning and implementing any real time monitoring system is effective use and subsequent archiving of the data which is collected. This section summarises the issues that need to be considered in relation to the use of real time data for early detection of internal erosion.

The issues for other uses of real time, or automated monitoring, may be different and are not considered here.

The following are discussed further in the Guide to Early Detection of Internal Erosion:

a) Setting trigger levels
b) Data management

5.2 Software providers

The functionality of a monitoring system and the visualisation of the resulting data are dependent upon both the programming software and subsequent data handling software. The software required to establish 'near to real time' monitoring can be divided into 3 subsections:-

Hardware control and communication software

Software for the programming of data logging CPU's is usually provided by the manufacturer of the data logger. It is usually in the form of a programme editor that converts instructions into machine code for transfer to the CPU. Software packages will usually include separate modules for communication with the CPU, recovery of data from storage devices and basic data visualisation facilities. This software is usually used up to the point where instrument readings are copied from remote data loggers and are resident upon a local or network storage facility.

Initially, programming of the CPUs would usually be carried out by the supplier of the hardware, using pre-defined criteria provided by the client. This software can also handle the activation of alarms, based upon criteria incorporated into the CPU program.

Data handling and presentation software

Most geotechnical and structural monitoring equipment suppliers have their own unique packages for the handling and presentation of instrument data. They are commonly able to tailor the visual presentation and storage options to the requirements of a particular project and client's requirements.

Often these packages include the facility to use Internet and Intranet data handling.

Data is usually presented on a PC monitor in easily interpreted forms, for example; spot data overlying drawings or site photographs, values overlying systematic system layouts or in 3D graphical forms

These software packages are also capable of detecting and triggering alarms based upon available data and pre-determined criteria. Alarm activation can be generated in many ways and is usually a client specific soft / hardware configuration.

Data conversion routines

In many cases clients will have established a Supervision, Control And Data Acquisition (SCADA) system for other elements of their operations. Data from the seepage monitoring data loggers can be incorporated into these systems but will require to be 'converted' into a compatible format. Automatic software routines are usually created by the SCADA management team to convert the incoming data into the required format.

The existing SCADA software is then used for handling and presenting the instrument readings, together with the triggering of alarms.

5.3 Receipt and management of alarms

Alarms triggered by automatic systems must be treated seriously. Action must be taken when they are activated.

As discussed previously, alarms can be triggered as a result of tests carried out by the onsite data logging CPU or by software at a central monitoring station.

The technique by which an alarm may be raised is dependent upon many factors that vary from site to site. These include; the communication constraints of the site, the location of responsible personnel and the level of danger.

Alarm procedures must be drawn up by the staff responsible for the monitoring and data handling. Procedures should be incorporated into any existing emergency action plan.

False alarms must also be taken seriously, reported to the systems management teams and the cause of the false alarms identified. Where possible, the source of the false alarms should be eliminated from future influence on the tested data.

6 References

British Standards Institution	1981	3680 Part 4a: Methods of measurement of liquid flow in open channels. Weirs and flumes. Method using thin-plate weirs
British Standards Institution	2000	BS EN ISO 7027:2000, BS 6068-2.13:2000 Water quality. Determination of turbidity
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European Commission	1988	Directive 98/83/EC of 3 November 1998 on the quality of water intended for human consumption.
HMG	2000	The Water Supply (Water Quality) Regulations 2000, Statutory Instrument 2000 No. 3184 which apply in England and Wales. Similar legislation applies in Scotland and Northern Ireland.
ICOLD	2000	Bulletin 118 Automatic dam monitoring systems
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Appendix A - Review of physical practicality of real time monitoring of V notch chambers at ten sites

TABLE A1: FEASIBILITY OF INSTALLING REAL TIME MONITORING AT A SAMPLE OF TEN RESERVOIR SITES

Dam No.	Existing Monitoring Provided	Constraints to Real Time Monitoring					**Potential for Real Time Monitoring**
		Submergence by Downstream Reservoir	Other Flows in Tunnel/Drainage System	Space Restrictions	Existing Electrical Supply	Existing Telemetry Link	
1	Plate weir situated in dedicated chamber constructed at downstream end of embankment under-drainage system. Manual recording of flows on a weekly basis.	No	No	No	Nearby	Nearby	Relatively easy to convert existing arrangement to real time monitoring.
2	Bank drain flow recorded by timed discharge in small chamber constructed at toe of dam.	No	No	No	Nearby	No	New chamber required for V-notch installation. Telemetry link required.
3	Tunnel seepage recorded by timed discharge at downstream end of tunnel.	No	No	Yes	Yes	No	Insufficient space available for installation of V-notch weir plate due to confines of tunnel and proximity of draw-off pipework.
4	Tunnel leakage recorded by timed discharge from four separate positions. Cumulative leakage flow recorded at downstream end of tunnel. Ochre accumulation around monitoring points is extensive.	No	No	Yes	Yes	Nearby	Installation of V-notch weirs at each leakage position would seriously restrict access through the tunnel. Frequent access to remove ochre deposits would also be required.
5	Tower leakage recorded by V-notch weir plate at base of shaft.	No	No	No	Yes	No	Relatively easy – telemetry link required.
6	Tunnel seepage recorded weekly by manual timed discharge at downstream end of tunnel. Valve shaft also serves as overflow.	No	Yes	No	Yes	No	Installations may disrupt overflow discharge capability or may be damaged by high flows.
7	Visual observation at tunnel outlet of aggregate flow through numerous weep pipes.	No	No	No	250m	250m	Relatively easy but moderate distance to existing power and telemetry.
8	Existing V-notch manually read when downstream reservoir level reduces.	Yes	No	No	150m	150m	Tunnel drowned through winter to mid summer – instrumentation would be damaged.
9	Existing un-calibrated V-notch within valve house at tunnel outlet.	No	No	Minor	Yes	Yes	Floor level restrictions, otherwise straightforward installation.
10	Visual observation at tunnel outlet of aggregate flow through numerous weep pipes.	No	Yes – when scour operated	No	No	No	Scour flow passes through tunnel – any equipment will be damaged.
	Summary	Impractical at 10%	Impractical at 20%	Impractical at 20%	90% have power within 0.3km	50% have existing telemetry nearby	

Appendix B - Case Studies

B.1 Case Study #1 – Dam 'A' Tunnel Leakage

Existing Situation

Four leakage points are manually monitored within the 120m long draw-off tunnel at Dam 'A.'

The leaks are situated at chainages 4m, 21m, 42m and 56m measured from the valve tower, and each generally has a flow rate historically in the order of 0.3 litres per minute to 0.8 litres per minute. Cumulative flow is of the order of 4 litres per minute

The leakage flows are locally piped through the tunnel lining. The flow from the end of each pipe is determined by noting the time taken to fill a measuring container. A cumulative leakage flow is also measured in a similar manner at the downstream end of the tunnel, from the flow in the tunnel invert.

Access to the point of leakage is hampered at some locations by the position of the twin draw-off pipes. Each leakage point also exhibits heavy concentrations of ochre deposits.

Practicality of Installing Real Time Monitoring

a) There is an existing electrical supply to the tunnel, and telemetry is located at the nearby treatment works. The transmitting of readings obtained by the recording instruments is therefore not an issue.
b) The confines of the tunnel and the position of the draw-off pipework would prevent a V-notch chamber from being constructed at each leakage point.
c) It would be feasible to construct a single small V-notch chamber at the downstream end of the tunnel, into which the four leakage flows could be conveyed via a new dedicated pipework system. This would only enable a cumulative leakage reading to be taken, rather than provide data for the four separate leaks.
d) Nevertheless it would still be possible to examine individual flows and take manual measurements.
e) The pipe(s) conveying the leakage flows to the measuring chamber would have a maximum length of 115m; in view of the low flow rates that occur and the severity of the ochre deposits, it is considered that blockages would be frequent and problematic to resolve.
f) It may be feasible to construct a turbidity monitoring chamber upstream of the V-notch. However, the accuracy of the readings may be affected by the presence of any disturbed ochre deposits within the water.

Conclusion

The installation of real time monitoring of cumulative leakages into the tunnel would be possible, in a chamber at the downstream end of the tunnel. However, if individual leakage readings were still required these would have to continue to be taken manually. There would also be significant maintenance issues associated with the cleaning of ochre deposits from the V-notch chamber/pipework.

B.2 Case Study #2 – Dam 'A' Bank Drains

Existing Situation

Flows through the high level bank drain system and the low level under-drain system are collected via a pipework system and discharged into an existing masonry chamber situated near the toe of the dam.

Flow readings are manually recorded by means of a rectangular notch weir plate situated in the monitoring chamber; these readings are typically in the range 20 litres per minute to 40 litres per minute.

Practicality of Installing Real Time Monitoring

- An electricity supply and telemetry is located at the nearby treatment works. The transmitting of readings obtained by the recording instruments is therefore not an issue.
- The existing plate weir could be retained, or a new V-notch provided.
- Provision of a settlement chamber is deemed to be impractical. Flow rates are too high, and construction would involve deep excavation within the toe of the dam.
- Turbidity monitoring within the existing collection chamber is feasible, as the chance of settlement affecting the readings is slight.

Conclusion

The installation of real time leakage flow and turbidity monitoring would be possible, and could be provided relatively easily.