seqwater
WATER FOR LIFE

WIVENHOE DAM

FIVE YEAR COMPREHENSIVE DAM SAFETY INSPECTION REPORT

September 2010

TABLE OF CONTENTS

1 INTRODUCTION

The Queensland Bulk Water Supply Authority trading as Seqwater took over ownership of Wivenhoe Dam from the previous SeqWater on 1 July 2008. The Dam Safety Conditions issued by the Dam Safety Regulator for Wivenhoe Dam in accordance with the Water Supply Act 2008 requires the following:

- The dam owner must carry out a comprehensive inspection of the dam in accordance with the Queensland Dam Safety Management Guidelines, on or before 1 October 2010.
- The comprehensive inspection must incorporate a review of the dam safety standards of the existing dam against current standards, a review of the adequacy of the dam safety documentation for the dam and reviews of the status on recommended actions from previous inspections.
- A Comprehensive Inspection Report detailing the findings of the comprehensive inspection in accordance with the Queensland Dam Safety Management Guidelines must be submitted to the Dam Safety Regulator, within three months after completion of the comprehensive inspection.

The Queensland Dam Safety Management Guidelines define the purpose of a Comprehensive Inspection to be a periodic inspection of the dam and a review of the owner's whole dam safety management program. The Guidelines require the Inspection Report to assess all aspects of the dam safety management program and fully document:

- Deficiencies identified in the dam safety management program and its documentation
- A strategy for overcoming the deficiencies (including prioritisation of actions if several deficiencies are identified).

The Guidelines also require the inspection to be undertaken by an experienced dam's engineer who is a RPEQ. This inspection is to incorporate:

- A periodic inspection.
- An assessment of the appropriateness and adequacy, the effectiveness and application (including the owner's response to inspection report and Safety Review recommendations) of the dam safety management program and documentation for the dam.

This is considered to be the third Comprehensive Five Yearly Inspection of Wivenhoe Dam undertaken in accordance with the Queensland Dam Safety Management Guidelines. The first formal dam safety review was undertaken by Gutteridge, Haskins & Davey Pty Ltd in 1997. This review included a review of the mechanical and electrical equipment at the dam by HECEC Pty Ltd. Seqwater also has records of a 2006 inspection undertaken by NSW Department of Commerce. It is understood that no final report was issued in relation to this inspection; however Seqwater has a copy of an advanced draft of the final report.

A comprehensive design review of the dam was also undertaken in 2003 by the Wivenhoe Alliance in association with the spillway upgrade works that were undertaken at that time. Some design deficiencies were identified at that time, but these have since been rectified by works including the post-tensioning of the spillway and right bank spillway retaining wall. A further comprehensive design review was undertaken by GHD in 2009 as part of the investigations associated with increasing the full supply level of the dam. This report found no significant design issues requiring further investigation or work.

2 EXECUTIVE SUMMARY

Wivenhoe Dam is generally in very good condition. The recent comprehensive design reviews undertaken by the Wivenhoe Alliance and GHD in 2003 and 2009 respectively conclude that the design of the dam is in accordance with modern day standards and that there are no outstanding design issues that require investigation at the present time.

Data obtained from the dam safety instrumentation at the dam shows that the structural performance of the dam is satisfactory and in accordance with design expectations. No issues were identified as a result of the comprehensive review of the instrumentation data.

The physical infrastructure at the dam is generally maintained in good condition; however the Standby Diesel Generator is nearing the end of its useful life and should be replaced within the next 12 months. All other major dam components are performing satisfactorily.

As part of the Comprehensive Inspection, Queensland Hydraulics completed a comprehensive investigation and review of the hydraulics systems that power the operation of the radial gates and crane. The subsequent report (see Appendix C) concluded that these systems are in good condition and should have a minimum of 10 addition years of working life before requiring major refurbishment. These systems will be reviewed again as part of the next comprehensive inspection in 2015.

3 DESCRIPTION

seqwater WATER FOR LIFE	WIVENHOE DAM
Population at Risk	Sunny Day Failure: 244,000 Flood: >1,000 (not fully assessed)
Failure Impact Rating	2
Hazard Category	Extreme
Dam Owner	Seqwater
Name of Reservoir	Lake Wivenhoe
Year Complete	1984
Location	Approximately 5km upstream of Fernvale
Water Course	Brisbane River
Purpose	Town water and flood mitigation
Type of Construction	Zoned earth and rockfill embankment
Outlet Works	Radial gated spillway with supplementary fuse plug spillway
Catchment Area	7020km^2
FSL	67m AHD
Full Supply Capacity	1,165,238 ML
Surface Area at FSL	10,750ha
Main Dam Crest	79m AHD
Main Dam Embankment Length	2,300m
Maximum Height of Main Dam Embankment	50m
Width at Top of Main Dam Embankment	10.0m
Spillway Crest	57.0m AHD
Spillway Length	60m
Gates	5 radial gates 12m wide x 16.6 m high
Top of Closed Gate	EL 73.0m
Saddle Dam Crest	80.0m AHD
Saddle Dam Length	3 x total length of 518

Maximum Height of Saddle Dam Embankment	10.0m
Peak Water Level as a Result of PMF	Dam Overtopped
Spillway Capacity (including Fuse Plugs)	28,100m^3/s (EL 79.0m)
Maximum Discharge as a Result of PMF	37,400m^3/s
AEP of Spillway Capacity (including Fuse Plugs)	1 in 100,000 (EL 79.0m)
Regulator valves	1 x 1.5m cone dispersion valve
Mean annual pan evaporation	1,600mm (BOM estimate)
Mean annual rainfall	986mm
Hydroelectric Facilities	4.3 mw mini-hydro
Notable events (Post Dam)	1986, 1989 (x 2), 1999
Maximum Historic Storage Level	71.45m AHD Late April 1989
Comment	Besides being a major source of urban water supply, Wivenhoe Dam provides a significant flood mitigation capacity to protect the urban areas downstream of the dam. During periods of heavy rainfall, flood water is temporarily stored in Wivenhoe Dam and released at a controlled rate to minimise the impact of downstream flooding. The dam was built in conjunction with Splityard Creek Dam and water from Wivenhoe is pumped into Splityard Creek Dam where it is used to generate electricity during periods of high demand.

4 DAM HISTORY

Wivenhoe Dam was designed by the Queensland Water Resources Commission. It was constructed by a consortium of contractors between 1977 and 1984. When completed, Wivenhoe Dam was a 56 metre high, zoned earth and rock embankment separated into two parts by a concrete gravity spillway. The spillway is controlled by 5 radial gates, each 12.0 metres wide by 16.0 metres high. Two saddle dam embankments are located on the left side of the reservoir. The Brisbane Valley Highway was relocated to pass over and along the crest of the dam embankment.

The dam spillway capacity was upgraded in 2005 by the Wivenhoe Alliance. The works associated with this upgrade are summarised as follows:

- Construction of a 164 metre wide secondary spillway through the right abutment of the existing dam, in an excavated chute that included concrete works for a three metre ogee crest, apron slabs, chute lining and the divider walls to enable construction of three eroding earth fill fuse plug embankments;

- Upgrading of the wave wall on the two main embankments to handle the new Maximum Flood Level (MFL) of EL 80.0;

- Strengthening of the primary spillway with post-tensioned anchors to cater for the increased loading due to the raised flood level.

- Provision of a steel deflection baffle upstream of the radial gates to ensure the gates clear the flow profile for the raised MFL.

These works raised the dam crest flood from a 1 in 22,000 AEP event to 1 in 100,000 AEP flood event. The initial trigger level for the first fuse plug embankment is at EL 75.7m (approximately the 1 in 6 000 AEP flood event).

The dam has four main functions by providing:

- A 1.165 GL storage at full supply level (FSL EL 67.0) providing an urban water supply for Brisbane and surrounding areas;

- Flood mitigation in the Brisbane River by providing a dedicated flood storage volume of 1.45 GL up to EL77 (the MFL was increased to EL80m as part of the Wivenhoe Alliance Upgrade works in 2005 changing the flood storage volume to 2.0GL at EL80m);

- A source of supply for the Split Yard Pumped Hydro-Electric power station which has a 500 MW generating capacity;

- A recreation area.

The dam has an EXTREME hazard classification under ANCOLD guidelines because of the significant development downstream in the Brisbane and Ipswich metropolitan areas, with the population at risk (PAR) numbering in the hundreds of thousands.

In accordance with the Queensland Regulatory program for dam spillway upgrades, a further upgrade of Wivenhoe Dam is scheduled to occur prior to 2035 to enable the dam to safely pass the Probable Maximum Flood (PMF). This work will involve the reconstruction of Saddle Dam 2 as a fuse plug spillway, so that the dam can accommodate the PMF.

5 DATA BOOK

In accordance with the Dam Safety Conditions for Wivenhoe Dam, the dam owner must update and maintain a Data Book in accordance with the Queensland Dam Safety Management Guidelines. The Data Book must include all pertinent records and history relating to the dam and encompass the documentation of investigation, design, construction, operation, maintenance, surveillance, monitoring measurements and any remedial action taken relating to the dam.

The Dam Data Book is held in Seqwater's Karalee Office and is generally comprehensive and contains information in accordance with the Data Book Checklist in the Queensland Dam Safety Management Guidelines. Seqwater has also taken electronic copies of the Data Book information and saved this information within a system that includes a similar provision for saving and back-up.

No recommendations for updating the Wivenhoe Dam Data Book are considered necessary at this time.

6 STANDING OPERATING PROCEDURES

In accordance with the Dam Safety Conditions for Wivenhoe Dam, the dam owner must develop Standing Operating Procedures in accordance with the Queensland Dam Safety Management Guidelines. The purpose of the Procedures is to:

- Define responsibilities for actions critical to the safety of the dam.
- Identify procedures for particular daily activities, which ensure that these activities are done safely, in the same way each time and in accordance with development permit conditions.
- Ensure appropriate people are notified when unforseen or unusual events occur.

Seqwater submitted copies of the Standard Operating Procedures for Wivenhoe Dam to the Dam Safety Regulator in March 2009 following an extensive update and review of the Procedures. Controlled copies of the document have also been issued to the following Seqwater staff:

- Principal Engineer Dam Safety.
- Operations Coordinator responsible for Wivenhoe Dam
- Wivenhoe Dam Storage Supervisor.

The dam is generally operated in accordance with the Standing Operating Procedures and the Procedures have been prepared in accordance with the Queensland Dam Safety Management Guidelines. The Procedures address the following areas:

DAM EMERGENCIES

Section 1 Dam Safety Organisational Structure and Responsibilities

Section 2 Emergency Action Planning

Section 3 Loss of Communication during an Emergency Event

Section 4 Dam Security and Restricted Areas

DAM SAFETY SURVEILLANCE

Section 5 Dam Attendance

Section 6 Dam Operating Log

Section 7 Dam Surveillance and Routine Inspection

Section 8 Dam Instrumentation Data Collection and Management

Section 9 Annual Dam Inspections

Section 10 Comprehensive Five Yearly Dam Safety Inspections

Section 11 Unscheduled Dam Inspections

DAM OPERATIONS AND MAINTENANCE

Section 12 Routine Dam Maintenance

Section 13 Routine Dam Operations

Section 14 Storage Inflow Control

Section 15 Renewal and Refurbishment of Dam Infrastructure

Section 16 Regulated Water Releases

Section 17 Uncontrolled Water Releases

DAM SAFETY ADMINISTRATION AND REGULATORY REQUIREMENTS

Section 18 Reporting

Section 19 Dam Safety Documentation

Section 20 Regulatory Requirements and Dam Safety Conditions

Section 21 Training

Some internal restructuring of Seqwater occurred in 2010 and this has resulted in a change to some Position Titles referred to in the Standing Operating Procedures. Accordingly it is recommended that the Standing Operating Procedures be amended to account for these changes. No other recommendations for updating the Wivenhoe Dam Standing Operating Procedures are considered necessary at this time.

RECOMMENDATION

Review and update the Standing Operating Procedures to account for the change in position titles due to the recent restructure of Seqwater.

7 OPERATION AND MAINTENANCE MANUAL

In accordance with the Dam Safety Conditions for Wivenhoe Dam, the dam owner must develop Operation and Maintenance Manuals in accordance with the Queensland Dam Safety Management Guidelines. The purpose of the Manuals is to provide instruction on how to operate, maintain and overhaul individual pieces of equipment for a dam and its associated structures. The manuals should contain the following:

- Work Instructions, which detail the way in which equipment should be operated and outline the steps involved in performing a task.
- Maintenance Schedules, which detail the asset, description of task, frequency of maintenance and special requirements for servicing and maintaining the equipment.
- Equipment data sheets or Manufacturer's Manuals, which comprise technical information needed for maintenance, repair and overhaul of equipment.

Seqwater has updated and reviewed the Operation and Maintenance Manual for Wivenhoe Dam. Controlled copies of the document have also been issued to the following Seqwater staff:

- Principal Engineer Dam Safety.
- Operations Coordinator responsible for Wivenhoe Dam
- Wivenhoe Dam Storage Supervisor.

The dam is generally maintained and operated in accordance with the Operation and Maintenance Manual and the Manual has been prepared in accordance with the Queensland Dam Safety Management Guidelines. However further review work is required to make to Manual consistent with the Dam Standing Operating Procedures. No recommendations for updating the Wivenhoe Dam Operation and Maintenance Manuals are considered necessary at this time.

8 EMERGENCY ACTION PLAN

In accordance with the Dam Safety Conditions for Wivenhoe Dam, the dam owner must develop an Emergency Action Plan in accordance with the Queensland Dam Safety Management Guidelines. The purpose of the Plan is to:

- Identify emergency conditions that could endanger the integrity of the dam and that require immediate action;
- Prescribe procedures that should be followed by the dam owner and operating personnel in the event of an emergency;
- Provide procedures to allow timely warning to Emergency Response Agencies for their implementation of protection measures to downstream communities.

Seqwater submitted copies of the Emergency Action Plan for Wivenhoe Dam to the Dam Safety Regulator in September 2009 following an extensive update and review of the previous Plan. Controlled copies of the document have also been issued to the following Seqwater staff and external agencies:

- Principal Engineer Dam Safety.
- Dam Safety and Source Operations Manager
- Wivenhoe Dam Storage Supervisor.
- Operations Coordinator responsible for Wivenhoe Dam
- Seqwater/SunWater Flood Operations Centre
- Department of Emergency Services
- Brisbane City Council
- Emergency Management Queensland

Relevant dam personnel are generally familiar with the Emergency Action Plan and the Plan has been prepared in accordance with the Queensland Dam Safety Management Guidelines. The Plan contains the following information:

- Register of notification.
- Emergency contacts.
- Emergency action triggers.
- Routes to the dam site.
- Flood maps.

Emergency communication from the dam itself is reasonable. No recommendations for updating the Wivenhoe Dam Emergency Action Plan are considered necessary at this time although it is noted that Seqwater will re-issue revised controlled copies of the manual in September 2010, prior to the 2010/11 Flood Season.

9 ROUTINE INSPECTIONS

The Hazard Category of Wivenhoe Dam is Extreme. Routine Inspections are undertaken daily in accordance with ANCOLD Guidelines. Rainfall, storage level and seepage are also measured during these inspections. A typical inspection sheet is shown below.

DAM SURVEILLANCE – WIVENHOE DAM	Week Commencing 24/7/2010
Daily	FSL EL 67.00

READINGS	Sat	Sun	Mon	Tue	Wed	Thu	Fri
Time							
Rainfall (mm)			2.0mm	6	1.4	17.4	.6
Storage Level (m AHD)	66.23	66.23	66.23	66.22	66.22	66.26	66.26
Temperature (°C)							
Seepage (Litres per hour) East	30.5	30.5	30.5	30.5	30.5	30.5	30.5
Seepage (Litres per hour) West	170	170	170	170	170	170	170
Seepage (Litres per hour) Old Div	623	623	623	623	623	1143	1214
Seepage (Litres per hour) East Toe	260	260	260	260	296	514	514
Water Clarity (Clear or Cloudy)	clear	clear	clear	clear	clear	clear	clear
CONDITION REPORT							
Main Embankment							
Earth Abutments	✓	✓	✓	✓	✓	✓	✓
Erosion	✓	✓	✓	✓	✓	✓	✓
Sink Holes	✓	✓	✓	✓	✓	✓	✓
Slumping, Cracking or Bulging	✓	✓	✓	✓	✓	✓	✓
Undesirable Weeds or Vegetation	✓	✓	✓	✓	✓	✓	✓
2 x Saddle Dams							✓
Wet Patches							✓
Sink Holes							✓
Slumping, Cracking or Bulging							✓
Undesirable Weeds or Vegetation							✓
Erosion							
Instrumentation							✓
Hydraulic Piezometers							✓
Inclinometers							✓
Foundation Drains							
Spillway (Crest EL 57.00)							✓
Concrete Condition							✓
5 x Radial Gates Condition							✓
Erosion							
Fuse Plugs							
Concrete Condition							✓
Erosion							
Reporting Officer's Initials	mbh	mbh	mbh	mbh	mbh	mbh	mbh

(✓) Indicates Satisfactory Condition
(X) Indicates Action Required (Provide details in Comments Section below)

COMMENTS x 5 Access at chainage 50 - saddle dam 1

Completed form to be emailed or faxed to Dam Operations Coordinator Central Region (Jayam Tennakoon)

Jayam Tennakoon - [redacted] Email: [redacted]

Seqwater commenced the current system of undertaking routine inspections in June 2009. Prior to that date, although routine inspections were being undertaken, the records were maintained on a weekly rather than on a daily basis. Seqwater now has a robust system in place for ensuring that Routine Inspections are undertaken daily (see SOP 4.3 – Dam Surveillance and Routine Inspection) in accordance with ANCOLD guidelines.

10 ANNUAL INSPECTIONS

The most recent Annual Inspection at the dam was undertaken in June 2009 by John Tibaldi (RPEQ 02525). The significant recommendations arising from the inspection and their current status are shown in the following table:

RECOMMENDATION	STATUS
Left Bank Embankment (Downstream Area) • There is a series of pipelines that gather runoff from the toe drains for outflow into suitable natural drainage points. Some repairs to these pipelines have been undertaken over the last 12 months; however a study is required to examine the relationship between flow in this drainage system and internal drainage within the embankment. It is possible that this drainage system relates only to surface water runoff, in which case maintenance of the system is not critical from a dam safety perspective.	An understanding has been developed of the separation between the drains managing seepage from the dam and those associated with managing rainfall run-off. Further maintenance work associated with this drainage system has been recommended in Section 12 of this report.
Left Bank Embankment (Upstream Area) • The flap gate drains near the left bank end of embankment are to be modified to reduce the risk of the flap gates jamming open. The EAP is to include instructions for checking of these gates in major flood events.	The EAP has been amended, but minor works to modify the gates remain outstanding. Recommendations to resolve this issue are contained in Section 12 of this report.
Dam Crest • The drains under the wave wall are to be modified to prevent blocking and a store of suitable plugs is to be kept at the dam to enable these drains to be closed off in the event of a flood that impacts on the wave wall (in these circumstances the road would be closed due to flooding and would not be used by the public). This issue is outstanding from the 2008 inspection.	Investigation and construction work to resolve this issue is underway in conjunction with the Department of Transport and main Roads. Recommendations to resolve this issue are contained in Section 12 of this report.

Right Bank Embankment • Vegetation growing in the area of the old river diversion is to be burned off each year just prior to the annual inspection to allow proper inspection of this area.	Complete.
Fuse Plug Embankments and Auxiliary Spillway • All trees within five metres of the toe of the embankment are to be removed and all trees within three metres of the spillway retaining walls are to be removed.	Complete.
Mechanical and Electrical Equipment • Undertake a risk assessment of the age and condition of the electrical and hydraulic equipment at the dam to determine remaining useful like of this equipment and develop a plan for renewal and replacement. In particular, the following components require examination: o Radial Gate Electric/Hydraulic System. o Radial gate Hydraulic Winch motors. o Standby Diesel generator. o High Voltage Transformer. o Radial Gate Fixed Diesel/Hydraulic System. o 79 Tonne Gantry Crane Electric/Hydraulic System. • Recommence the electrical condition monitoring program associated with the radial gate infrastructure. • Install a suitable hydraulic oil overflow collection and oil transfer system to manage hydraulic balancing between the electric hydraulic and fixed diesel hydraulic systems. • Engage a suitable hydraulic specialist to investigate the recent low hydraulic oil pressure alarms that have occurred during radial gate operations and repair the creeping anchor pin on the 79 tonne Gantry Crane. • Repair the leak in the Standby Diesel generator oil cooler system. It is considered that this leak requires urgent attention. • Initiate a painting program for the downstream sides of the radial gates. It may be sensible to paint one gate per year over the next five years. • Repair the mechanical problems causing the hoist chains to disengage for the drive wheels on the selective baulks.	Complete (see Section 12 and Appendix C) Complete. This work was postponed to following the completion of an assessment of the Hydraulic System (see Appendix C). The work has been programmed for the 2010/11 financial year. Complete. Standby Diesel Generator to be replaced, see Section 12. Complete. (Gate scheduled for painting in 2011) Complete.

Spillway • Repair the concrete damage to the spillway floor and replace the missing flap gate on one of the spillway underdrain outlets.	Not Complete. Recommendations to resolve this issue are contained in Section 12 of this report.
• Post tensioning anchor Cables No. 1 and No. 3 are to be retested in 2010 to determine if the anchor strength remains outside desirable values.	Not Complete. Recommendations to resolve this issue are contained in Section 11 of this report.
• Post tensioning anchor Cables No. 16, No. 17, No. 18 and No. 19 are to be tested by 2010	Not Complete. Recommendations to resolve this issue are contained in Section 11 of this report.
Outlet Works • Seal the service penetrations to the mini-hydro facility as these are causing water leaks into the outlet works.	Complete
• Suitable engineering works are to be constructed to eliminate the hazard to persons and dam infrastructure caused by the erosion of the sandstone cliffs adjacent to the outlet works.	Substantial works have been completed, but the issue is not fully resolved. Recommendations to resolve this issue are contained in Section 12 of this report.
• Install a new float well water level recorder in the intake works.	Complete.
• Install a flow meter to allow measurement of the sump pump outflows from the mini hydro and record these outflows on the weekly inspection sheets.	Not Complete. Recommendations to resolve this issue are contained in Section 12 of this report.
Instrumentation • All seepage measuring points, survey points and foundation drains are to be suitably labelled and numbered on site and a suitable engineering plan prepared to show instrumentation point locations and corresponding numbering.	Complete, except for survey stations, see Section 12.
• The presentation of the instrumentation data is to be reviewed and updated to provide graphs that are better able to identify dam safety issues, in accordance with the Wivenhoe Dam Design Report.	Complete.

The most recent Comprehensive Inspection at the dam was undertaken in July 2006 by the NSW Department of Commerce. There are no recommendations from this report that are not accounted for in the above table or elsewhere in this report.

In summary, there are no outstanding items critical to the safety of the dam and all outstanding work has been addressed in the recommendations of this report.

11 INSTRUMENTATION

A summary of the dam safety monitoring instrumentation at Wivenhoe Dam is contained in the following table.

WIVENHOE DAM – DAM SAFETY INSTRUMENTATION	
TYPE	**DESCRIPTION**
Pore Pressure (Hydraulic Piezometers)	There are 60 hydraulic piezometers installed at the dam to monitor pore pressure. The location of these piezometers is shown on Plans A1 50780, A1-53375 and A1-56230. There are 24 piezometers at Ch 1600 and 22 piezometers at Ch 1800, in the right bank earth embankment. There are 14 piezometers at Ch 1200, in the concrete spillway section. There are 5 piezometers at Ch 1960, in the core of the diversion channel section of the right bank embankment. These instruments are read monthly.
Pore Pressure (Total Pressure Cells)	There are 25 total pressure cells installed at the dam. The location of these total pressure cells is shown on Plans A1-50780 and A1-53375. There are 11 total pressure cells at Ch 1600 and 11 total pressure cells at Ch 1800, in the right bank earth embankment. There are 3 total pressure cells at Ch 1960, in the core of the diversion channel section of the main embankment. The reading of these instruments was abandoned in the 1990s (see discussion below).
Deformation Monitoring	There are 60 movement monitoring points installed at the dam to measure embankment movement. The location of these movement monitoring points is shown on Plans A1-53374 and CG-1032. There are 48 movement monitoring points installed in the right bank earth embankment and 12 movement monitoring points installed in the right abutment spillway. A deformation survey is undertaken annually.
Structural Movement	There are 10 inclinometers installed at the dam to measure structural movement. The location of these inclinometers is shown on Plans A1-53374 and CG-1031. There are 4 inclinometers installed in the right bank earth embankment and 6 inclinometers installed in the right abutment spillway. These instruments are read monthly.
Seepage	V-notch weirs are located in lower gallery of spillway and in the diversion channel section of the right bank embankment to measure seepage. V-notch weirs are also used to measure seepage flows from the left and right bank embankment drainage systems. These instruments are generally read on a daily basis.

Rainfall and Storage Level	Alert canisters transmit this data continuously in real time. All data is stored by Seqwater within a database.

Pore Pressure (Hydraulic Piezometers)

A summary of the piezometer results is shown in the table below. Detailed graphs showing the behaviour of individual piezometers over time are contained in Appendix B. When examining the graphs it is important to note the disruption to readings associated with the piezometer board replacements that occurred in 2007. Plans showing the locations of the piezometers are shown in Appendix A.

PIEZOMETERS	DESCRIPTION	COMMENTS	CURRENT TRIGGER
WVH01 WVH02 WVH03	These three piezometers are located within the sandstone foundation at EL 15 metres under the embankment core at Ch 1600. WVH01 is 11 metres upstream of the embankment centreline, WVH02 is on the embankment centreline and WVH03 is 11 metres downstream of the embankment centreline. The grout curtain in located midway between WVH01 and WVH02.	The pressure readings from these piezometers are consistent with historical performance dating back to the first filling of the dam in 1988 and historical peak readings have not been exceeded over the last five years. The pressure drop across the grout curtain remains in the order of five metres, indicating some leakage across the curtain. This is in line with historical performance. Some seepage is evident below the embankment in this location which supports the readings indicating some seepage across the grout curtain.	Any reduction in the pressure differential between WVH01 and WVH02 to a value equal to or below 4.5 metres should trigger additional monitoring and investigation. Any increase in the pressure reading for WHV02 in excess of EL 42 metres should trigger additional monitoring and investigation.

WVH04 WVH05 WVH06 WVH07 WVH08 WVH09	These six piezometers are located at EL 25 metres within the embankment core and downstream filter at Ch 1600. The piezometers are fairly evenly spaced. WVH04 and WVH05 are within the core, 11 metres and 5 metres respectively, upstream of the embankment centreline. WVH06 is within the core on the embankment centreline. WVH07 and WVH08 are within the core, 5 metres and 9.5 metres respectively downstream of the embankment centreline. WVH09 is within the downstream filter, 13.6 metres downstream of the embankment centreline.	The pressure readings from these piezometers are consistent with historical performance dating back to the first filling of the dam in 1988 and historical peak readings have not been exceeded over the last five years. It appears that the core has dried out to some extent during the recent drought as there is currently quite a steep pressure drop between WVH04 and WVH05, that is in excess of the levels experienced prior to 2001. This gradient is not of concern and would be expected to reduce over time if the level of the storage remained high.	Any increase in the pressure reading for WHV05 in excess of EL 55 metres should trigger additional monitoring and investigation. Any increase in the pressure reading for WHV08 in excess of EL 35 metres should trigger additional monitoring and investigation.
WVH10 WVH11 WVH12 WVH13	These four piezometers are located at EL 35 metres within the embankment core at Ch 1600. The piezometers are fairly evenly spaced. WVH10 and WVH11 are 8 metres and 3 metres respectively, upstream of the embankment centreline. WVH12 and WVH13 are 3 metres and 8 metres respectively downstream of the embankment centreline.	The pressure readings from these piezometers are consistent with historical performance dating back to the first filling of the dam in 1988 and historical peak readings have not been exceeded over the last five years.	Any increase in the pressure reading for WHV11 in excess of EL 47 metres should trigger additional monitoring and investigation. Any increase in the pressure reading for WHV13 in excess of EL 37 metres should trigger additional monitoring and investigation.

WVH14 WVH15 WVH16 WVH17	These four piezometers are located at EL 45 metres within the embankment core at Ch 1600. The piezometers are fairly evenly spaced. WVH14 and WVH15 are 7.5 metres and 2.5 metres respectively, upstream of the embankment centreline. WVH16 and WVH17 are 2.5 metres and 6 metres respectively downstream of the embankment centreline.	The pressure readings from these piezometers are consistent with historical performance dating back to the first filling of the dam in 1988 and historical peak readings have not been exceeded over the last five years.	Any increase in the pressure reading for WHV15 in excess of EL 54 metres should trigger additional monitoring and investigation. Any increase in the pressure reading for WHV17 in excess of EL 47 metres should trigger additional monitoring and investigation.
WVH18 WVH19 WVH20	These three piezometers are located at EL 55 metres within the embankment core at Ch 1600. WVH18 is 4 metres upstream of the embankment centreline, WVH19 is on the embankment centreline and WVH20 is 4 metres downstream of the embankment centreline.	The pressure readings from these piezometers are consistent with historical performance dating back to the first filling of the dam in 1988 and historical peak readings have not been exceeded over the last five years.	Any increase in the pressure reading for WHV19 in excess of EL 58 metres should trigger additional monitoring and investigation.
WVH21 WVH22	These two piezometers are located at EL 65 metres within the embankment core at Ch 1600. WVH21 is 3 metres upstream of the embankment centreline and WVH22 is on the embankment centreline.	The pressure readings from these piezometers are consistent with historical performance dating back to the first filling of the dam in 1988 and historical peak readings have not been exceeded over the last five years.	Any increase in the pressure reading for WHV22 in excess of EL 64.5 metres should trigger additional monitoring and investigation.

WVH23 WVH24	These two piezometers are located at EL 32 metres within the alluvium at Ch 1600. WVH23 is 42 metres upstream of the embankment centreline and WVH24 is 42 metres downstream of the embankment centreline.	As expected, WVH23 is connected directly to the storage and WVH24 is free draining with no apparent connection to the storage.	Any increase in the pressure reading for WHV24 in excess of EL 64.5 metres should trigger additional monitoring and investigation.
WVH25 WVH26 WVH27	These three piezometers are located within the sandstone foundation at EL 15 metres under the embankment core at Ch 1800. WVH25 is 11 metres upstream of the embankment centreline, WVH26 is on the embankment centreline and WVH27 is 11 metres downstream of the embankment centreline. The grout curtain in located midway between WVH25 and WVH26.	The pressure readings from these piezometers are consistent with historical performance dating back to the first filling of the dam in 1988 and historical peak readings have not been exceeded over the last five years. The pressure drop across the grout curtain remains in the relatively high, indicating that seepage across the curtain is unlikely. This is in line with historical performance.	Any increase in the pressure reading for WHV26 in excess of EL 35 metres should trigger additional monitoring and investigation.
WVH28 WVH29 WVH30 WVH31 WVH32 WVH33	These six piezometers are located at EL 25 metres within the embankment core and downstream filter at Ch 1800. The piezometers are fairly evenly spaced. WVH28 and WVH29 are within the core, 11 metres and 5 metres respectively, upstream of the embankment centreline. WVH30 is within the core on the embankment centreline. WVH31	The pressure readings from these piezometers are consistent with historical performance dating back to the first filling of the dam in 1988 and historical peak readings have not been exceeded over the last five years. It appears that the core has dried out to some extent during the recent drought as there is currently quite a steep pressure drop	Any increase in the pressure reading for WHV29 in excess of EL 57 metres should trigger additional monitoring and investigation. Any increase in the pressure reading for WHV32 in excess of EL 36 metres should trigger additional monitoring and investigation.

	and WVH32 are within the core, 5 metres and 9.5 metres respectively downstream of the embankment centreline. WVH33 is within the downstream filter, 13.6 metres downstream of the embankment centreline.	between WVH28 and WVH29, that is in excess of the levels experienced prior to 2001. This gradient is not of concern and would be expected to reduce over time if the level of the storage remained high.	
WVH34 WVH35 WVH36 WVH37	These four piezometers are located at EL 35 metres within the embankment core at Ch 1800. The piezometers are fairly evenly spaced. WVH34 and WVH35 are 8 metres and 3 metres respectively, upstream of the embankment centreline. WVH36 and WVH37 are 3 metres and 8 metres respectively downstream of the embankment centreline.	The pressure readings from these piezometers are consistent with historical performance dating back to the first filling of the dam in 1988 and historical peak readings have not been exceeded over the last five years.	Any increase in the pressure reading for WHV36 in excess of EL 53 metres should trigger additional monitoring and investigation. Any increase in the pressure reading for WHV37 in excess of EL 41 metres should trigger additional monitoring and investigation.
WVH38 WVH39 WVH40 WVH41	These four piezometers are located at EL 45 metres within the embankment core at Ch 1800. The piezometers are fairly evenly spaced. WVH38 and WVH39 are 7.5 metres and 2.5 metres respectively, upstream of the embankment centreline. WVH40 and WVH41 are 2.5 metres and 6 metres respectively downstream of the embankment centreline.	The pressure readings from these piezometers are consistent with historical performance dating back to the first filling of the dam in 1988 and historical peak readings have not been exceeded over the last five years.	Any increase in the pressure reading for WHV39 in excess of EL 59 metres should trigger additional monitoring and investigation. Any increase in the pressure reading for WHV41 in excess of EL 48 metres should trigger additional monitoring and investigation.

WVH42 WVH43 WVH44	These three piezometers are located at EL 55 metres within the embankment core at Ch 1800. WVH42 is 4 metres upstream of the embankment centreline, WVH43 is on the embankment centreline and WVH44 is 4 metres downstream of the embankment centreline.	The pressure readings from these piezometers are consistent with historical performance dating back to the first filling of the dam in 1988 and historical peak readings have not been exceeded over the last five years.	Any increase in the pressure reading for WHV44 in excess of EL 57 metres should trigger additional monitoring and investigation.
WVH45 WVH46	These two piezometers are located at EL 65 metres within the embankment core at Ch 1800. WVH45 is 3 metres upstream of the embankment centreline and WVH46 is on the embankment centreline.	The pressure readings from these piezometers are consistent with historical performance dating back to the first filling of the dam in 1988 and historical peak readings have not been exceeded over the last five years. However the reading from WVH46 appears to be high as it is in excess of the current storage level. The reason for this high reading requires further investigation.	Any increase in the pressure reading for WHV46 in excess of EL 66 metres should trigger additional monitoring and investigation. This is currently occurring and further investigations will be undertaken.
WVH47 WVH48 WVH49	These three piezometers are located at EL 28 metres within the embankment core at around Ch 1960. WVH47 is 10.5 metres upstream of the embankment centreline. WVH48 is on the embankment centreline. WVH49 is 10.5 metres downstream of the embankment centreline.	The pressure readings from these piezometers are consistent with historical performance dating back to the first filling of the dam in 1988 and current readings are in line with historical peak readings.	Any increase in the pressure reading for WHV49 in excess of EL 29 metres should trigger additional monitoring and investigation.

WVH50 WVH51	These two piezometers are located within the embankment core at around Ch 1960. WVH50 is at EL 30 at an unknown distance upstream of the embankment centreline. WVH51 is at EL 34 on the embankment centreline.	The pressure readings from these piezometers are consistent with historical performance dating back to the first filling of the dam in 1988 and current readings are in line with historical peak readings.	No trigger levels are considered valid for these piezometers.
WVH52 WVH53 WVH54 WVH55 WVH56 WVH57	These six piezometers are located between EL 44 and EL 36 at the interface of spillway monolith 52 and the spillway foundations, at Ch 1170. The piezometers are spaced over a distance of approximately 25 metres, with WVH57 being the most upstream piezometer moving sequentially downstream to WVH52, the most downstream piezometer.	The pressure readings from these piezometers are consistent with historical performance dating back to the first filling of the dam in 1988 and historical peak readings have not been exceeded over the last five years.	Any trend showing an increase in the pressure reading for any piezometer.
WVH58	This piezometer is located at EL 38 at the interface of spillway monolith 53 and the spillway foundations, at Ch 1185 (spillway centreline). The piezometer is located directly under the lower gallery.	The pressure readings from this piezometer are consistent with historical performance dating back to the first filling of the dam in 1988 and historical peak readings have not been exceeded over the last five years.	Any trend showing an increase in the pressure reading for the piezometer.
WVH59 WVH60 WVH61 WVH62 WVH63 WVH64	These six piezometers are located between EL 44 and EL 38 at the interface of spillway monolith 54 and the spillway foundations, at Ch 1200. The piezometers are spaced over a distance of approximately 25 metres, with	The pressure readings from these piezometers are consistent with historical performance dating back to the first filling of the dam in 1988 and historical peak readings have not been exceeded	Any trend showing an increase in the pressure reading for any piezometer.

	WVH64 being the most upstream piezometer moving sequentially downstream to WVH59, the most downstream piezometer.	over the last five years.	
WVH65	This piezometer is located at EL 39 at the interface of spillway monolith 55 and the spillway foundations, at Ch 1215. The piezometer is located directly under the lower gallery.	The pressure readings from this piezometer are consistent with historical performance dating back to the first filling of the dam in 1988 and historical peak readings have not been exceeded over the last five years.	Any trend showing an increase in the pressure reading for the piezometer.

The instruments are read and serviced in accordance with ANCOLD Guidelines. The only issue of concern with the instruments is that the right bank piezometer huts cannot be access during a flood event due to backwater effects associated with Brisbane River flooding. Accordingly it is recommended that a system be installed to allow remote collection of this data from the Dam Control Room.

Pore Pressure (Total Pressure Cells)

Collection of data from the Total Pressure Cells appeared to cease in the 1980s and no record on why this decision was made can be found. Additionally, no data records at all can be located.

The Total Pressure Cells were primarily installed to monitor embankment settlement following construction. Accordingly, the data from the Total Pressure Cells would have been the most value in the ten year period immediately following construction of the embankment, while the majority settlement was occurring. Now that embankment settlement has concluded from a practical sense, the Total Pressure Cells could be used to provide data in relation to embankment pore pressure. However as the Total Pressure Cells are generally located in close proximity to the hydraulic piezometers, the value of collecting data from these cells is expected to be low, unless some piezometers cease to function.

With modern electronics and data collection systems, collection of the Total Pressure Cell data should be a simple matter requiring very few resources. Accordingly it is recommended

that the cost/benefits of collocation of this data be analysed to determine if data collection should recommence.

Deformation Monitoring

Deformation surveys are undertaken annually at Wivenhoe Dam. The last survey was undertaken in April 2010 and the detailed results are contained in Appendix B. Following a review of the movements, no values could be found that are cause for any concern. The level of deformation is less than expected for an embankment dam of 56 metres in height, assuming 1% long term settlement.

Maximum settlement since the 1990 base survey of 64 millimetres was measured at Point 8, which is near the highest section of the embankment. This is in line with other settlements at surrounding points 3 to 12 which are greater than 24 millimetres. The maximum horizontal movement of 19 millimetres at point 6 is considered insignificant. Over the last annual period, 6 millimetres was the maximum settlement and maximum horizontal movement was 5 to 7 millimetres, which is also considered insignificant.

The survey shows that control point No. 109 is displaying significant progressive settlement of 52 millimetres between 2007 and 2009 and a further 9 millimetres in 2010. This control point was established on loose material downstream of the embankment following the 2005 spillway upgrade and may need to be re-established. It is recommended that this issue be investigated in conjunction with the 2011 survey.

Structural Movement (Inclinometers)

A summary of the inclinometer results is shown in the table below. Detailed graphs showing the behaviour of individual inclinometers over time are contained in Appendix B. Plans showing the locations of the inclinometers are shown in Appendix A.

INCLINOMETER	DESCRIPTION	COMMENTS
I1 I2 I3	These three inclinometers are located in the embankment at Ch 1600. I1 is 6.5 metres downstream of the embankment centreline and is 60 metres in depth. I2 is 40 metres downstream of the embankment	Cumulative displacement since the dam was constructed is generally less than 20 millimetres over the length of the inclinometers. There are currently no obvious displacement trends that are of

	centreline is now 18 metres in depth as an old instrument is jammed at this depth. I3 is 68 metres downstream of the embankment centreline and is 24 metres in depth.	concern or that require further investigation. The inclinometers will continue to be read on a monthly basis.
I4	This inclinometer is located in the embankment at Ch 1800. I4 is 6.5 metres downstream of the embankment centreline and is 68 metres in depth.	Cumulative displacement since the dam was constructed is generally less than 20 millimetres over the length of the inclinometer. There are currently no obvious displacement trends that are of concern or that require further investigation. The inclinometer will continue to be read on a monthly basis.

Seepage

A summary of the seepage results is shown in the table below. Detailed graphs showing the behaviour of individual seepage points over time are contained in Appendix B. Plans showing the locations of the seepage points are shown in Appendix A.

V- NOTCH WEIR	DESCRIPTION	COMMENTS
Gallery East Gallery West	These two V-notch weirs monitor seepage through the spillway section of the dam and are located in the lower gallery.	A review of the results over the last ten years shows no trends for increased seepage. Recent increases associated with increased storage level are consistent with historical trends. Current steady state seepage levels in the order of 150 litres per hour are not cause for concern.
V-Notch East	This V-notch weir monitors seepage through the left bank embankment. A series of gravel finger drains collect water seeping through the core and foundations as shown on Plans A1-45403 and A2-79207. This water is directed to the V-notch via a series of pipelines.	A review of the results over the last ten years shows no trends for increased seepage. Recent increases associated with increased storage level are consistent with historical trends. Current steady state seepage levels in the order of 150 litres per hour are not cause for concern.

V-Notch West	This V-notch weir monitors seepage through the right bank embankment. A blanket drain collects water seeping through the core and foundations as shown on Plans A1-50789 and A2-79257. This water is directed to the V-notch via a series of pipelines.	A review of the results over the last ten years shows no trends for increased seepage. Recent increases associated with increased storage level are consistent with historical trends. Current steady state seepage levels in the order of 600 litres per hour are not cause for concern.

Monitoring Frequencies

Monitoring frequencies are undertaken in accordance with the following table that meets ANCOLD Guidelines.

WIVENHOE DAM – DAM SAFETY INSTRUMENTATION	
TYPE	**MONITORING FREQUENCY**
Rainfall and Storage Level	Monitored daily through ALERT
Seepage	Daily
Pore Pressure	Monthly
Structural Movement	Monthly
Deformation Monitoring	Yearly

The Hazard Category of Wivenhoe Dam is Extreme. Instrumentation monitoring is undertaken in accordance with ANCOLD Guidelines.

Post Tensioning

As noted in the 2009 Annual Inspection, most of the post tensioning anchors were load tested in 2009 in accordance with ANCOLD guidelines and the results of this testing are shown in the following table.

Wivenhoe Testing Results - 2009											
Cable No	Location	Position	Load Cell Gauge Reading No 1	Load Cell Gauge Reading No 2	Average Reading	Calculated Load	MBL for Cable	Design Load for Cable	Measured vs Design Difference	OK?	Test Date
1	Bay 1	LHS	38.2	38.2	38.20	10.16	16.51	10.73	-0.57	NO	24/11/2008
2	Bay 1	Centre	42.0	42.0	42.00	11.18	16.51	10.73	0.45	YES	12/02/2009
3	Bay 1	RHS	39.5	39.5	39.50	10.51	16.51	10.73	-0.22	NO	24/02/2009
4	Bay 2	LHS	42.6	42.7	42.65	11.35	16.51	10.73	0.62	YES	9/04/2009
5	Bay 2	Centre	41.8	41.8	41.80	11.13	16.51	10.73	0.40	YES	15/04/2009
6	Bay 2	Centre	41.9	41.9	41.90	11.15	16.51	10.73	0.42	YES	16/04/2009
7	Bay 2	RHS	41.8	41.8	41.80	11.13	16.51	10.73	0.40	YES	20/04/2009
8	Bay 3	LHS	40.8	40.9	40.85	10.87	16.51	10.73	0.14	YES	17/06/2009
9	Bay 3	Centre	40.6	40.5	40.55	10.79	16.51	10.73	0.06	YES	18/06/2009
10	Bay 3	Centre	40.9	40.9	40.90	10.88	16.51	10.73	0.16	YES	23/06/2009
11	Bay 3	RHS	41.2	41.3	41.25	10.98	16.51	10.73	0.25	YES	24/06/2009
12	Bay 4	LHS	41.3	41.3	41.30	10.99	16.51	10.73	0.26	YES	29/06/2009
13	Bay 4	Centre	42.0	42.0	42.00	11.18	16.51	10.73	0.45	YES	30/06/2009
14	Bay 4	Centre	41.2	41.2	41.20	10.96	16.51	10.73	0.24	YES	1/07/2009
15	Bay 4	RHS	41.8	41.8	41.80	11.13	16.51	10.73	0.40	YES	2/07/2009
16	Bay 5	LHS					16.51	10.73			
17	Bay 5	Centre					16.51	10.73			
18	Bay 5	Centre					16.51	10.73			
19	Bay 5	RHS					16.51	10.73			

The table above shows that Cable No. 1 is 5% outside the required test load and that Cable No. 3 is 2% outside the required test load. In the first instance both cables will need to be retested to verify these results. Cables 16 to 19 still require testing.

Recommendations

- **A system is to be installed to allow remote collection of piezometer data from the embankment piezometers. This will allow this critical data to be gathered during flood events when the piezometer huts cannot be accessed due to flooding. The data should be transmitted to the Dam Control Room for collection.**
- **The reasons for the movements associated with survey control point No. 109 are to be investigated in conjunction with the 2011 survey.**
- **Post tensioning anchor Cables No. 1 and No. 3 are to be retested in 2010 to determine if the anchor strength remains outside desirable values.**
- **Post tensioning anchor Cables No. 16, No. 17, No. 18 and No. 19 are to be tested in 2010.**

12 INSPECTION

12.1 Inspection Team

John Tibaldi, Principal Engineer Dam Safety (Seqwater)
Louw Van Blerk, Engineer Dam Safety (Seqwater)

12.2 Operational status at time of inspection

Date of Inspection: 3, 10 and 17 September
Reservoir Water Surface Elevation: near FSL

12.3 Dam Embankment

Wivenhoe Dam is a 56 m high, zoned earth and rock embankment separated into two parts by a concrete gravity spillway, controlled by five radial gates. Two saddle dam embankments are located on the left side of the reservoir. A secondary spillway consisting of three fuse plug embankments was constructed on the right abutment in 2005.

The Left Bank embankment is approximately 1.1 kilometres long and has a sloping upstream core protected by both upstream and downstream filters and supported by a downstream shell of miscellaneous fill. Batter slopes are 3 horizontal to 1 vertical on the upstream face and 2 horizontal to 1 vertical on the downstream face. Riprap is in place on both the upstream and downstream shoulders of the embankment.

The Right Bank embankment is 1.2 kilometres long and 56 metres high with a central clay core. The embankment contains both upstream and downstream filters supported by outer shells of compacted sandstone with river run gravel in the upper portion. The shoulder slopes are 2 horizontal to 1 vertical with a local steepening in the upper portion to 1.5 horizontal to 1 vertical. Riprap is in place on both the upstream and downstream shoulders of the embankment.

Two saddle dams close off low saddles on the left abutment of the dam. Saddle Dam 1 is a homogeneous embankment constructed from miscellaneous fill. Saddle Dam 2 is the higher of the two embankments and is constructed with a central clay core and random fill

shoulders. Rip Rap is provided for both embankment on the upstream face for wave protection and the downstream slope is topsoiled and grassed. The Saddle Dams have a crest level at EL 80 and have a maximum height of 10 m. The Saddle Dams only retain water during flood operation.

The crest and upstream and downstream faces of the earth embankments and saddle dams were inspected and generally found to be in a satisfactory condition. Some minor deficiencies were identified and these are listed below, along with recommendations for remedial actions.

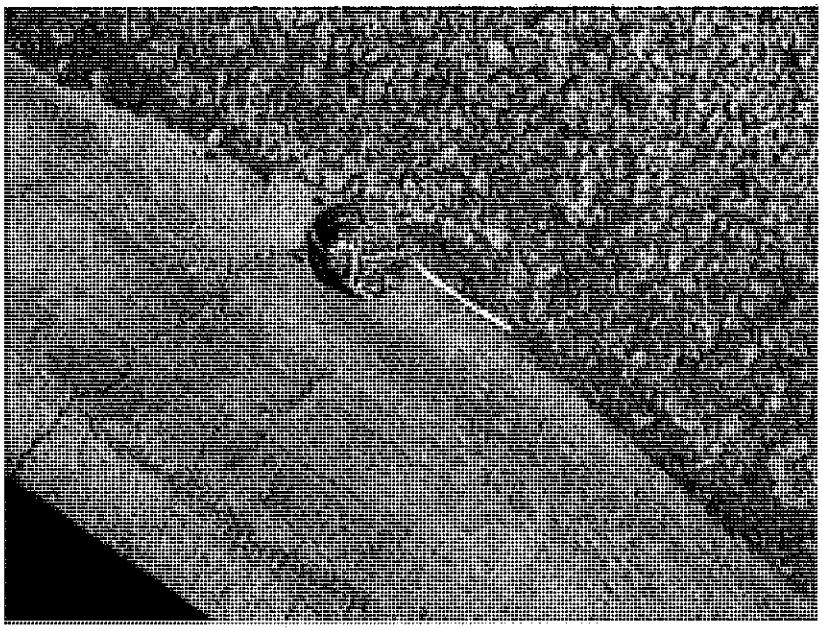
Inspection Recommendations:

Left Bank Embankment (Downstream Area)

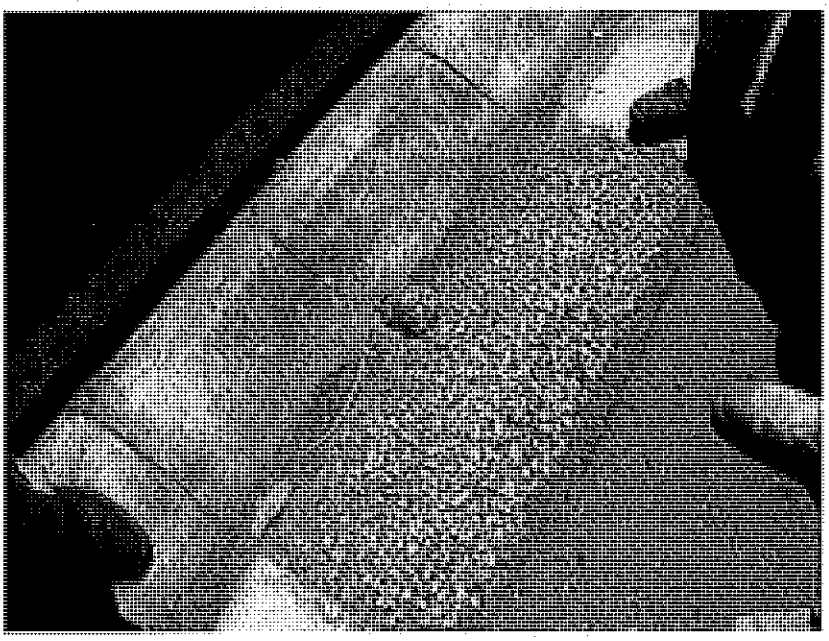
- ***As noted in previous inspections, there is some breakdown of rip rap on the downstream side of the embankment. These areas should continue to be closely monitored for signs of any erosion damage. Presently the areas generally appear sound and stable.***
- ***Some minor erosion repairs are required along the downstream toe of the embankment.***
- ***Some vegetation is evident on the embankment face and the current weed spraying program should continue.***
- ***The flap gate drains near the left bank end of embankment are to be modified to reduce the risk of the flap gates jamming open. The EAP is to include instructions for checking of these gates in major flood events.***
- ***Road repairs are required along the bench to prevent water ponding, with resurfacing required along the length of the road.***
- ***Additional surface drainage is to be constructed to drain the wet areas below the road bench.***
- ***Further investigations are required to determine if the V-notch weir flows are being supplemented by a break in the treated or raw water supply pipelines that are located in these areas.***

Dam Crest

- ***The drains under the wave wall are to be modified to prevent blocking and a store of suitable plugs is to be kept at the dam to enable these drains to be closed off in the event of a flood that impacts on the wave wall (in these circumstances the road would be closed due to flooding and would not be used by the public). This issue is outstanding from the 2008 inspection.***



Broken/Blocked Road Drain



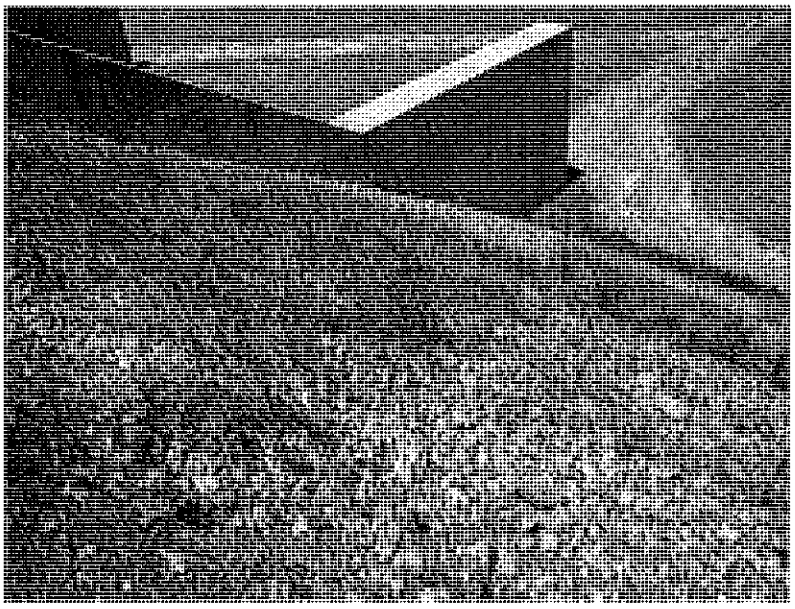
Broken/Blocked Road Drain

Right Bank Embankment

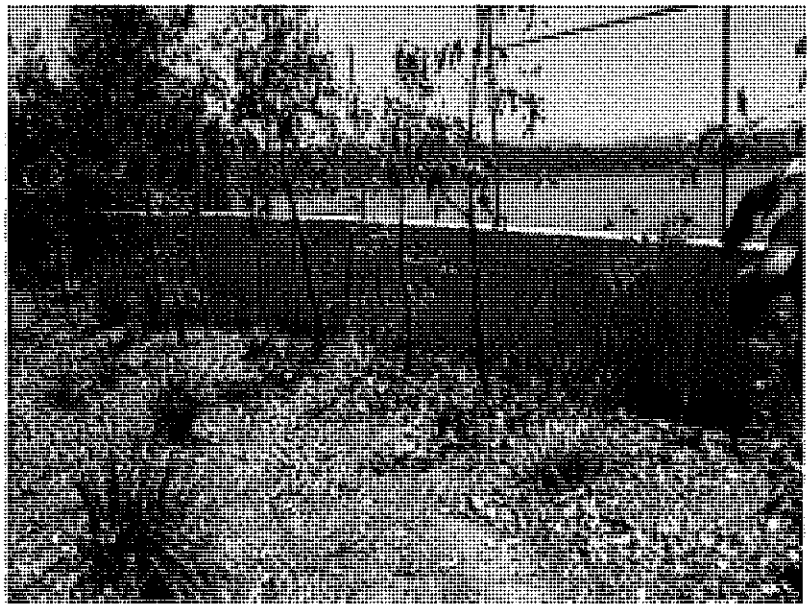
- ***Some minor vegetation is evident on the embankment face and the current weed spraying program should continue.***
- ***All termite mounds within five metres are to be sprayed and destroyed.***
- ***Vegetation growing in the area of the old river diversion is to be burned off each year just prior to the annual inspection to allow proper inspection of this area.***
- ***The erosion hole along the toe of the embankment is to be filled.***
- ***The location of the drainage outflow from the filter blanket drains in the vicinity of the old diversion in uncertain. Accordingly the area along the pond downstream of the V-notch weirs is to be drained and examined. If an outflow is occurring in this area, a suitable V-notch is to be constructed to monitor this flow.***

Fuse Plug Embankments and Auxiliary Spillway

- ***Some minor vegetation is evident on the embankment face and the current weed spraying program should continue.***
- ***Some seepage is evident through the fuse plug embankments and a suitable V-notch weir is to be constructed to allow monitoring of this seepage.***



Vegetation to be sprayed



Trees to be removed

Saddle Dams

- ***Any undesirable vegetation is to be removed from the embankments and the current weed spraying and mowing program is to continue.***
- ***All cattle must be excluded from the embankments and the damage caused by the cattle must be repaired.***

Saddle Dam

12.4 SPILLWAY

The spillway is located in a low saddle between the two dam earth and rockfill embankments and is controlled by five radial gates supported on a mass concrete ogee crest. The radial gates are 12 metres wide by 16 metres high and discharge via a flip bucket spillway to an unlined rock discharge channel. The five radial gates are operated by hydraulic motor driven wire rope winches, one on each side of each gate. The power units for the spillway gates and penstock gate are located in a winch room in the left abutment of the dam. Also located in this winch room is an auxiliary diesel operated hydraulic unit capable of operating the gates.

A left bank underground control complex in the dam comprises the winch room, water quality control room, main high voltage substation, main switchboard, fire control equipment, storeroom diesel alternator set, and ventilation system. A 79 tonne travelling gantry crane on the service bridge over the spillway structure serves to handle the bulkhead gate used for maintenance of the radial gates. A smaller gantry over the intake structure is used for handling the trash racks and water quality baulks.

As part of the Comprehensive Inspection, Queensland Hydraulics completed a comprehensive investigation and review of the hydraulics systems that power the operation of the radial gates and crane. The subsequent report (see Appendix C) concluded that these systems are in good condition and should have a minimum of 10 addition years of working life before requiring major refurbishment. However some recommendations were made to improve the reliability of these systems, and these are included within the recommendations below.

Generally, the spillway and associated gates, hoisting gear and cranes looked to be in good condition. Undertaking regular routine maintenance in accordance with the dam Operation and Maintenance Manuals appears to be producing good results and it is important that this program is continued. The main issues found during the inspection relate to ensuring the on-going reliability of the standby diesel generator. This unit is now over 25 years old and appears to be approaching the end of its useful working life.

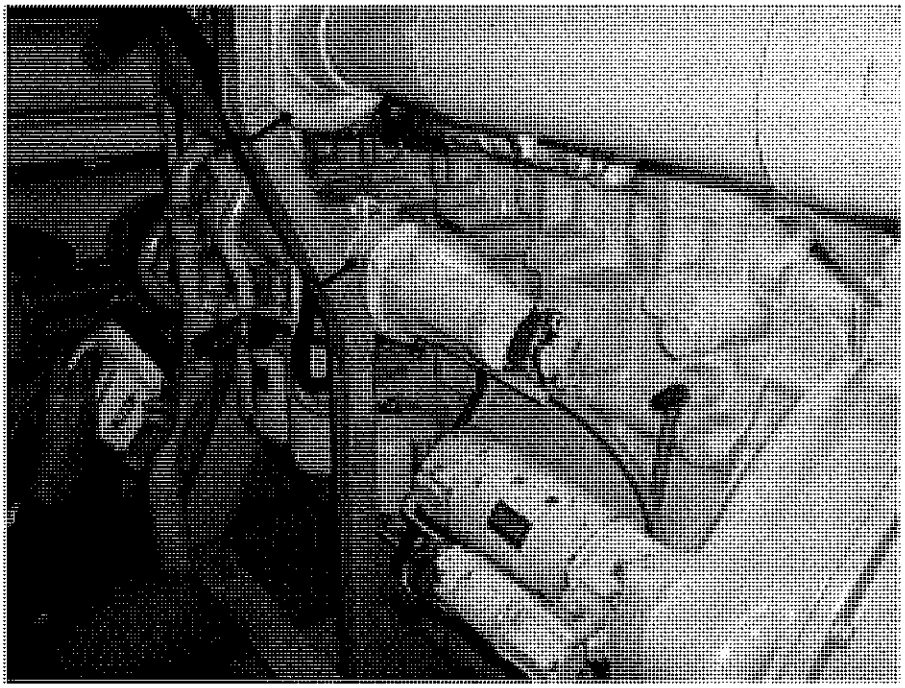
Inspection Recommendations

Hydraulic System Recommendations

- ***Ensure that a sufficient store or O-ring, hydraulic seal and pressure switch spares is held at the dam.***
- ***Check the accumulator gas charge at least annually.***
- ***Check the hydraulic pump/motor couplings annually. This includes the couplings on the Mobile Hydraulic and Diesel Hydraulic Units.***
- ***The hydraulic pump seals are to be replaced within a ten year cycle. All existing seals require replacement within the next two years.***
- ***Add a rust preventative to the hydraulic oil if the hydraulic motors are not run for periods exceeding one month. Hagglunds should be consulted on the type of additive to be used; however running the motors monthly would be the preferred option.***
- ***The winch brake hydraulic cylinders should be resealed and tested in a regular maintenance program on a ten year cycle using a spare set of cylinders rotated into service in a regular routine. All existing cylinders require resealing and testing within the next 12 months.***
- ***The Cam Operated Hydraulic Directional Valves are to be serviced and tested in a regular maintenance program on a two year cycle using a spare set of cylinders rotated into service in a regular routine. All existing valves require servicing and testing within the next 12 months.***
- ***The Reservoir Breathers are to be replaced and the reservoir is to be drained, inspected and cleaned. This work should be undertaken on a three year cycle.***
- ***Install appropriate pressure filtration and return line filtration to the Mobile Hydraulic Unit.***
- ***Annually inspect the hoses on the Mobile Hydraulic Unit and replace if necessary.***
- ***Install a suitable hydraulic oil overflow collection and oil transfer system to manage hydraulic balancing between the electric hydraulic and fixed diesel hydraulic systems.***

General Recommendations

- ***Replace the Standby Diesel generator as it is no longer reliable.***
- ***Repair the concrete damage to the spillway floor and replace the missing flap gate on one of the spillway underdrain outlets.***
- ***Initiate a painting program for the downstream sides of the radial gates. It may be sensible to paint one gate per year over the next five years.***



Standby Diesel Generator

12.5 RESERVOIR RIM AND DOWNSTREAM WATERWAY

The reservoir rim slopes appear generally stable and above the Full Supply Level are relatively well vegetated with no signs of slips or movement that would be of concern from a dam safety perspective.

There were also no slips or restrictions that would prevent spillway outflow or raise tail water levels to an unacceptable level during a dam outflow event.

12.6 OUTLET WORKS

The outlet works extend over 4 monoliths LH11 to LH14 with the entrances to the penstock and river outlet being in Monolith 11 and the regulating valves in Monolith 14. At the entrance to the outlet works in Monolith 11 is a 3.6 metre diameter penstock, located below a 1.9 metre diameter river outlet. A single fixed wheel bulkhead gate is provided to command either outlet (but not both outlets at the same time) to provide for emergency closure or dewatering.

The 3.6m diameter penstock is sealed off with a semi-ellipsoidal dome. A 1.5 metre diameter off-take from this penstock provides an outlet into the river that diverts water through a mini hydro Power Station constructed in 2002. Control of this conduit is provided through mini-hydro facility. The second outlet into the river is a 1.5 metre diameter stainless steel Fixed Cone Dispersion Valve located at the downstream end of the 1.9 metre diameter river outlet.

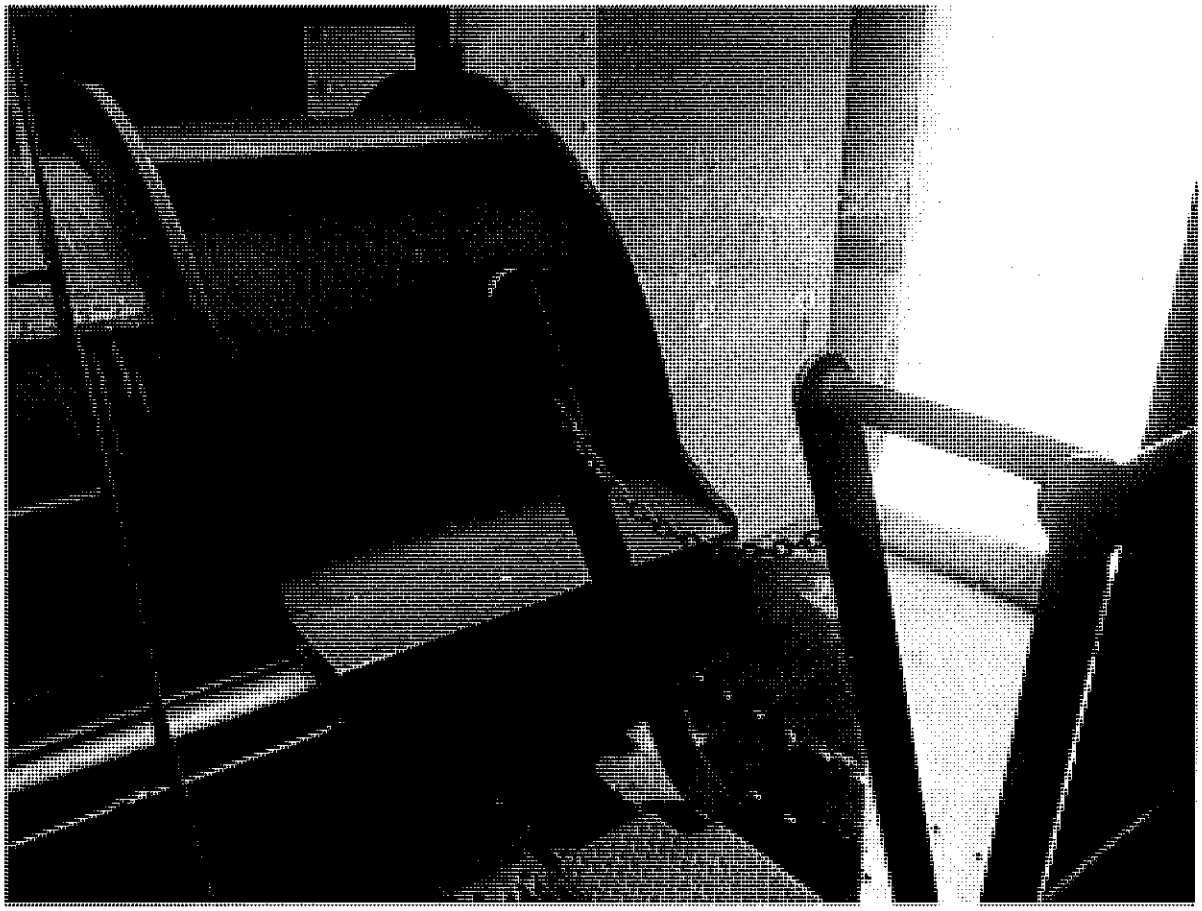
Within the intake structure in the left abutment there is an arrangement of trash racks and six telescoping vertical lift gates to allow selective withdrawal of water for quality control purposes.

The mechanical equipment in the outlet works was inspected and found to be in generally good condition. Internal inspection of the conduits and valves had occurred within the last 12 months and the 1.9 metre river outlet had been internally repainted and refurbished in 2010. These conduits are generally inspected annually.

Issues relating to water leaking into the outlet works area through the service penetrations to the mini-hydro facility remain outstanding from the 2008 Inspection as to issues relating to the stability of the sandstone cliffs adjacent to the outlet works. There is an issue with chains disengaging on the chain hoists associated with the selective baulks and a new and accurate float well recorder is to be installed at the dam. It was also noted that sump pump flows from the mini hydro are not monitored and a suitable flow recording device should be installed to allow this to occur.

Inspection Recommendations

- ***Suitable engineering works are to be constructed to eliminate the hazard to persons and dam infrastructure caused by the erosion of the sandstone cliffs adjacent to the outlet works.***
- ***Install a flow meter to allow measurement of the sump pump outflows from the mini hydro and record these outflows on the weekly inspection sheets.***



Cone Valve

12.7 INSTRUMENTATION

Surveillance instrumentation at the dam monitors movement of the dam embankment, seepage and pressure within the embankment. The instrumentation consists of:

- 10 foundation drains.
- 65 hydraulic piezometers
- 24 surface settlement points
- 2 V-notch weirs
- 1 automatic water level recorder

The instrumentation results are contained in Appendix A and discussed in detail in Section11. No trends of concern were noted.

The instrumentation was also inspected, and the following works recommendations were made:

Inspection Recommendations:

- ***All survey points are to be suitably labelled and numbered on site and a suitable engineering plan prepared to show instrumentation point locations and corresponding numbering.***
- ***Chainage markers are to be installed at 100 metre intervals along the embankment and full supply level markets are to be installed along the downstream side of the embankment at suitable locations.***

13 RECOMMENDATIONS

Section Reference	Recommendation	Rating (See Below)
6.0	• *Review and update the Standing Operating Procedures to account for the change in position titles due to the recent restructure of Seqwater.*	2
11.0	• *A system is to be installed to allow remote collection of piezometer data from the embankment piezometers. This will allow this critical data to be gathered during flood events when the piezometer huts cannot be accessed due to flooding. The data should be transmitted to the Dam Control Room for collection.*	3
	• *The reasons for the movements associated with survey control point No. 109 are to be investigated in conjunction with the 2011 survey.*	3
	• *Post tensioning anchor Cables No. 1 and No. 3 are to be retested in 2010 to determine if the anchor strength remains outside desirable values.*	3
	• *Post tensioning anchor Cables No. 16, No. 17, No. 18 and No. 19 are to be tested in 2010.*	3
12.0	<u>*Left Bank Embankment (Downstream Area)*</u>	
	• *As noted in the previous year's Annual Inspection, there is some breakdown of rip rap on the downstream side of the embankment, with some areas of rip rap are close to requiring replenishment. These areas should continue to be closely monitored for signs of any erosion damage. Presently the areas generally appear sound and stable.*	3
	• *Some minor erosion repairs are required along the downstream toe of the embankment.*	3

	• *Some minor vegetation is evident on the embankment face and the current weed spraying program should continue.*	4
	• *The flap gate drains near the left bank end of embankment are to be modified to reduce the risk of the flap gates jamming open. The EAP is to include instructions for checking of these gates in major flood events.*	3
	• *Road repairs are required along the bench to prevent water ponding, with resurfacing required along the length of the road.*	3
	• *Additional surface drainage is to be constructed to drain the wet areas below the road bench.*	3
	• *Further investigations are required to determine if the V-notch weir flows are being supplemented by a break in the treated or raw water supply pipelines that are located in these areas.*	3
	Dam Crest	
	• *The drains under the wave wall are to be modified to prevent blocking and a store of suitable plugs is to be kept at the dam to enable these drains to be closed off in the event of a flood that impacts on the wave wall (in these circumstances the road would be closed due to flooding and would not be used by the public). This issue is outstanding from the 2008 inspection.*	3

	Right Bank Embankment	
	• ***Some minor vegetation is evident on the embankment face and the current weed spraying program should continue.***	
	• ***All termite mounds within five metres are to be sprayed and destroyed.***	4
	• ***Vegetation growing in the area of the old river diversion is to be burned off each year just prior to the annual inspection to allow proper inspection of this area.***	4
	• ***The erosion hole along the toe of the embankment is to be filled.***	3
	• ***The location of the drainage outflow from the filter blanket drains in the vicinity of the old diversion in uncertain. Accordingly the area along the pond downstream of the V-notch weirs is to be drained and examined. If an outflow is occurring in this area, a suitable V-notch is to be constructed to monitor this flow.***	3
	Fuse Plug Embankments and Auxiliary Spillway	
	• ***Some minor vegetation is evident on the embankment face and the current weed spraying program should continue.***	4
	• ***Some seepage is evident through the fuse plug embankments and a suitable V-notch weir is to be constructed to allow monitoring of this seepage.***	3

	Saddle Dams	
	• *Any undesirable vegetation is to be removed from the embankments and the current weed spraying and mowing program is to continue.*	4
	• *All cattle must be excluded from the embankments and the damage caused by the cattle must be repaired.*	2
	Hydraulic System	
	• *Ensure that a sufficient store or O-ring, hydraulic seal and pressure switch spares is held at the dam.*	3
	• *Check the accumulator gas charge at least annually.*	3
	• *Check the hydraulic pump/motor couplings annually. This includes the couplings on the Mobile Hydraulic and Diesel Hydraulic Units.*	3
	• *The hydraulic pump seals are to be replaced within a ten year cycle. All existing seals require replacement within the next two years.*	3
	• *Add a rust preventative to the hydraulic oil if the hydraulic motors are not run for periods exceeding one month. Hagglunds should be consulted on the type of additive to be used; however running the motors monthly would be the preferred option.*	3
	• *The winch brake hydraulic cylinders should be resealed and tested in a regular maintenance program on a ten year cycle using a spare set of cylinders rotated into service in a regular routine. All existing cylinders require resealing and testing within the next 12 months.*	3

	• *The Cam Operated Hydraulic Directional Valves are to be serviced and tested in a regular maintenance program on a two year cycle using a spare set of cylinders rotated into service in a regular routine. All existing valves require servicing and testing within the next 12 months.*	3
	• *The Reservoir Breathers are to be replaced and the reservoir is to be drained, inspected and cleaned. This work should be undertaken on a three year cycle.*	3
	• *Install appropriate pressure filtration and return line filtration to the Mobile Hydraulic Unit.*	3
	• *Annually inspect the hoses on the Mobile Hydraulic Unit and replace if necessary.*	3
	• *Install a suitable hydraulic oil overflow collection and oil transfer system to manage hydraulic balancing between the electric hydraulic and fixed diesel hydraulic systems.*	3
	Spillway Infrastructure	
	• *Replace the Standby Diesel generator as it is no longer reliable.*	1
	• *Repair the concrete damage to the spillway floor and replace the missing flap gate on one of the spillway underdrain outlets.*	3
	• *Initiate a painting program for the downstream sides of the radial gates. It may be sensible to paint one gate per year over the next five years.*	3

	• ***Suitable engineering works are to be constructed to eliminate the hazard to persons and dam infrastructure caused by the erosion of the sandstone cliffs adjacent to the outlet works.***	3
	• ***Install a flow meter to allow measurement of the sump pump outflows from the mini hydro and record these outflows on the weekly inspection sheets.***	3
	<u>Instrumentation</u>	
	• ***All survey points are to be suitably labelled and numbered on site and a suitable engineering plan prepared to show instrumentation point locations and corresponding numbering.***	3
	• ***Chainage markers are to be installed at 100 metre intervals along the embankment and full supply level markets are to be installed along the downstream side of the embankment at suitable locations.***	3

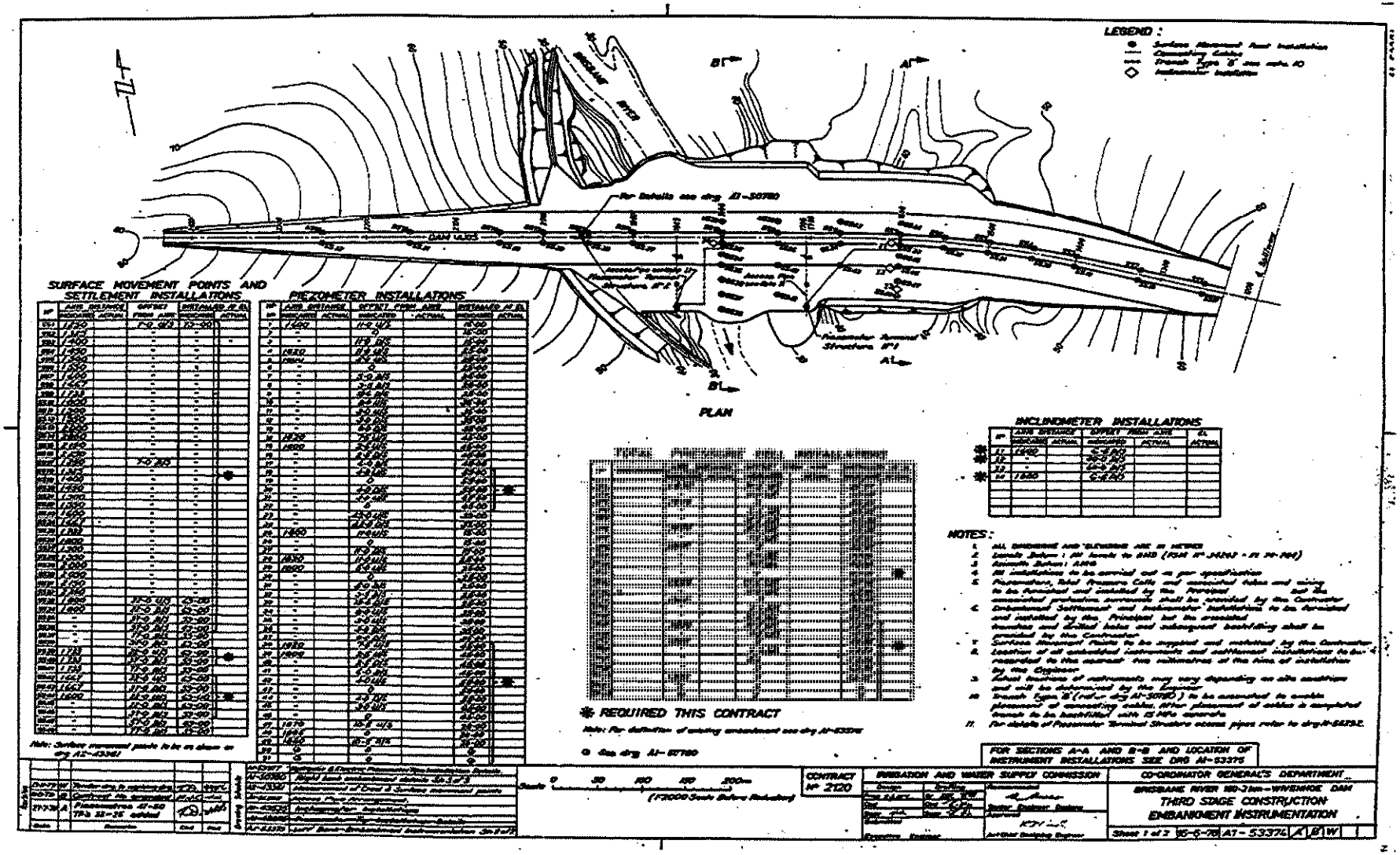
Legend of Criticality Rating

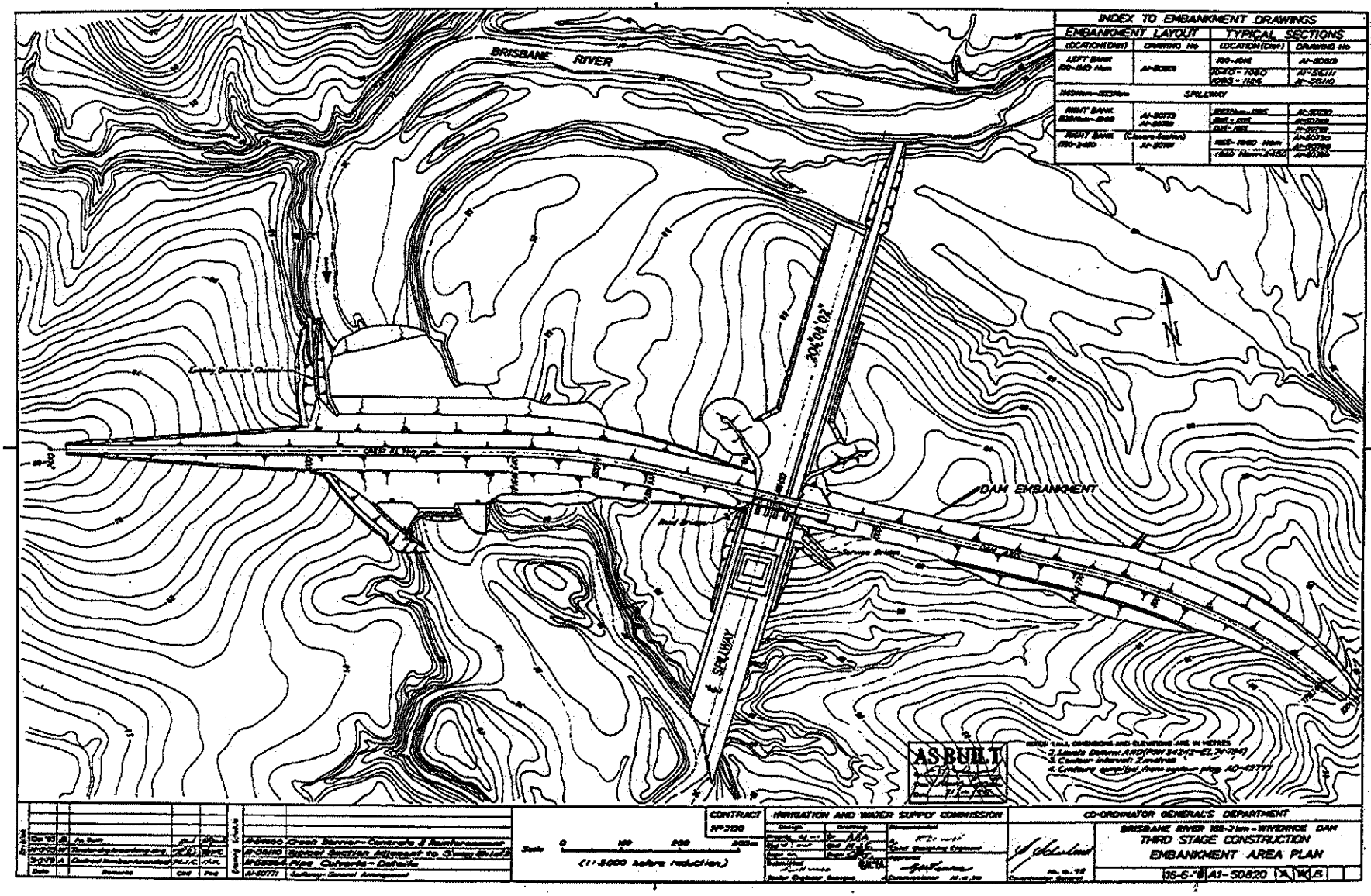
Rating 1	Rectification required immediately, i.e. within 1 month
Rating 2	Rectification required within 3 months
Rating 3	Rectification required within 12 months
Rating 4	Ongoing

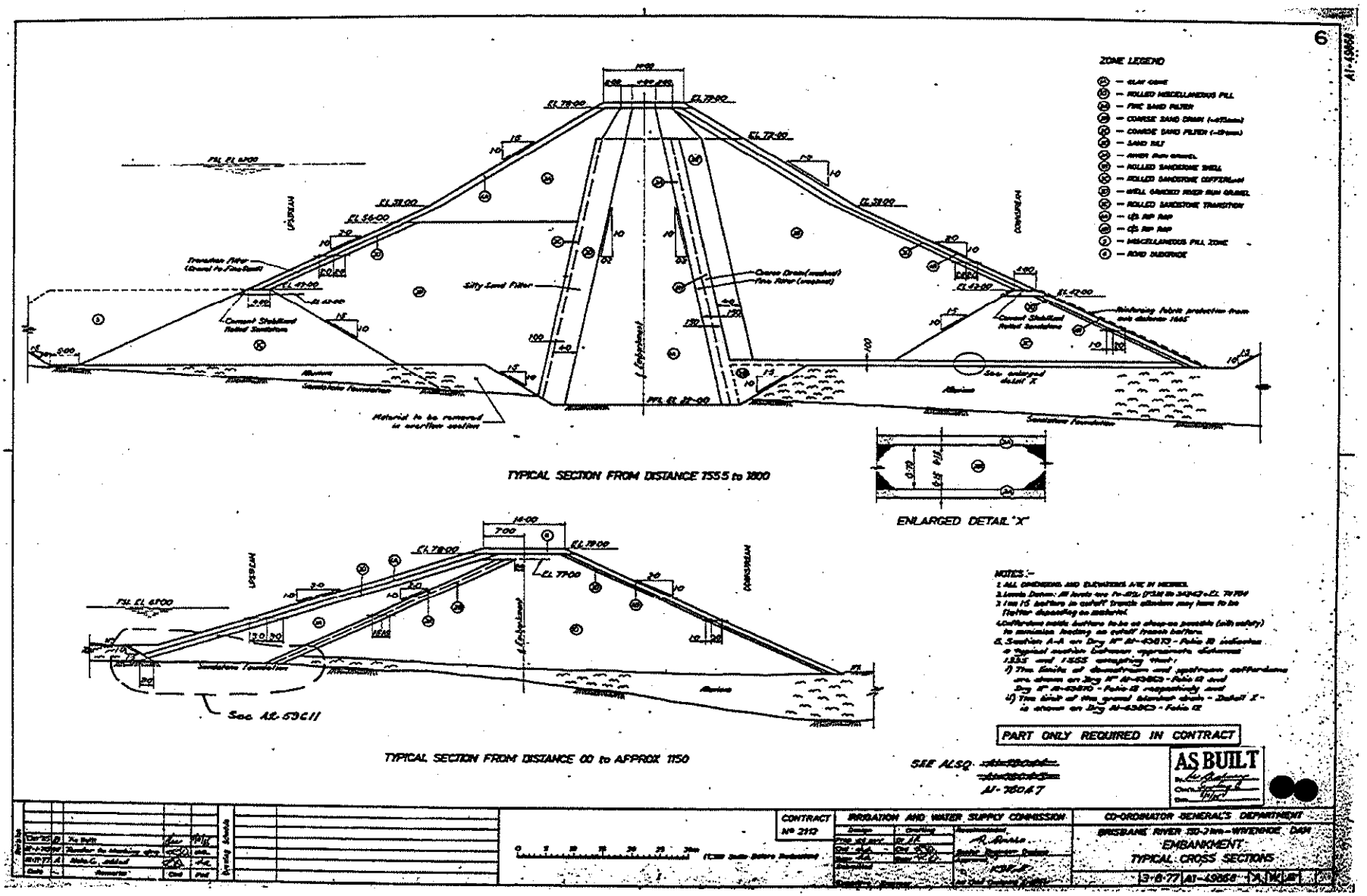
14 REFERENCES

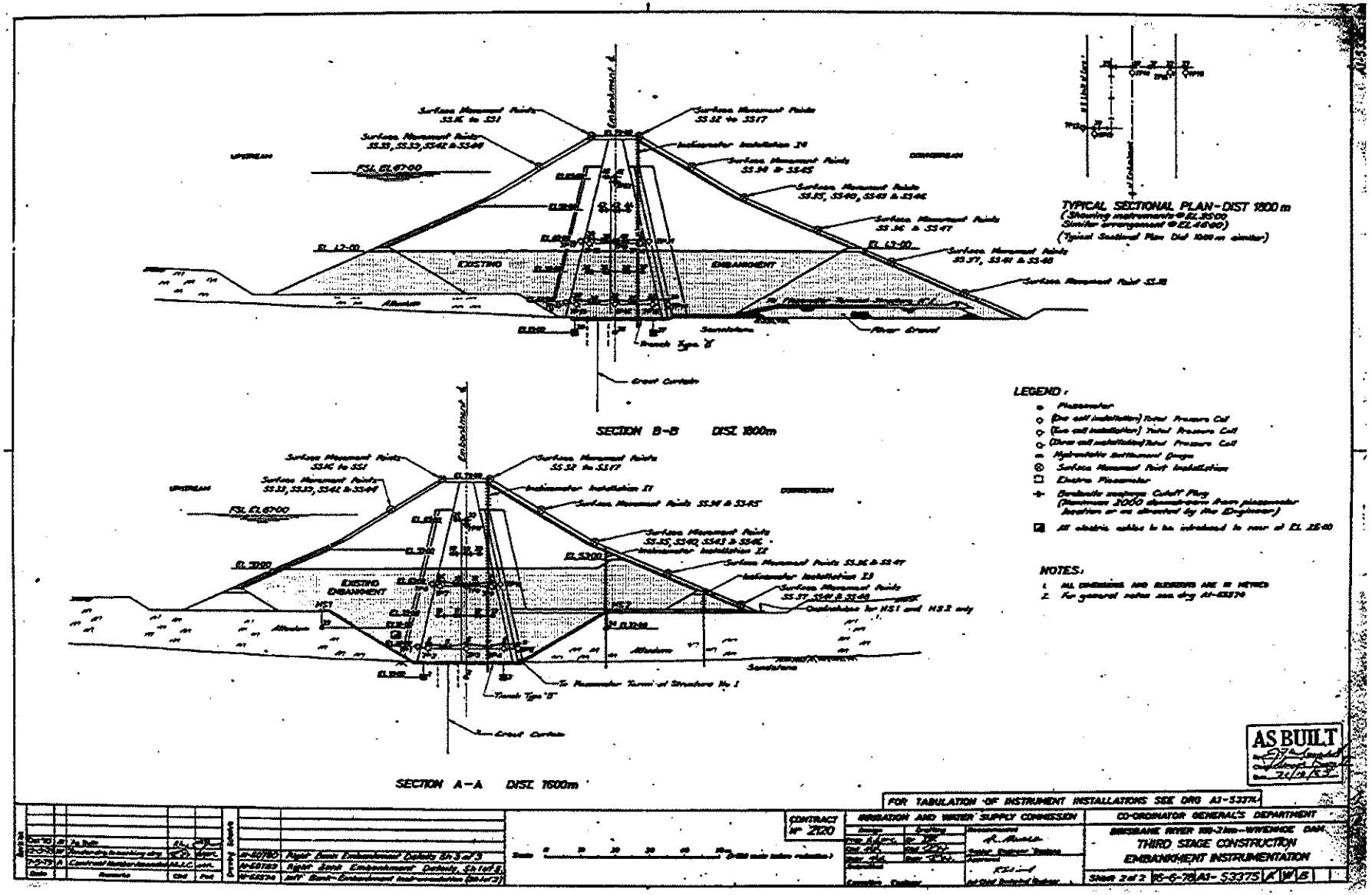
- (DPI Water Commercial 1995) "Wivenhoe Dam Design Report", September 1995.
- (GHD, 1997) "Wivenhoe Dam Safety Review", April 1997.
- (SunWater) "Detailed Stability Check of the Spillway Wall Monoliths at Wivenhoe Dam", June 2001.
- (SunWater 2001) "Assessment of Piping Potential in the Wivenhoe Dam Saddle Dams", November 2001.
- (Wivenhoe Alliance 2005) "Wivenhoe Upgrade Design and Construction Report", December 2005.
- (Glen Hobbs and Associates 2006) "Wivenhoe Dam Radial gate Trunnion Bearings Review", May 2006.
- (NSW Department of Commerce 2006) "Wivenhoe Dam Comprehensive Inspection Draft Report", July 2006.
- (Seqwater 2009) "Wivenhoe Dam – Emergency Action Plan, September 2009.
- (Seqwater 2009) "Wivenhoe Dam – Standing Operating Procedures, March 2009.
- (Seqwater 2009) "Wivenhoe Dam – Operation and Maintenance Manuals, March 2009.
- (GHD 2009) "Report for Raising Wivenhoe Dam Full Supply Level Review", December 2009.

APPENDIX A DRAWINGS


LEGEND :
PLAN
SURFACE MOVEMENT POINTS AND SETTLEMENT INSTALLATIONS
PIEZOMETER INSTALLATIONS
INCLINOMETER INSTALLATIONS
REQUIRED THIS CONTRACT
NOTES :
FOR SECTIONS A-A AND B-B AND LOCATION OF INSTRUMENT INSTALLATIONS SEE DRG AI-53375
CONTRACT Nº 2120
IRRIGATION AND WATER SUPPLY COMMISSION
CO-ORDINATOR GENERAL'S DEPARTMENT
BRISBANE RIVER 100·7km – WIVENHOE DAM
THIRD STAGE CONSTRUCTION
EMBANKMENT INSTRUMENTATION
Sheet 1 of 2 16-6-76 AI7 - 53374


BRISBANE RIVER
DAM EMBANKMENT
SPILLWAY
AS BUILT
INDEX TO EMBANKMENT DRAWINGS
EMBANKMENT LAYOUT
TYPICAL SECTIONS
IRRIGATION AND WATER SUPPLY COMMISSION
CO-ORDINATOR GENERAL'S DEPARTMENT
BRISBANE RIVER 165·2km – WIVENHOE DAM
THIRD STAGE CONSTRUCTION
EMBANKMENT AREA PLAN
A1-50820


6
ZONE LEGEND
TYPICAL SECTION FROM DISTANCE 1555 to 1800
ENLARGED DETAIL 'X'
TYPICAL SECTION FROM DISTANCE 00 to APPROX 1150
NOTES:-
PART ONLY REQUIRED IN CONTRACT
AS BUILT
CONTRACT Nº 2112
IRRIGATION AND WATER SUPPLY COMMISSION
CO-ORDINATOR GENERAL'S DEPARTMENT
BRISBANE RIVER 150-2 km - WIVENHOE DAM
EMBANKMENT
TYPICAL CROSS SECTIONS
3-6-77 AI-49856


SECTION B-B DIST 1800m
SECTION A-A DIST 1600m
TYPICAL SECTIONAL PLAN - DIST 1800 m
LEGEND :
NOTES:
AS BUILT
FOR TABULATION OF INSTRUMENT INSTALLATIONS SEE DRG A3-53374
CONTRACT № 2120
IRRIGATION AND WATER SUPPLY COMMISSION
CO-ORDINATOR GENERAL'S DEPARTMENT
BRISBANE RIVER 100-2 km - WIVENHOE DAM
THIRD STAGE CONSTRUCTION
EMBANKMENT INSTRUMENTATION
Sheet 2 of 2 16-6-78 A3-53375 A

APPENDIX B INSTRUMENTATION DATA

Anchor No	No of Strands	Original Lock Off (kN)	Date of Lock Off	First Monitor (kN)	Date of 1st Monitor	Second Monitor (kN)	Date of 2nd Monitor	Original as a % of MBL	First Monitor as a % of MBL	Second Monitor as a % of MBL
T-121.0	42	7350	24/10/2007	7561	18/11/2007	6989	20/11/2009	70.0	72.0	66.6
T-127.0	42	7350	25/10/2007	7267	18/11/2007	6894	20/11/2009	70.0	69.2	65.7
T-132.7	42	7350	14/11/2007	7493	19/11/2009	6798	19/11/2009	70.0	71.4	64.7
T-135.4	42	7350	14/11/2007	7350	19/11/2007	6588	19/11/2009	70.0	70.0	62.7
T-141.1	55	9625	19/11/2007	9590	22/11/2007	9050	18/11/2009	70.0	69.7	65.8
T-143.95	55	9625	19/11/2007	9625	22/11/2007	9250	18/11/2009	70.0	70.0	67.3
T-146.65	55	9625	20/11/2007	9702	22/11/2007	8950	18/11/2009	70.0	70.6	65.1
T-149.5	55	9625	20/11/2007	9625	22/11/2007	9250	18/11/2009	70.0	70.0	67.3
T-155.5	65	11375	3/12/2007	11375	10/12/2007	11050	20/11/2009	70.0	70.0	68.0
T-159.85	65	11375	4/12/2007	11375	10/12/2007	10950	20/11/2009	70.0	70.0	67.4
T-163.5	65	11375	2/10/2007	11643	5/10/2007	10850	17/11/2009	70.0	71.6	66.8
T-166.5	65	11375	4/10/2007	11220	8/10/2007	11050	17/11/2009	70.0	69.0	68.0
T-169.5	64	11200	31/7/2007	11079	2/8/2007	10750	17/11/2009	70.0	69.2	67.2
T-172.5	65	11375	4/10/2007	10994	8/10/2007	10750	17/11/2009	70.0	67.7	66.2
T-175.5	65	11375	3/10/2007	11502	5/10/2007	11010	16/11/2009	70.0	70.8	67.8
T-178.5	65	11375	3/10/2007	11502	5/10/2007	11010	16/11/2007	70.0	70.8	67.8
T-181.5	55	9625	11/10/2007	9625	15/10/2007	8550	16/11/2009	70.0	70.0	62.2
T-184.5	55	9625	11/10/2007	9366	16/10/2007	8760	14/11/2009	70.0	68.1	63.6
T-190.2	55	9625	13/10/2007	9702	17/10/2007	9250	14/11/2009	70.0	70.6	67.3
T-196.1	55	9625	13/10/2007	9926	17/10/2007	9150	14/11/2009	70.0	72.2	66.5
T-202.1	55	9625	17/10/2007	9926	22/10/2007	9150	13/11/2009	70.0	72.2	66.5
T-208.1	42	7350	18/10/2007	7448	22/10/2007	6798	12/11/2009	70.0	70.9	64.7
C-116.5	65	11375	18/1/2008	11502	23/1/2008	11050	23/11/2009	70.0	70.8	68.0
C-119.5	65	11375	19/1/2008	11502	23/1/2008	10850	25/11/2009	70.0	70.8	66.8
C-122.5	65	11375	19/1/2008	11502	23/1/2008	10950	25/11/2009	70.0	70.8	67.4
C-125.5	65	11375	19/1/2008	11375	23/1/2008	10850	25/11/2009	70.0	70.0	66.8
C-128.5	65	11375	19/1/2008	11375	23/1/2008	10950	25/11/2009	70.0	70.0	67.4
C-131.35	65	11375	20/1/2008	11220	23/1/2008	10950	25/11/2009	70.0	69.0	67.4
C-134.05	65	11375	20/1/2008	11375	25/1/2008	10950	25/11/2009	70.0	70.0	67.4
C-136.75	65	11375	20/1/2008	11375	25/1/2008	10850	25/11/2009	70.0	70.0	66.8
C-139.6	65	11375	20/1/2008	11375	25/1/2008	10850	25/11/2009	70.0	70.0	66.8
C-142.6	65	11375	20/1/2008	11213	24/1/2008	10950	25/11/2009	70.0	69.0	67.4
C-145.3	65	11375	21/1/2008	11213	25/1/2008	10850	25/11/2009	70.0	69.0	66.8
C-148.0	65	11375	21/1/2008	11213	25/1/2008	11050	25/11/2009	70.0	69.0	68.0
C-151.0	65	11375	21/11/2008	11213	25/1/2008	10850	25/11/2009	70.0	69.0	66.8
C-154.0	65	11375	21/1/2008	11375	25/1/2008	10950	25/11/2009	70.0	70.0	67.4
C-157.25	65	11375	23/1/2008	11213	25/1/2008	10950	25/11/2009	70.0	69.0	67.4
C-162.0	65	11375	22/1/2008	11375	25/1/2008	10850	27/11/2009	70.0	70.0	66.8
C-165.0	65	11375	18/1/2008	11375	25/1/2008	10950	27/11/2009	70.0	70.0	67.4
C-168.0	65	11375	17/1/2008	11375	25/1/2008	11152	27/11/2009	70.0	70.0	68.6
C-171.0	65	11375	17/1/2008	11213	24/1/2008	10950	27/11/2009	70.0	69.0	67.4
C-174.0	65	11375	17/1/2008	11213	24/1/2008	10950	27/11/2009	70.0	69.0	67.4
C-177.0	65	11375	17/1/2008	11375	24/1/2008	11050	27/11/2009	70.0	70.0	68.0
C-180.0	65	11375	18/7/2007	11375	8/1/2008	11050	27/11/2009	70.0	70.0	68.0
C-183.0	65	11375	19/12/2007	11375	8/1/2008	11050	27/11/2009	70.0	70.0	68.0
C-186.0	65	11375	19/12/2007	11213	8/1/2008	10950	27/11/2009	70.0	69.0	67.4
C-188.8	65	11375	16/1/2008	11375	24/1/2008	11050	27/11/2009	70.0	70.0	68.0
C-191.6	65	11375	16/1/2008	11375	24/1/2008	10950	27/11/2009	70.0	70.0	67.4
C-194.6	65	11375	16/1/2008	11375	24/1/2008	11050	27/11/2009	70.0	70.0	68.0
C-197.6	65	11375	14/1/2008	11375	24/1/2008	10850	27/11/2009	70.0	70.0	66.8
C-200.6	65	11375	14/1/2008	11213	24/1/2008	10850	27/11/2009	70.0	69.0	66.8
C-203.6	65	11375	10/1/2008	11375	12/1/2008	11050	27/11/2009	70.0	70.0	68.0
C-206.6	65	11375	10/1/2008	11375	14/1/2008	10850	27/11/2009	70.0	70.0	66.8
C-209.6	65	11375	10/1/2008	11375	14/1/2008	10850	27/11/2009	70.0	70.0	66.8
C-212.4	65	11375	10/1/2008	11375	12/1/2008	10950	27/11/2009	70.0	70.0	67.4
C-215.2	65	11375	10/1/2008	11375	12/1/2008	10950	30/11/2009	70.0	70.0	67.4
C-218.2	65	11375	9/1/2008	11502	12/1/2008	11050	30/11/2009	70.0	70.8	68.0
C-222.5	65	11375	9/1/2008	11502	12/1/2008	11050	30/11/2009	70.0	70.8	68.0
C-226.5	65	11375	9/1/2008	11375	12/1/2008	11050	30/11/2009	70.0	70.0	68.0
C-230.5	65	11375	7/1/2008	11375	12/1/2008	10950	30/11/2009	70.0	70.0	67.4
C-234.5	65	11375	7/1/2008	11502	12/1/2008	11050	30/11/2009	70.0	70.8	68.0
C-238.5	65	11375	7/1/2008	11375	12/1/2008	10850	30/11/2009	70.0	70.0	66.8
C-243.2	65	11375	5/1/2008	11502	8/1/2008	11050	30/11/2009	70.0	70.8	68.0
C-247.5	65	11375	5/1/2008	11375	8/1/2008	10950	30/11/2009	70.0	70.0	67.4
C-250.5	65	11375	20/12/2007	11502	3/1/2008	11152	30/11/2009	70.0	70.8	68.6
C-255.5	65	11375	4/1/2008	11375	8/1/2008	11050	30/11/2009	70.0	70.0	68.0
C-260.5	65	11375	3/1/2008	11502	7/1/2008	11050	30/11/2009	70.0	70.8	68.0
C-265.5	65	11375	4/1/2008	11375	7/1/2008	10850	30/11/2009	70.0	70.0	66.8
C-270.5	65	11375	3/1/2008	11502	7/1/2008	11458	30/11/2009	70.0	70.8	70.5

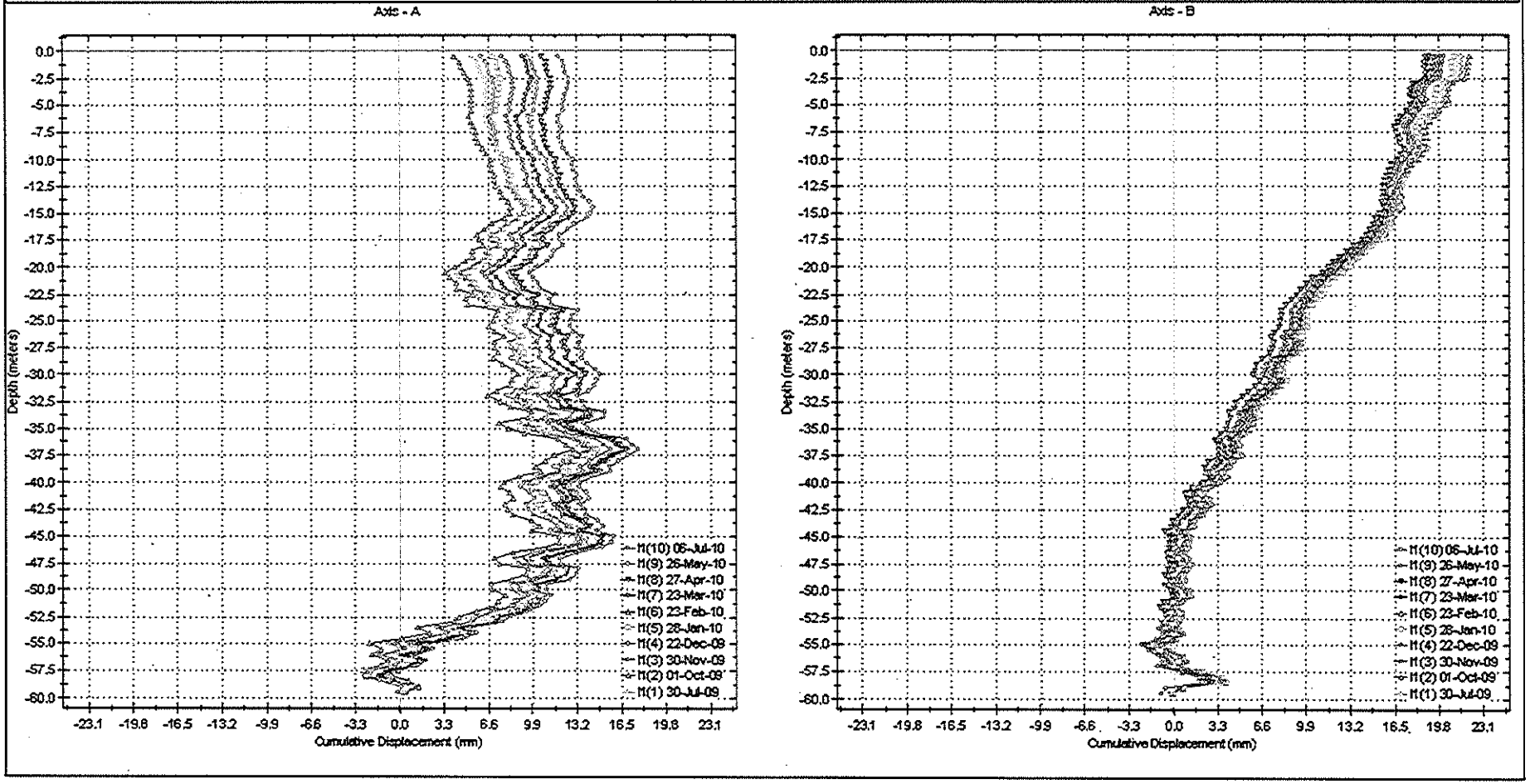
RST Instruments Ltd.

CUMULATIVE DISPLACEMENT

Inclinalysis v.2.35

Borehole: I1
Project: Wivenhoe
Location:
Northing:
Easting:
Collar:

Spiral Correction: N/A
Collar Elevation: 0.0 meters
Borehole Total Depth: 59.5 meters
North Groove Azimuth:
Base Reading: 1989 Aug 30 11:01
Axis A Azimuth: 0.0 degrees



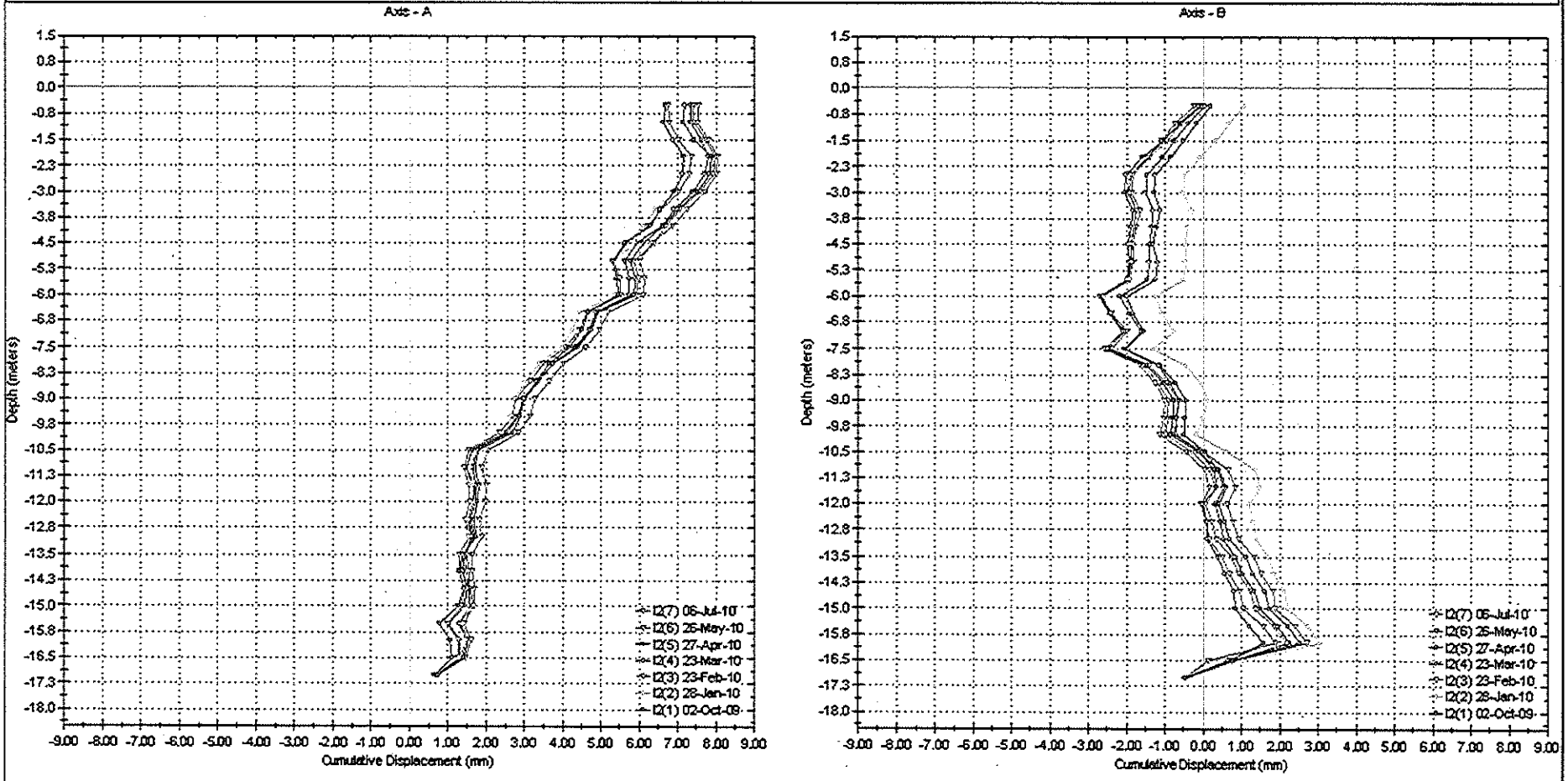
RST Instruments Ltd.

CUMULATIVE DISPLACEMENT

Inclinalysis v.2.35

Borehole : I2
Project : Wivenhoe
Location :
Northing :
Easting :
Collar :

Spiral Correction : N/A
Collar Elevation : 0.0 meters
Borehole Total Depth : 17.0 meters
North Groove Azimuth :
Base Reading : 1989 Aug 3011:01
Axis A Azimuth : 0.0 degrees



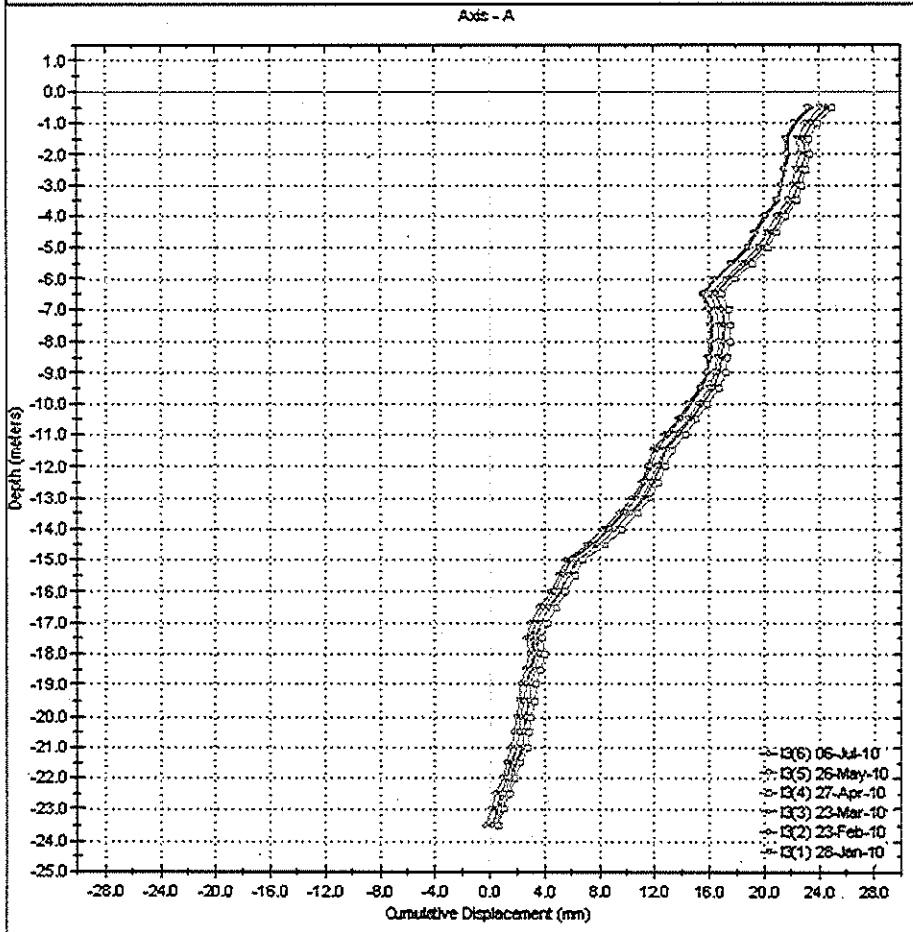
RST Instruments Ltd.

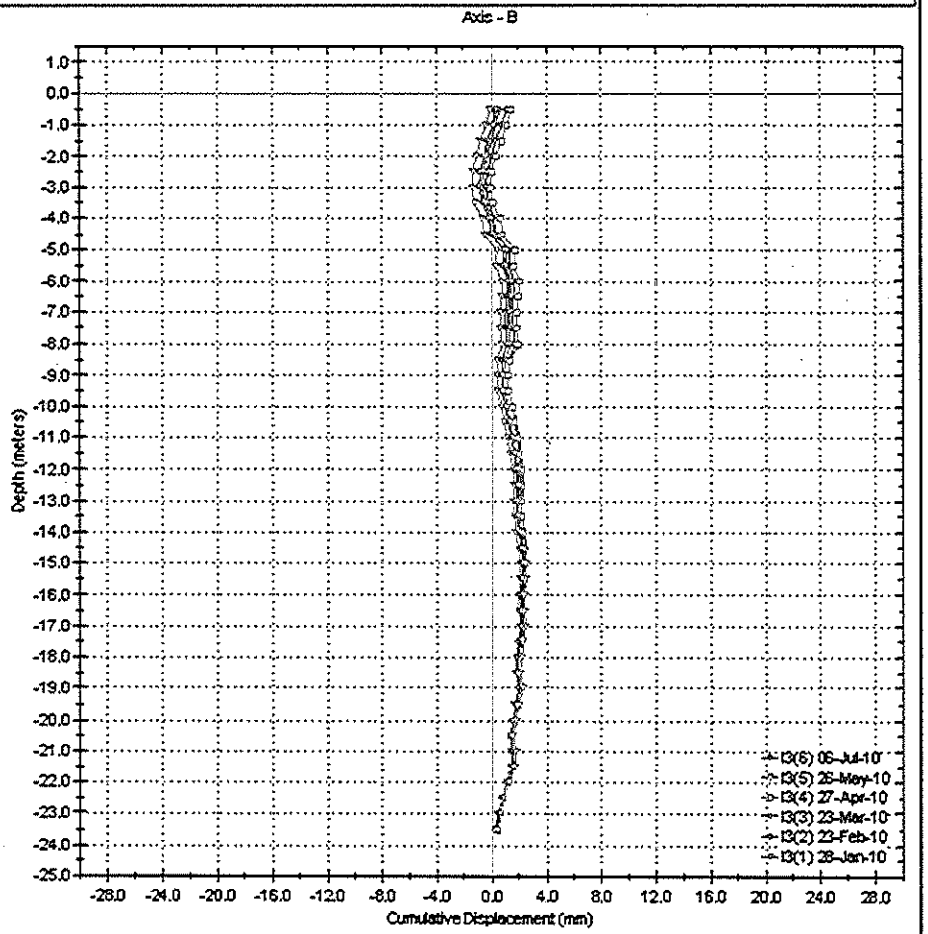
CUMULATIVE DISPLACEMENT

Inclinalysis v.2.35

Borehole : I3
Project : Wivenhoe
Location :
Northing :
Easting :
Collar :

Spiral Correction : N/A
Collar Elevation : 0.0 meters
Borehole Total Depth : 23.5 meters
North Groove Azimuth :
Base Reading : 1990 Jan 12 11:01
Axis A Azimuth : 0.0 degrees





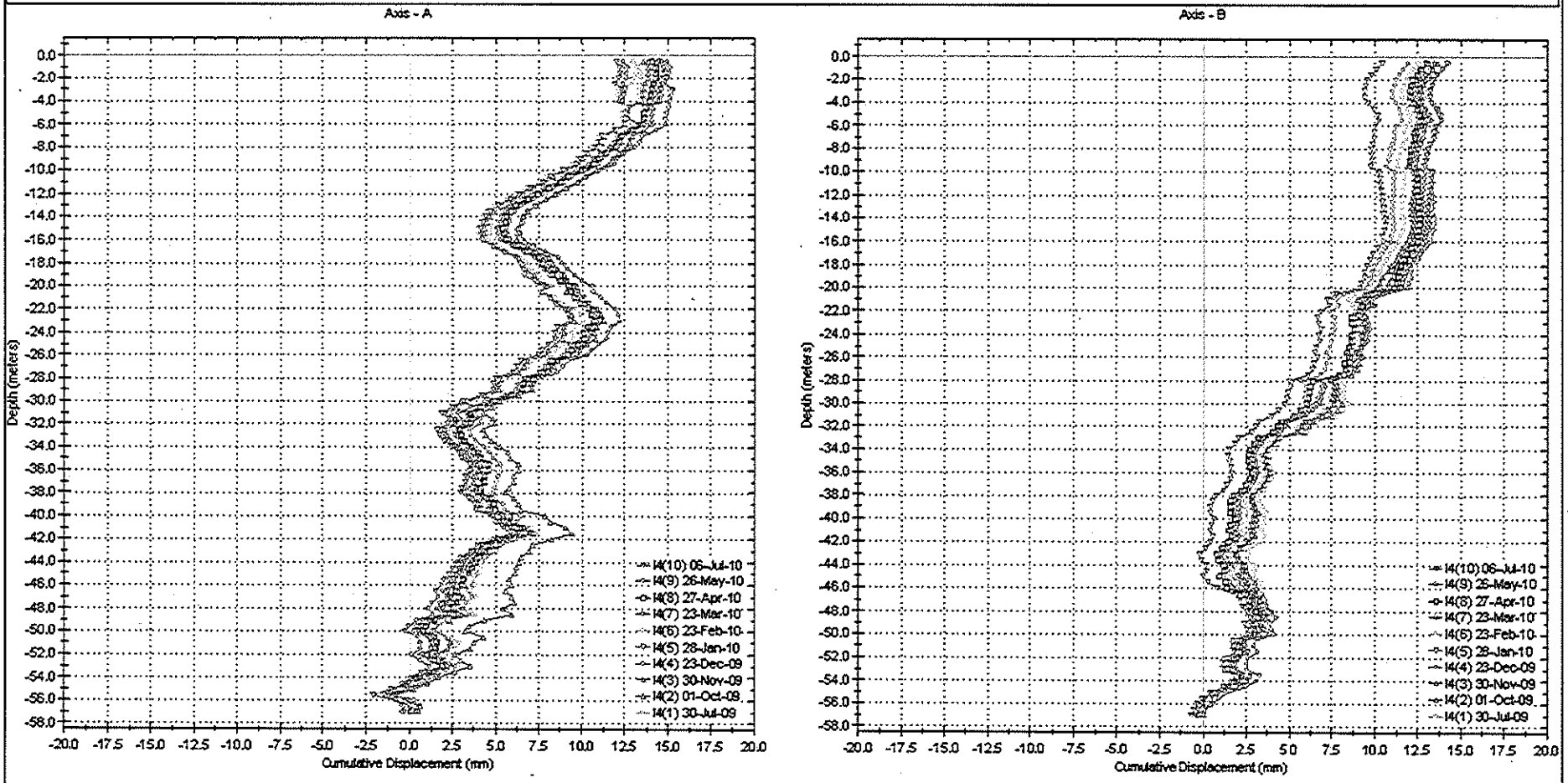
RST Instruments Ltd.

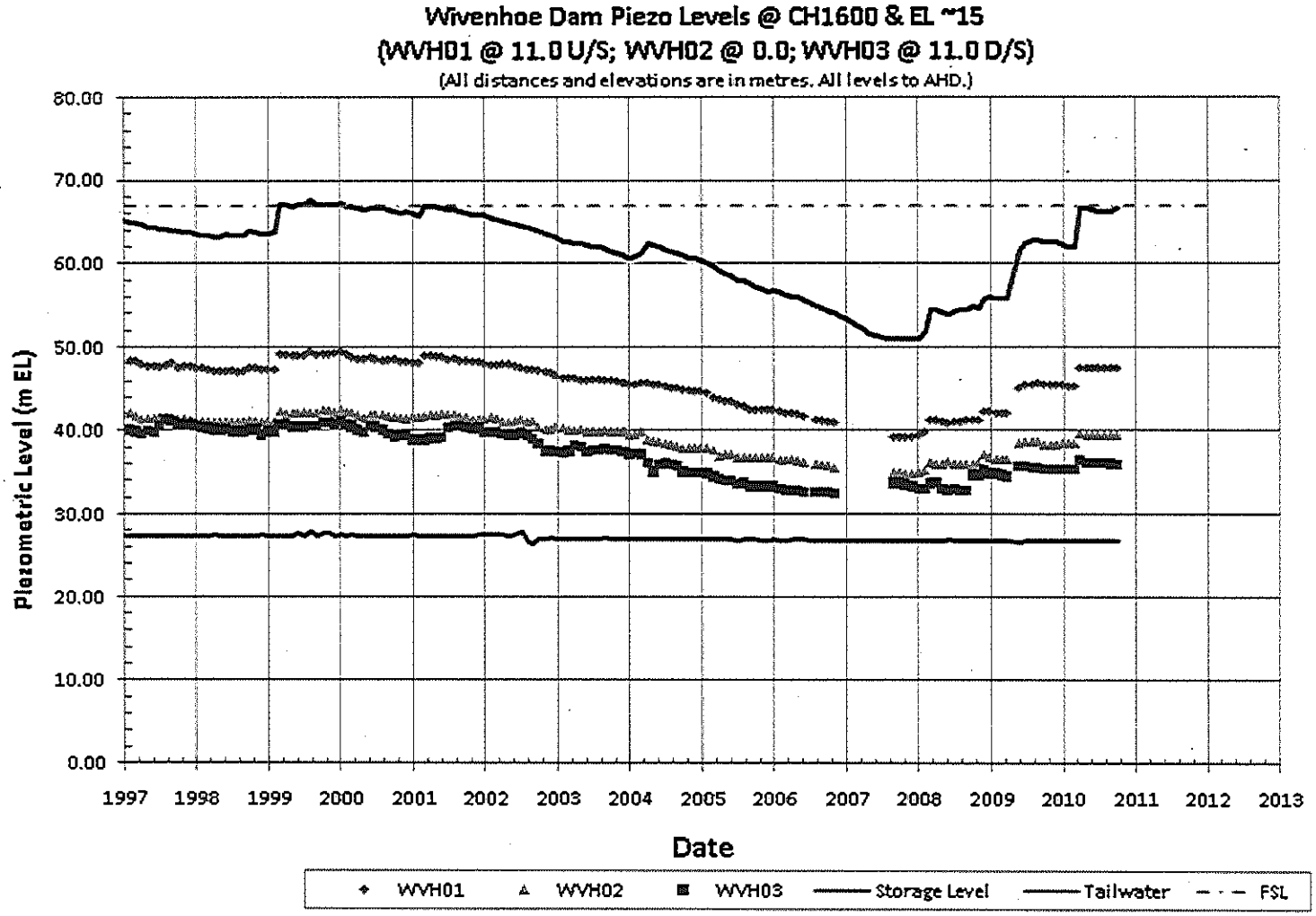
CUMULATIVE DISPLACEMENT

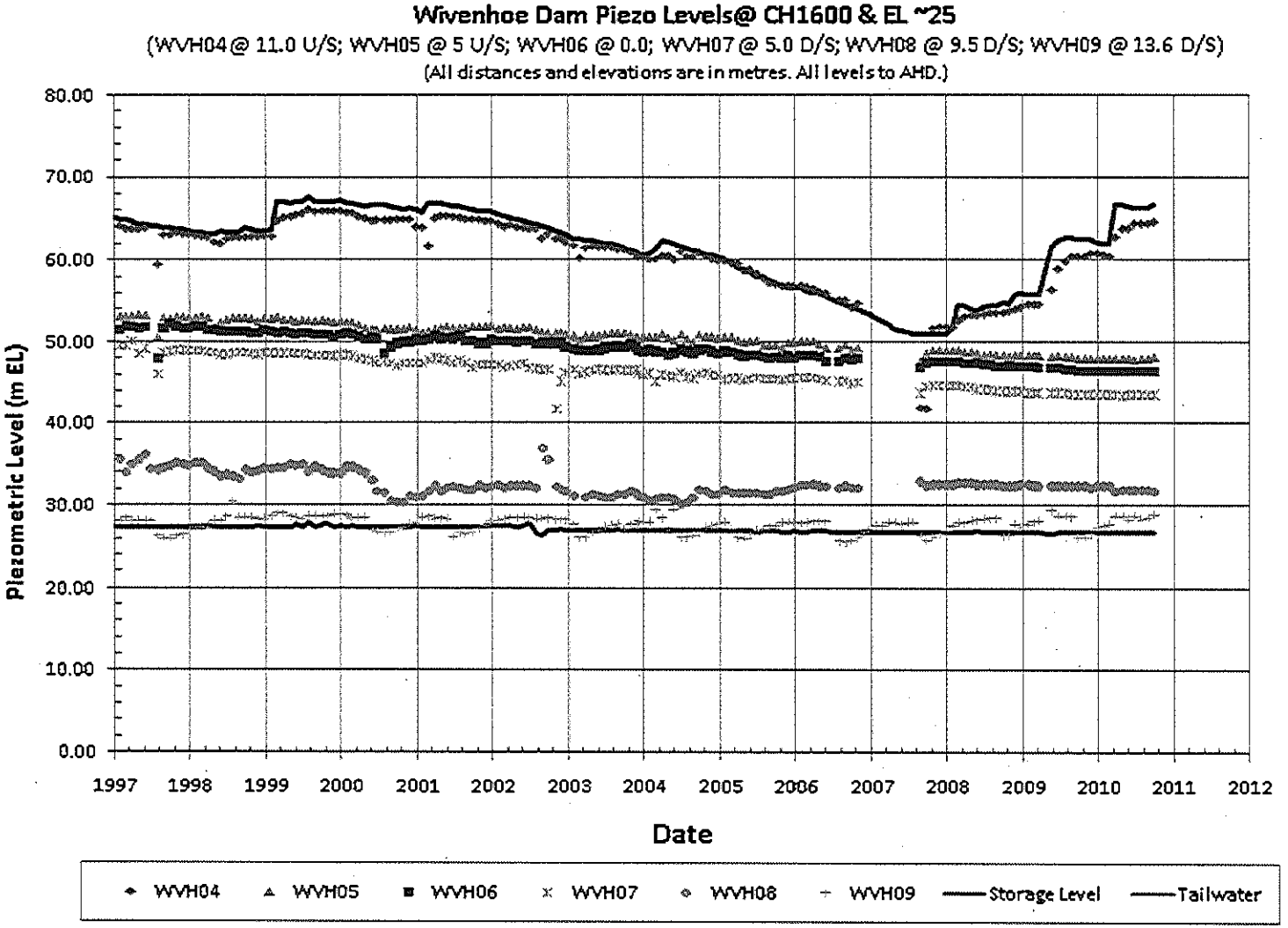
Inclinalysis v.2.35

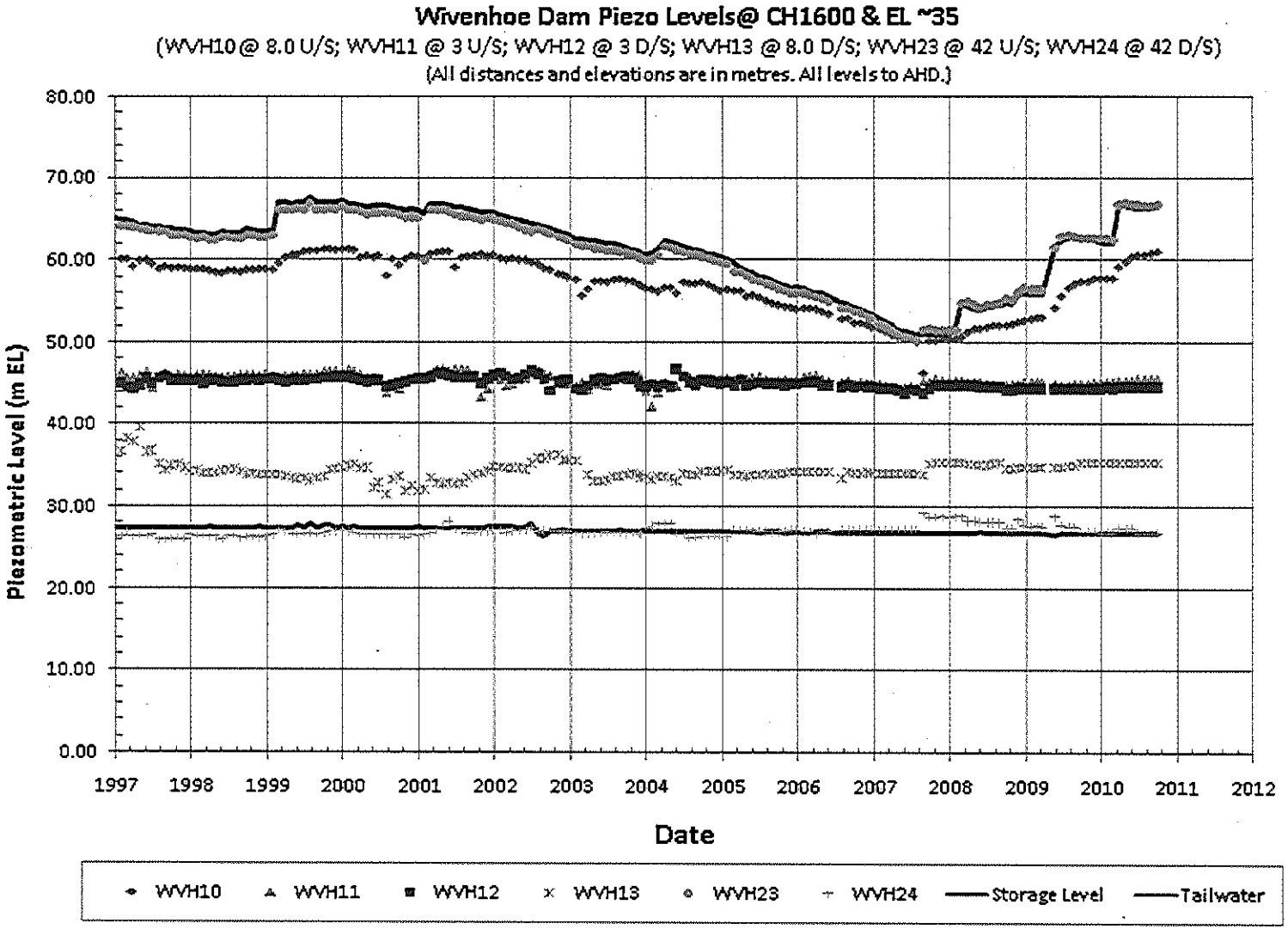
Borehole : I4
Project : Wivenhoe
Location :
Northing :
Easting :
Collar :

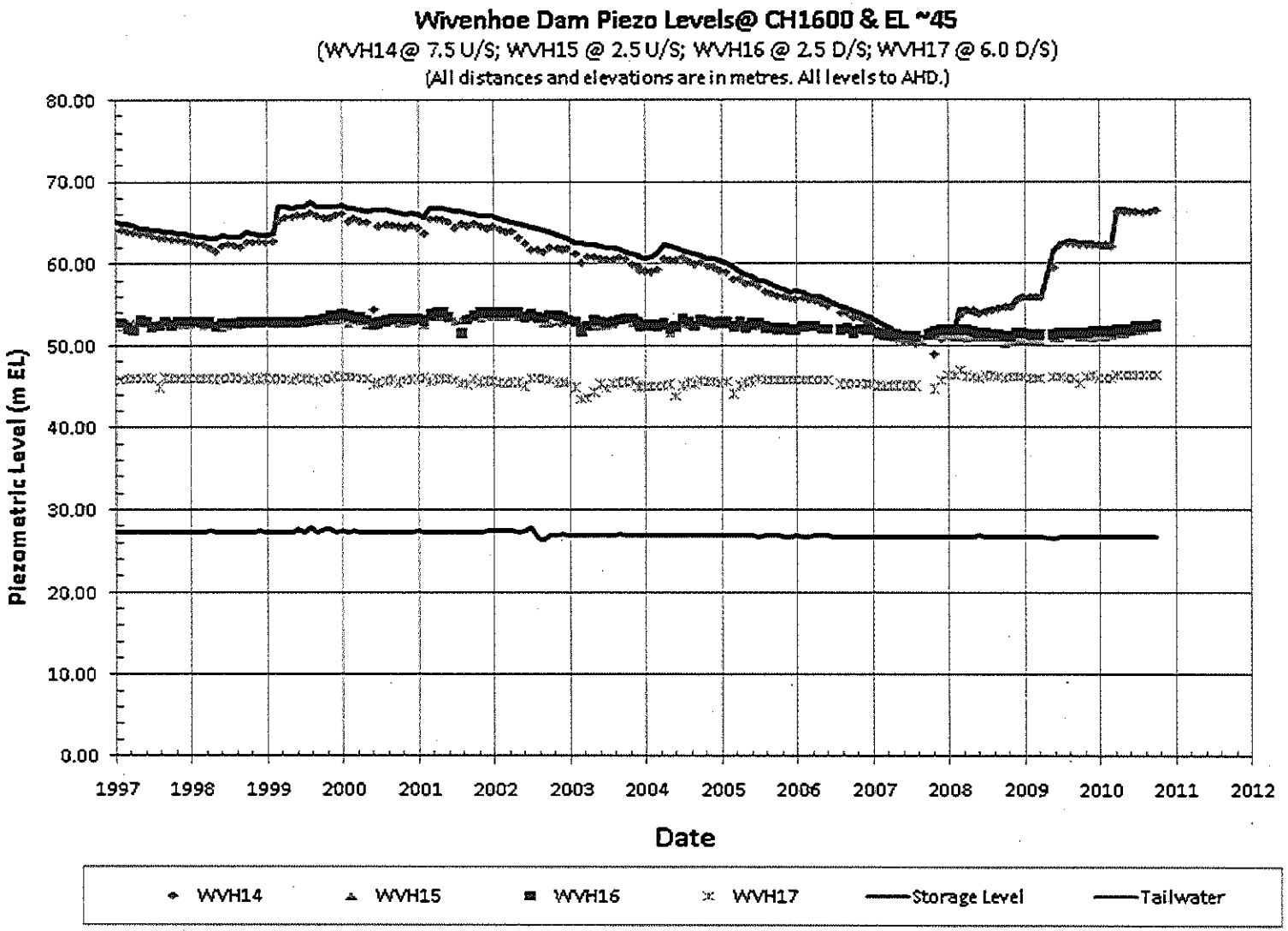
Spiral Correction : N/A
Collar Elevation : 0.0 meters
Borehole Total Depth : 57.0 meters
North Groove Azimuth :
Base Reading : 1990 Jan 09 11:01
Axis A Azimuth : 0.0 degrees

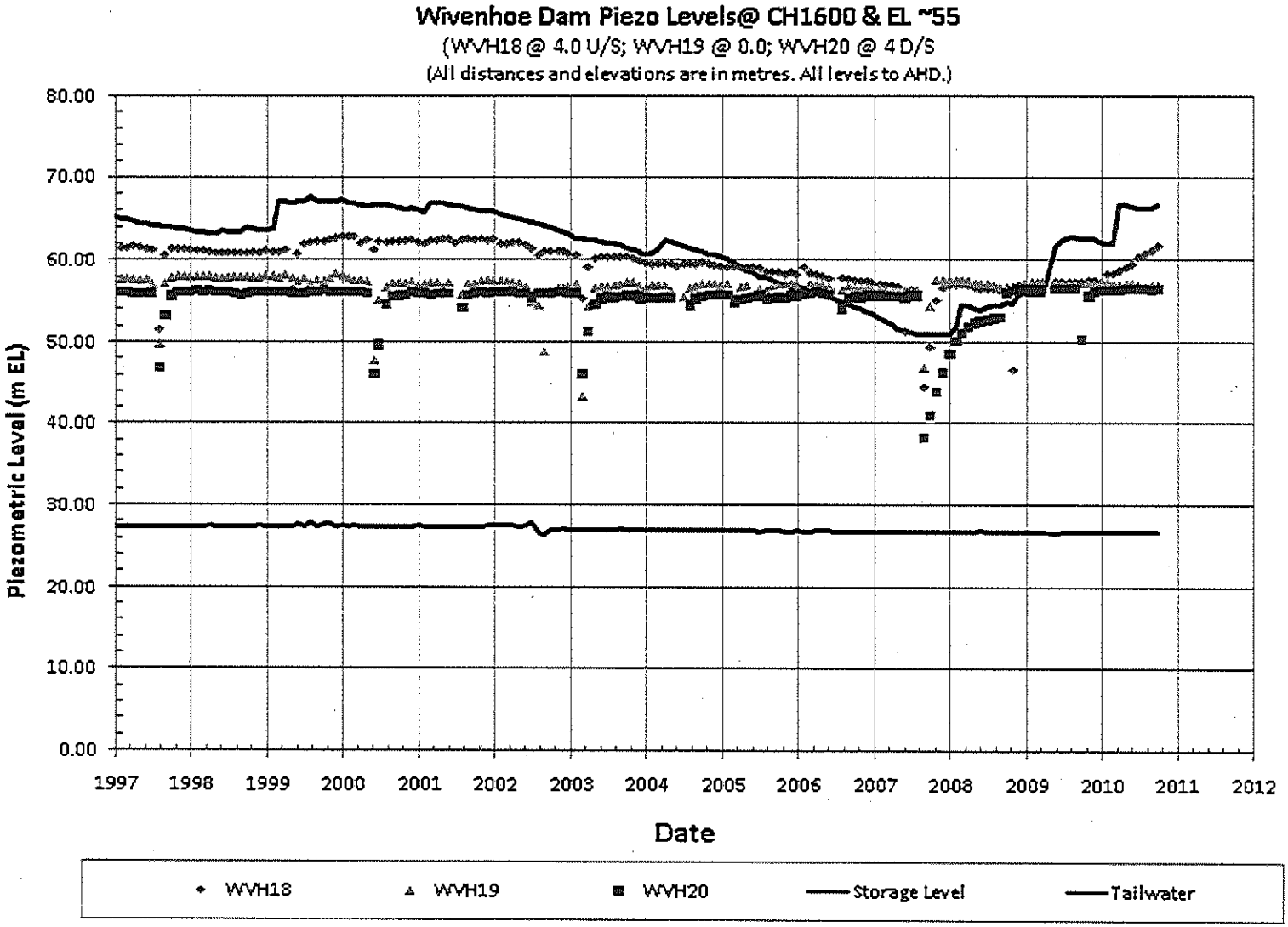


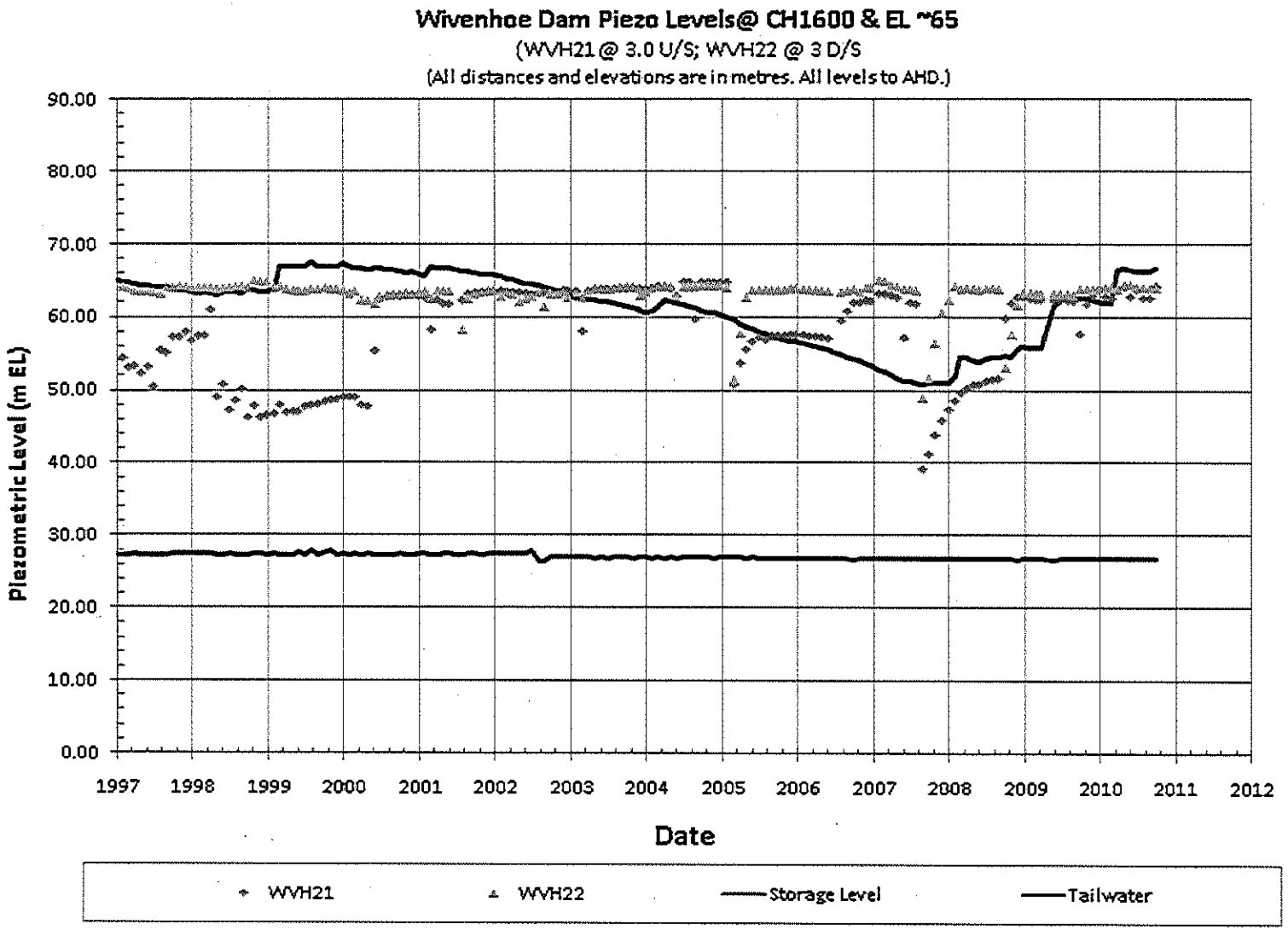

Wivenhoe Dam Piezo Levels @ CH1600 & EL ~15
(WVH01 @ 11.0 U/S; WVH02 @ 0.0; WVH03 @ 11.0 D/S)
(All distances and elevations are in metres. All levels to AHD.)
Piezometric Level (m EL)
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
Date
WVH01
WVH02
WVH03
Storage Level
Tailwater
FSL


Wivenhoe Dam Piezo Levels@ CH1600 & EL ~25
(WVH04 @ 11.0 U/S; WVH05 @ 5 U/S; WVH06 @ 0.0; WVH07 @ 5.0 D/S; WVH08 @ 9.5 D/S; WVH09 @ 13.6 D/S)
(All distances and elevations are in metres. All levels to AHD.)
Piezometric Level (m EL)
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
Date
WVH04
WVH05
WVH06
WVH07
WVH08
WVH09
Storage Level
Tailwater


Wivenhoe Dam Piezo Levels@ CH1600 & EL ~35
(WVH10 @ 8.0 U/S; WVH11 @ 3 U/S; WVH12 @ 3 D/S; WVH13 @ 8.0 D/S; WVH23 @ 42 U/S; WVH24 @ 42 D/S)
(All distances and elevations are in metres. All levels to AHD.)
Piezometric Level (m EL)
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
Date
WVH10
WVH11
WVH12
WVH13
WVH23
WVH24
Storage Level
Tailwater


Wivenhoe Dam Piezo Levels@ CH1600 & EL ~45
(WVH14 @ 7.5 U/S; WVH15 @ 2.5 U/S; WVH16 @ 2.5 D/S; WVH17 @ 6.0 D/S)
(All distances and elevations are in metres. All levels to AHD.)
Piezometric Level (m EL)
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
Date
WVH14
WVH15
WVH16
WVH17
Storage Level
Tailwater


Wivenhoe Dam Piezo Levels@ CH1600 & EL ~55
(WVH18 @ 4.0 U/S; WVH19 @ 0.0; WVH20 @ 4 D/S
(All distances and elevations are in metres. All levels to AHD.)
Piezometric Level (m EL)
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
Date
WVH18
WVH19
WVH20
Storage Level
Tailwater


Wivenhoe Dam Piezo Levels@ CH1600 & EL ~65
(WVH21 @ 3.0 U/S; WVH22 @ 3 D/S
(All distances and elevations are in metres. All levels to AHD.)
Piezometric Level (m EL)
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
1997
1998
1999
2000
2001
2002
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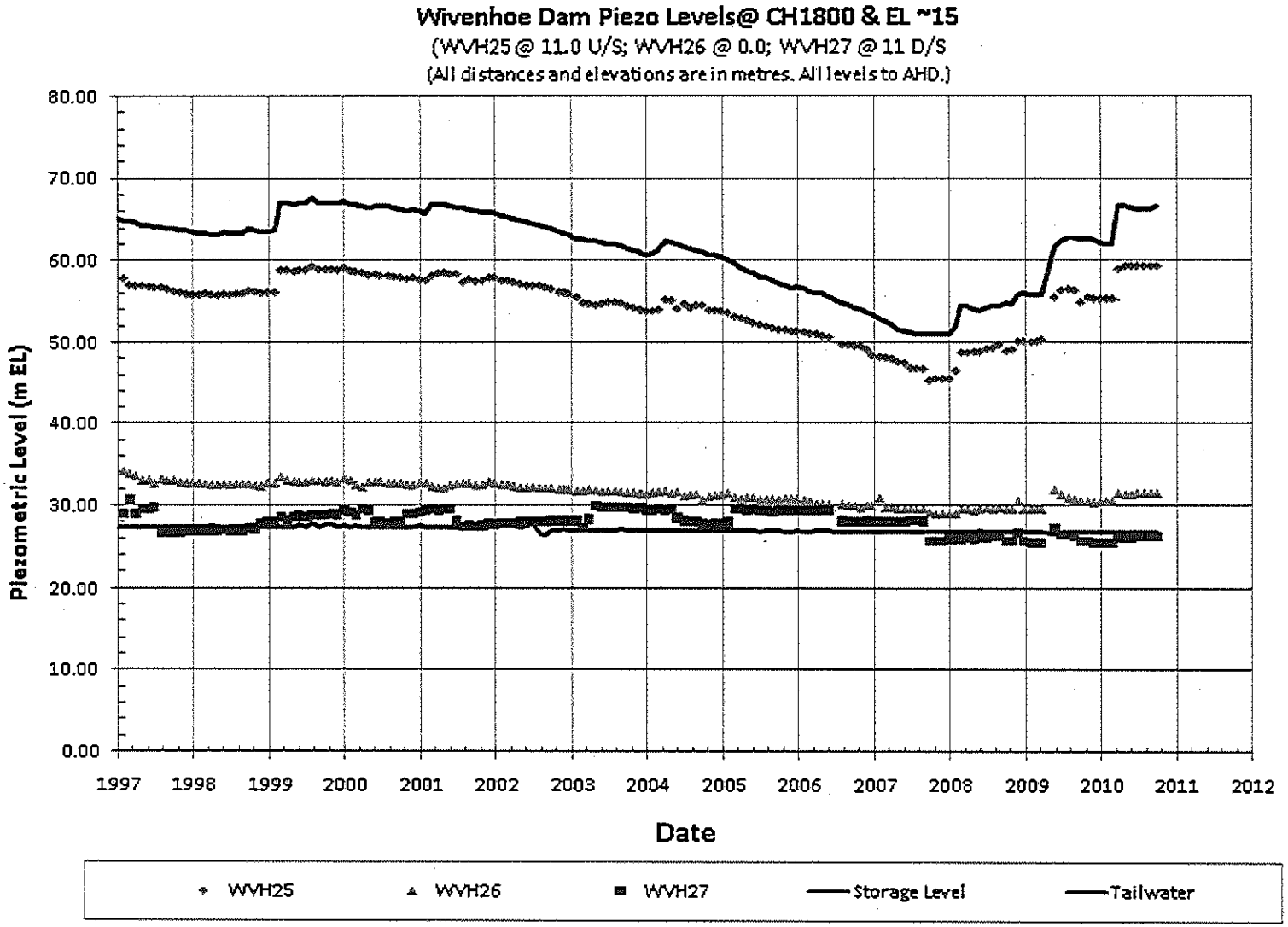
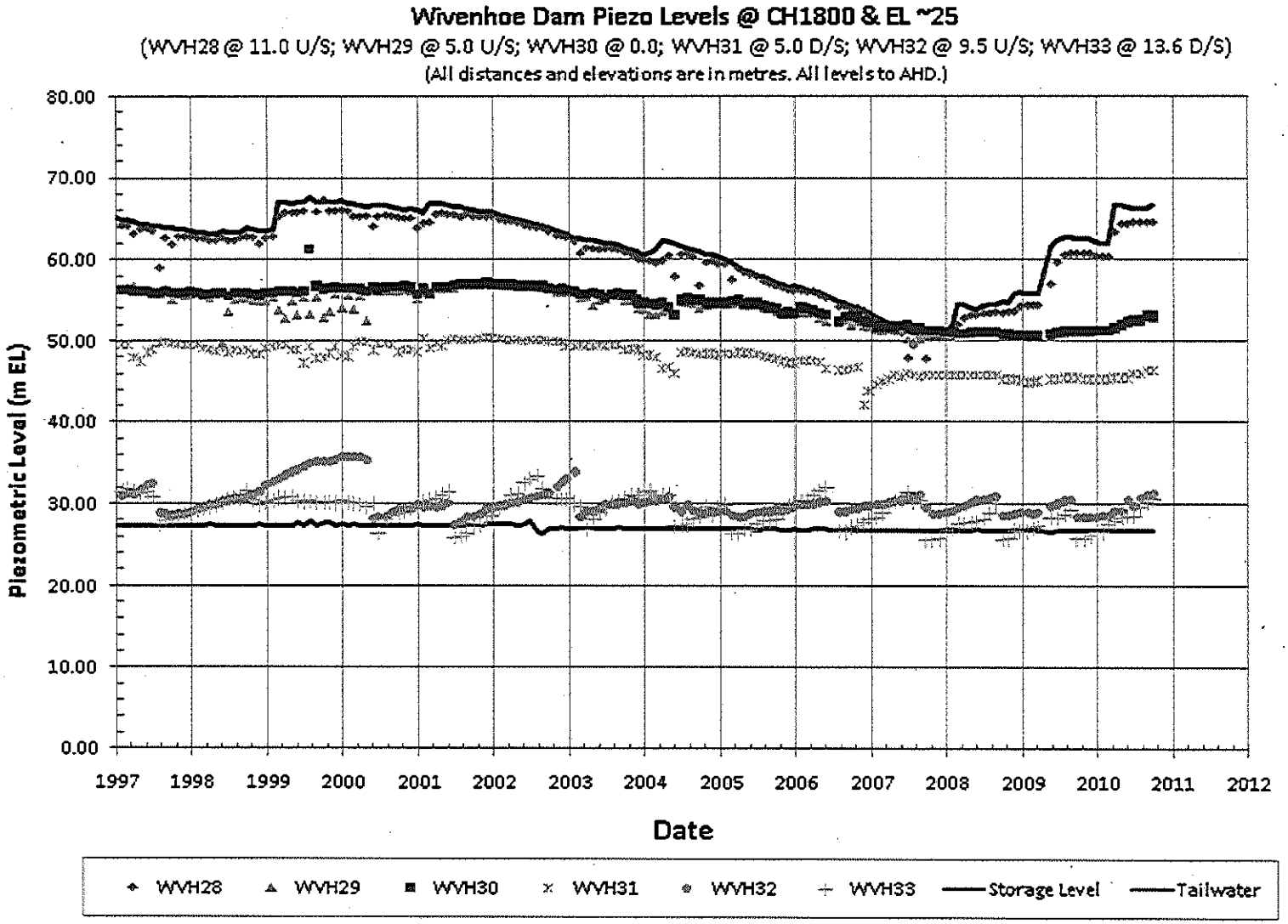
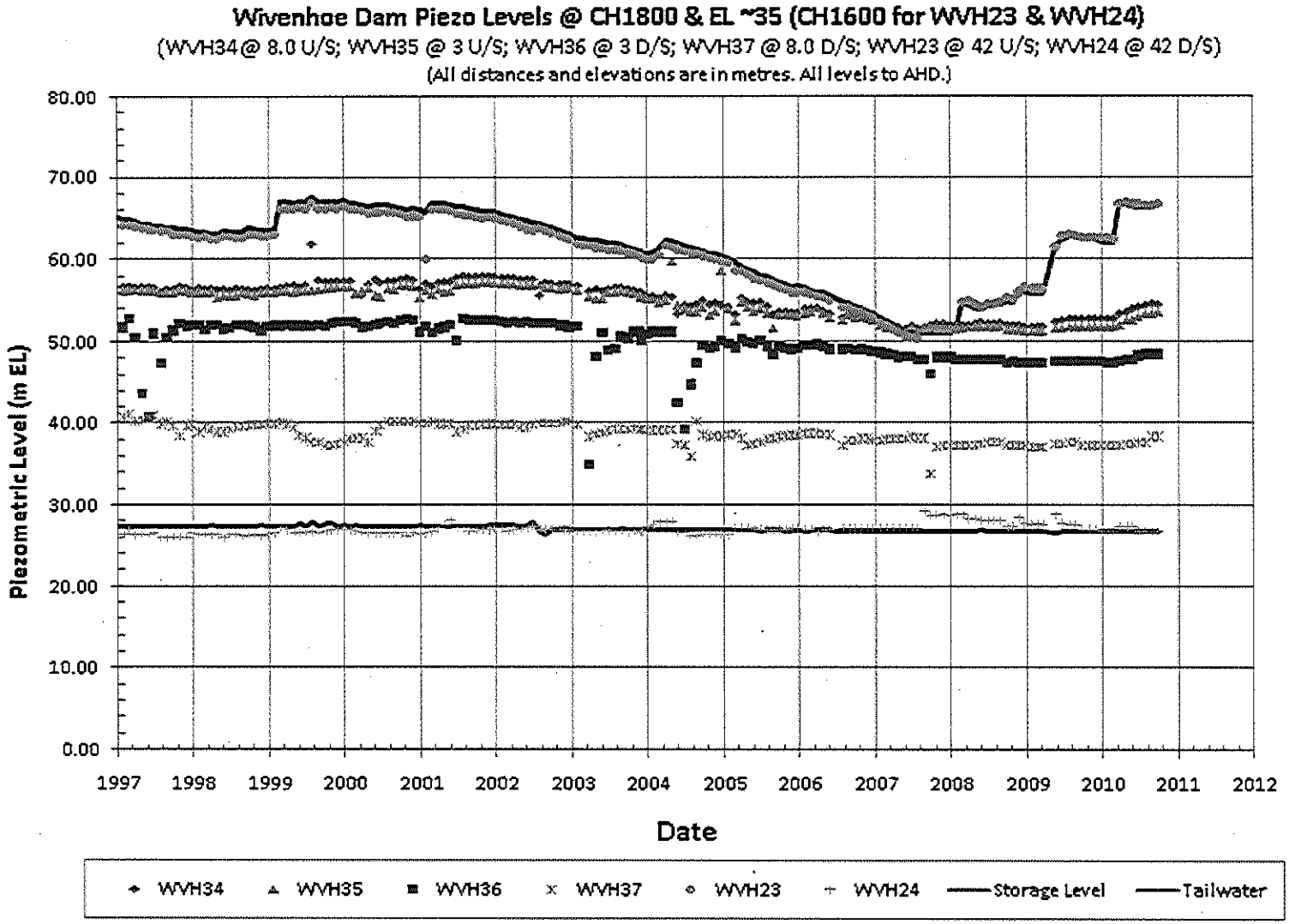
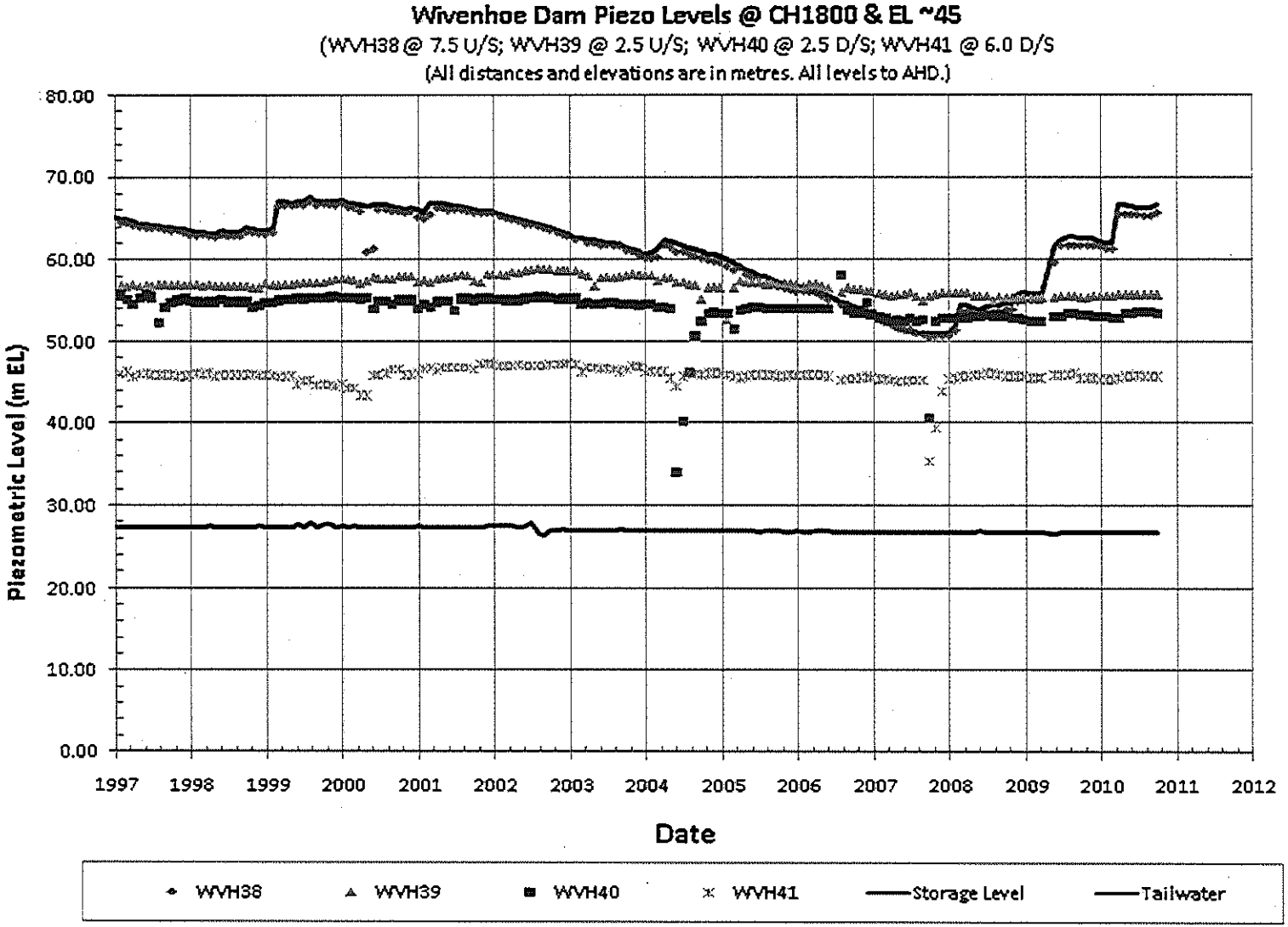
2004
2005
2006
2007
2008
2009
2010
2011
2012
Date
WVH21
WVH22
Storage Level
Tailwater


Wivenhoe Dam Piezo Levels@ CH1800 & EL ~15
(WVH25 @ 11.0 U/S; WVH26 @ 0.0; WVH27 @ 11 D/S
(All distances and elevations are in metres. All levels to AHD.)
Piezometric Level (m EL)
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
Date
WVH25
WVH26
WVH27
Storage Level
Tailwater


Wivenhoe Dam Piezo Levels @ CH1800 & EL ~25
(WVH28 @ 11.0 U/S; WVH29 @ 5.0 U/S; WVH30 @ 0.0; WVH31 @ 5.0 D/S; WVH32 @ 9.5 U/S; WVH33 @ 13.6 D/S)
(All distances and elevations are in metres. All levels to AHD.)
Piezometric Level (m EL)
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
Date
WVH28
WVH29
WVH30
WVH31
WVH32
WVH33
Storage Level
Tailwater


Wivenhoe Dam Piezo Levels @ CH1800 & EL ~35 (CH1600 for WVH23 & WVH24)
(WVH34 @ 8.0 U/S; WVH35 @ 3 U/S; WVH36 @ 3 D/S; WVH37 @ 8.0 D/S; WVH23 @ 42 U/S; WVH24 @ 42 D/S)
(All distances and elevations are in metres. All levels to AHD.)
Piezometric Level (m EL)
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
Date
WVH34
WVH35
WVH36
WVH37
WVH23
WVH24
Storage Level
Tailwater


Wivenhoe Dam Piezo Levels @ CH1800 & EL ~45
(WVH38 @ 7.5 U/S; WVH39 @ 2.5 U/S; WVH40 @ 2.5 D/S; WVH41 @ 6.0 D/S
(All distances and elevations are in metres. All levels to AHD.)
Piezometric Level (m EL)
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
1997
1998
1999
2000
2001
2002
2003
2004
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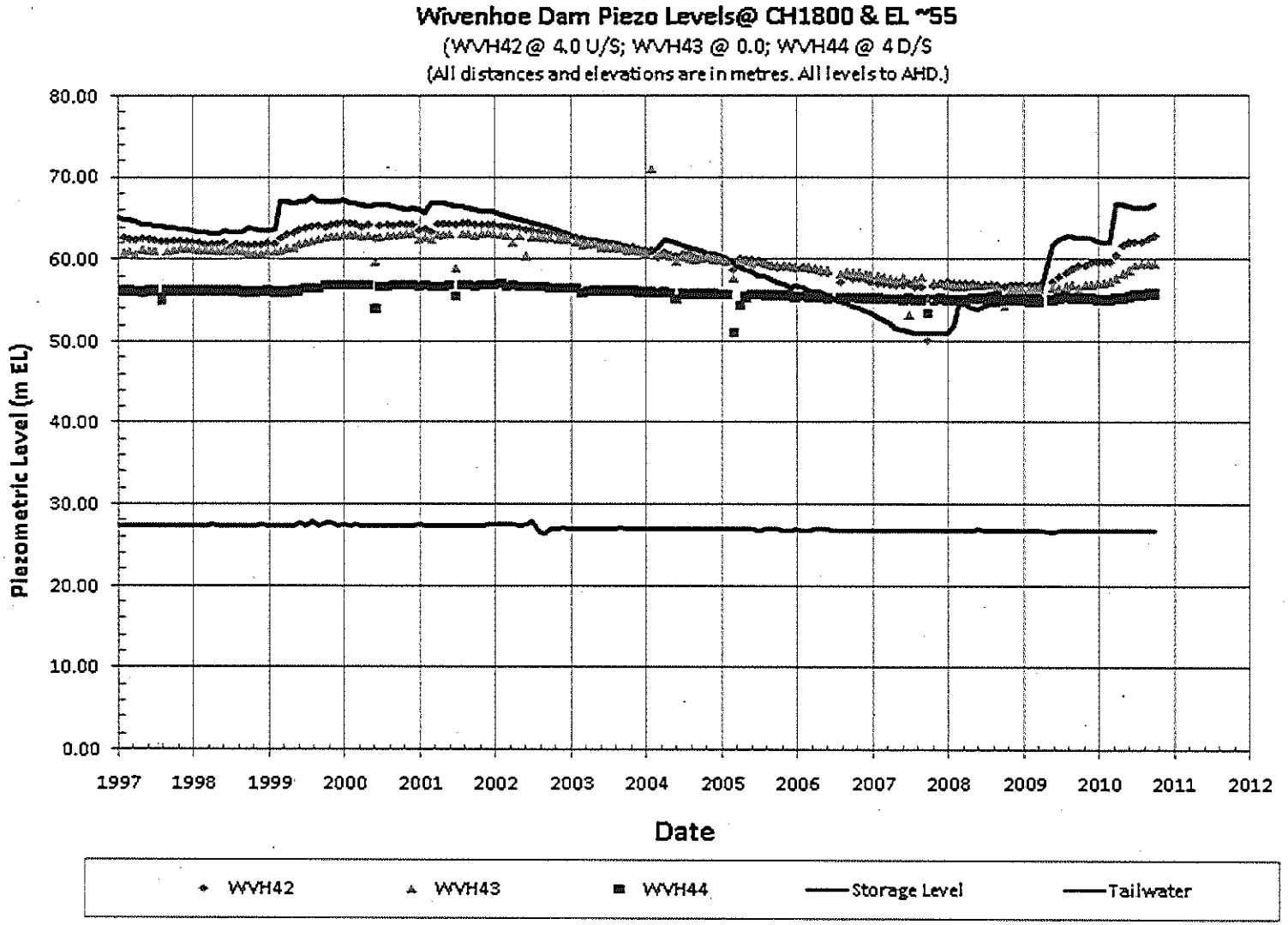
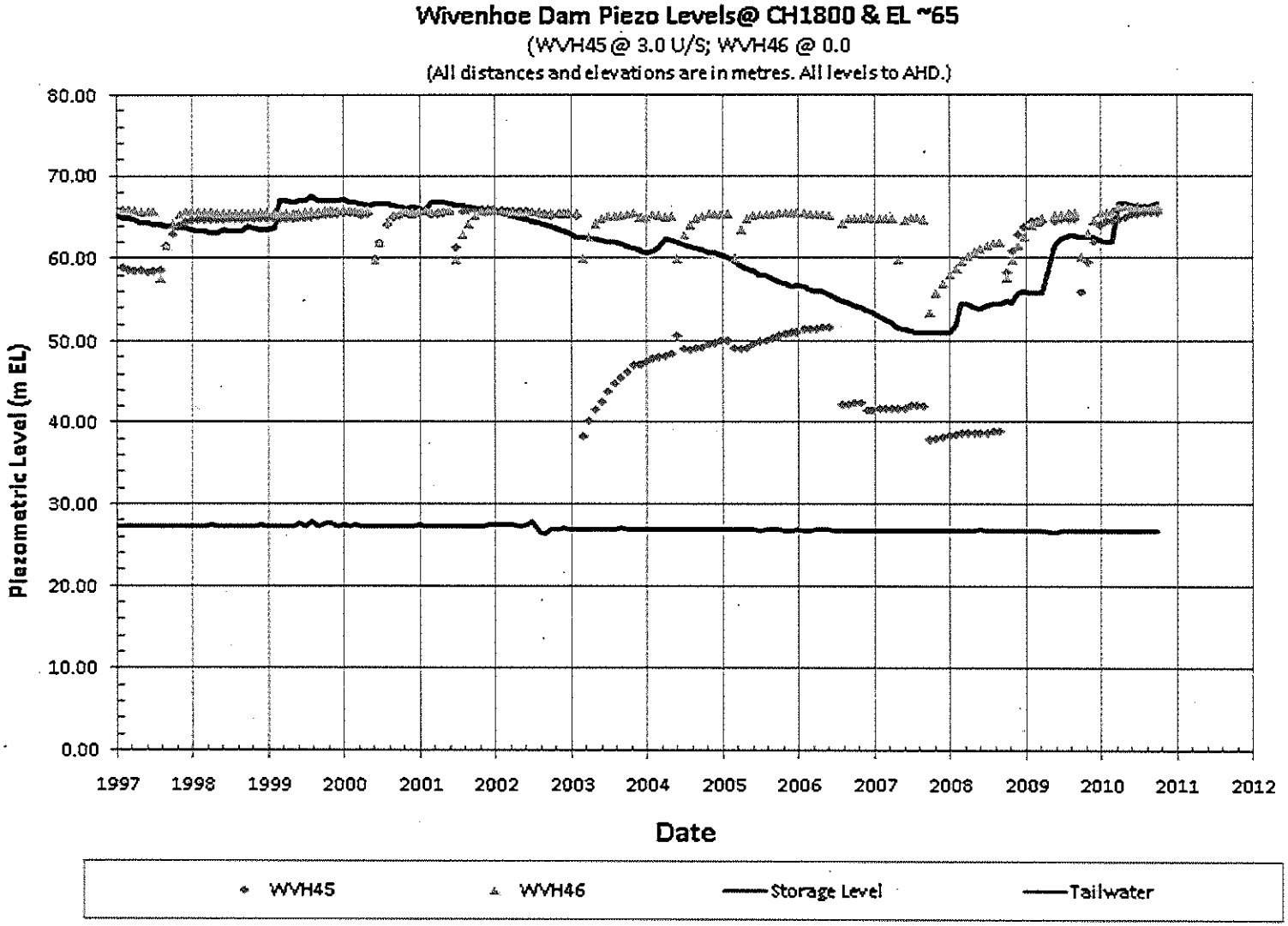
2006
2007
2008
2009
2010
2011
2012
Date
WVH38
WVH39
WVH40
WVH41
Storage Level
Tailwater


Wivenhoe Dam Piezo Levels@ CH1800 & EL ~55
(WVH42 @ 4.0 U/S; WVH43 @ 0.0; WVH44 @ 4 D/S
(All distances and elevations are in metres. All levels to AHD.)
Piezometric Level (m EL)
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
Date
WVH42
WVH43
WVH44
Storage Level
Tailwater


Wivenhoe Dam Piezo Levels@ CH1800 & EL ~65
(WVH45 @ 3.0 U/S; WVH46 @ 0.0
(All distances and elevations are in metres. All levels to AHD.)
Piezometric Level (m EL)
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
1997
1998
1999
2000
2001
2002
2003
2004
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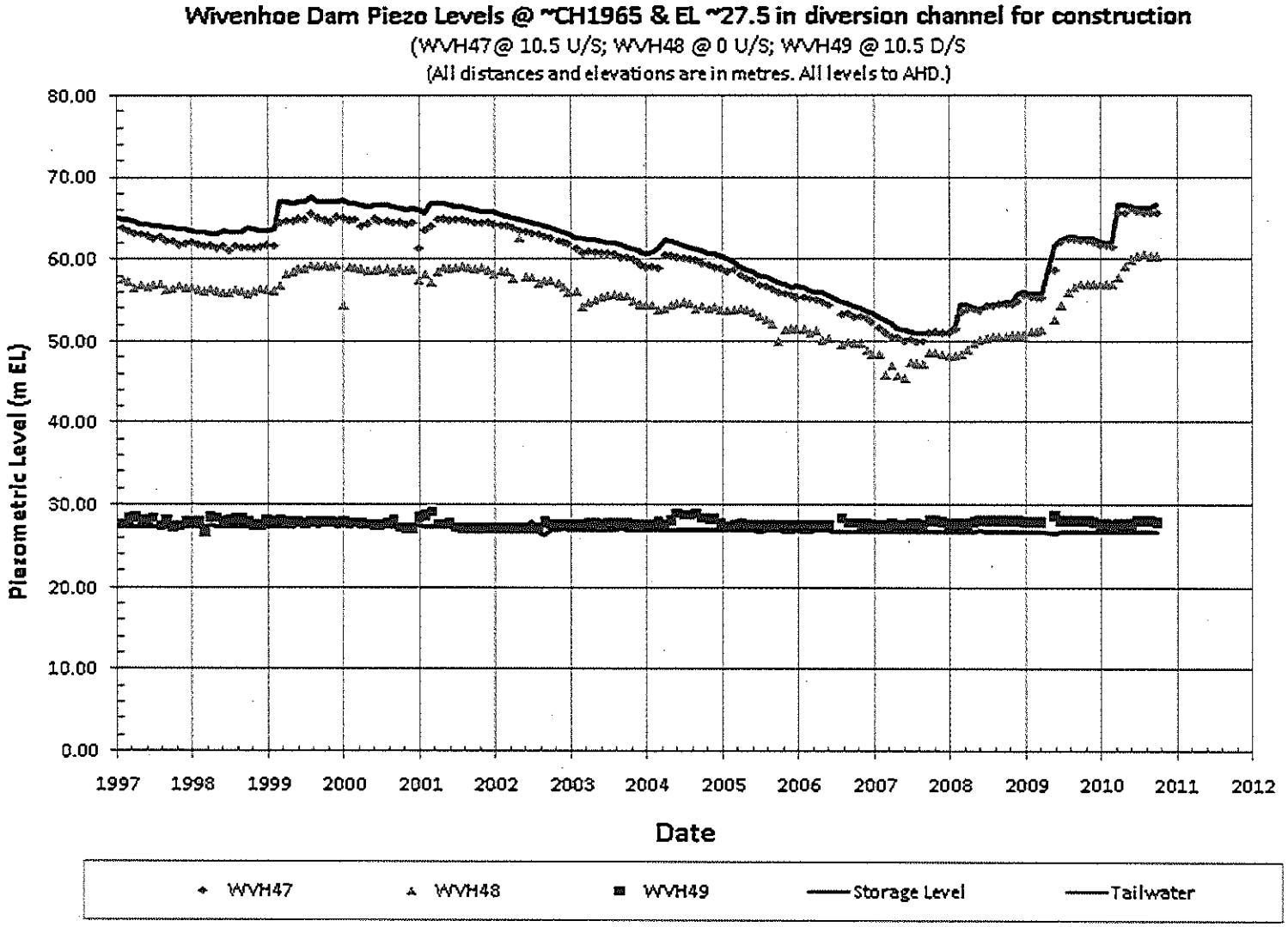
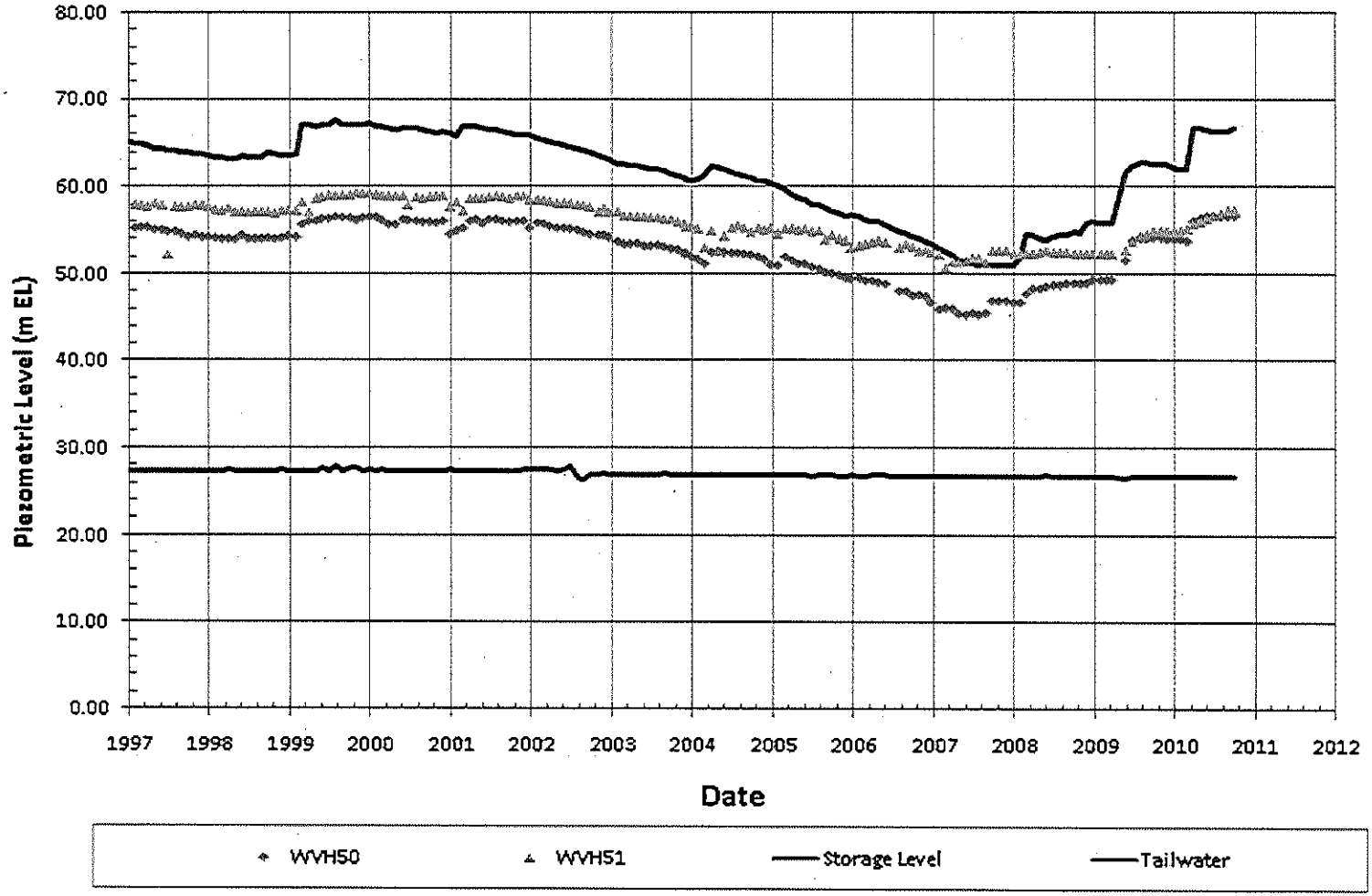
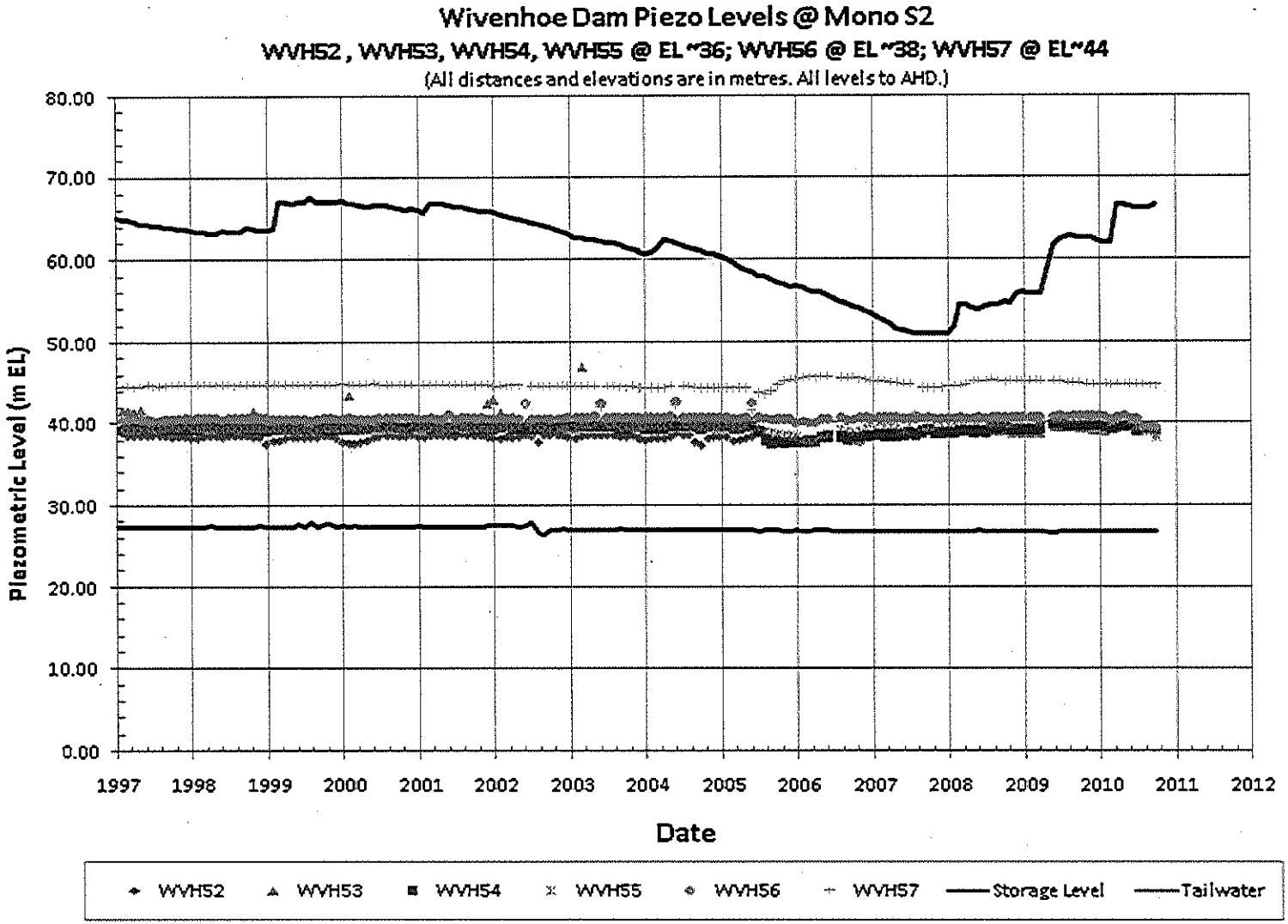
2006
2007
2008
2009
2010
2011
2012
Date
WVH45
WVH46
Storage Level
Tailwater


Wivenhoe Dam Piezo Levels @ ~CH1965 & EL ~27.5 in diversion channel for construction
(WVH47 @ 10.5 U/S; WVH48 @ 0 U/S; WVH49 @ 10.5 D/S
(All distances and elevations are in metres. All levels to AHD.)
Piezometric Level (m EL)
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
Date
WVH47
WVH48
WVH49
Storage Level
Tailwater

Wivenhoe Dam Piezo Levels WVH50 and WVH51 in diversion channel for construction

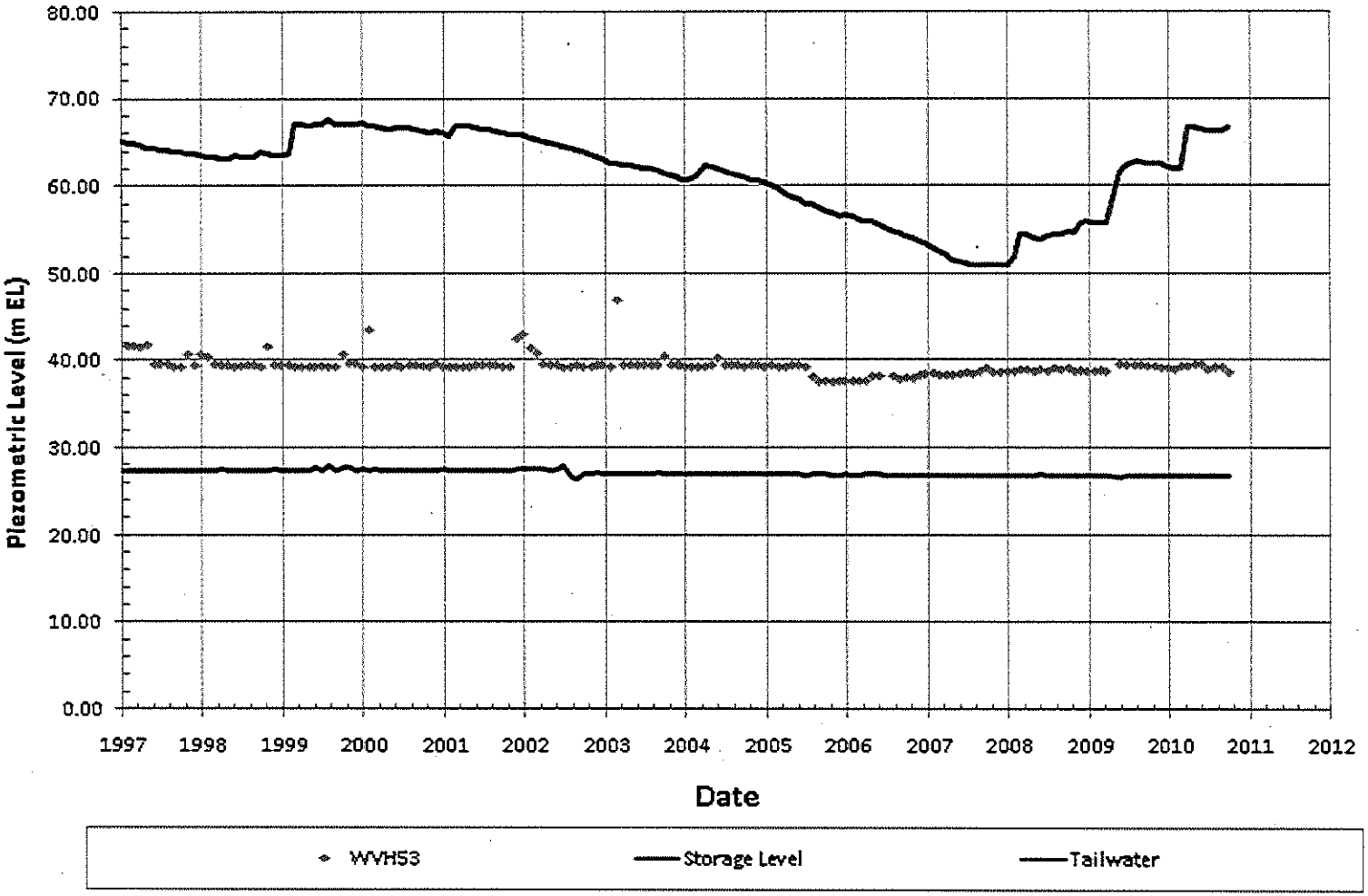
(All distances and elevations are in metres. All levels to AHD.)

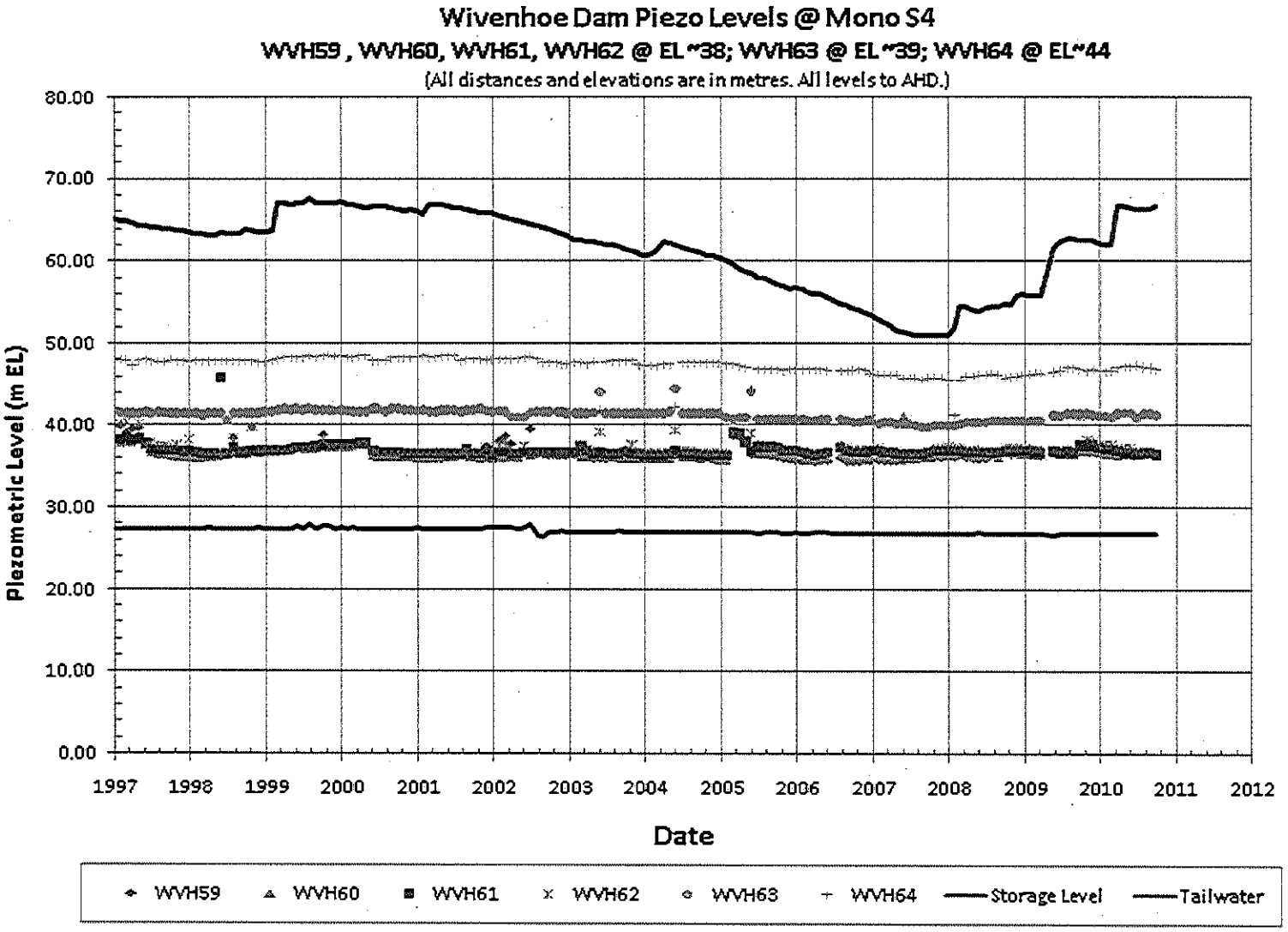



Wivenhoe Dam Piezo Levels @ Mono S2
WVH52 , WVH53, WVH54, WVH55 @ EL~36; WVH56 @ EL~38; WVH57 @ EL~44
(All distances and elevations are in metres. All levels to AHD.)
Piezometric Level (m EL)
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
Date
WVH52
WVH53
WVH54
WVH55
WVH56
WVH57
Storage Level
Tailwater

Wivenhoe Dam Piezo Levels at Mono S3 - WVH58 @ EL ~ 37

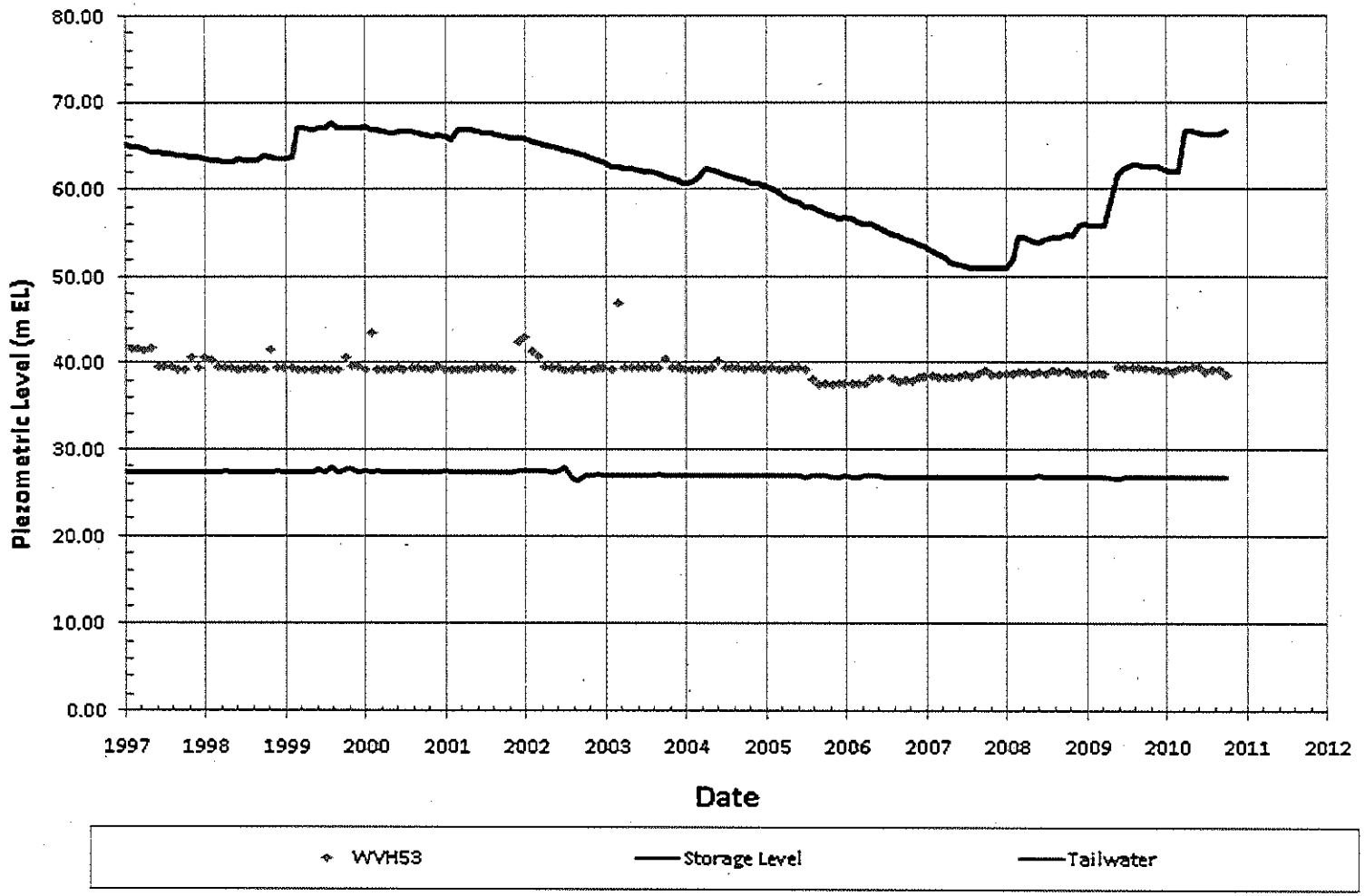
(All distances and elevations are in metres. All levels to AHD.)



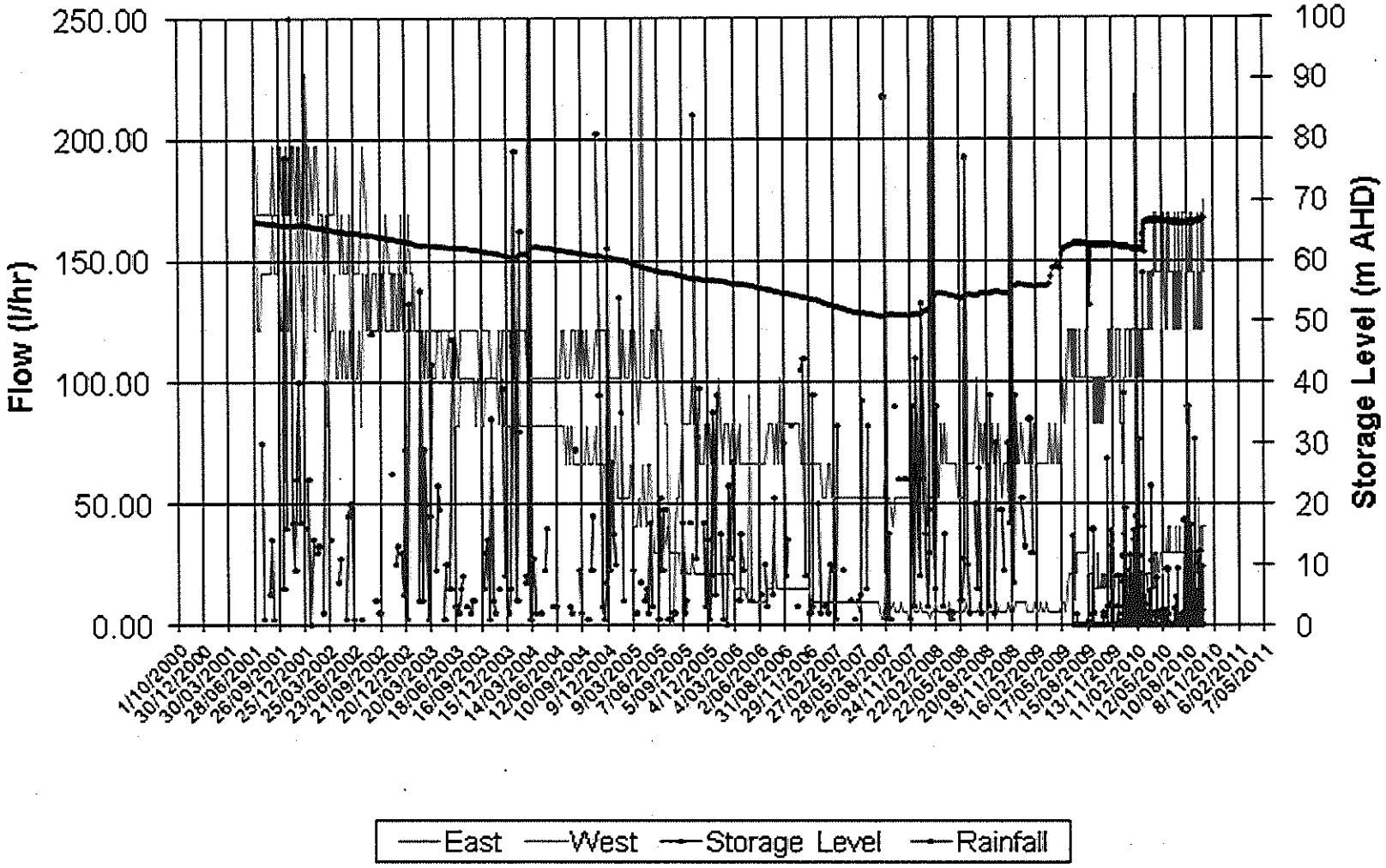

Wivenhoe Dam Piezo Levels @ Mono S4
WVH59 , WVH60, WVH61, WVH62 @ EL~38; WVH63 @ EL~39; WVH64 @ EL~44
(All distances and elevations are in metres. All levels to AHD.)
Plezometric Level (m EL)
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
Date
WVH59
WVH60
WVH61
WVH62
WVH63
WVH64
Storage Level
Tailwater

Wivenhoe Dam Piezo Levels at Mono S5 - WVH65 @ EL ~39

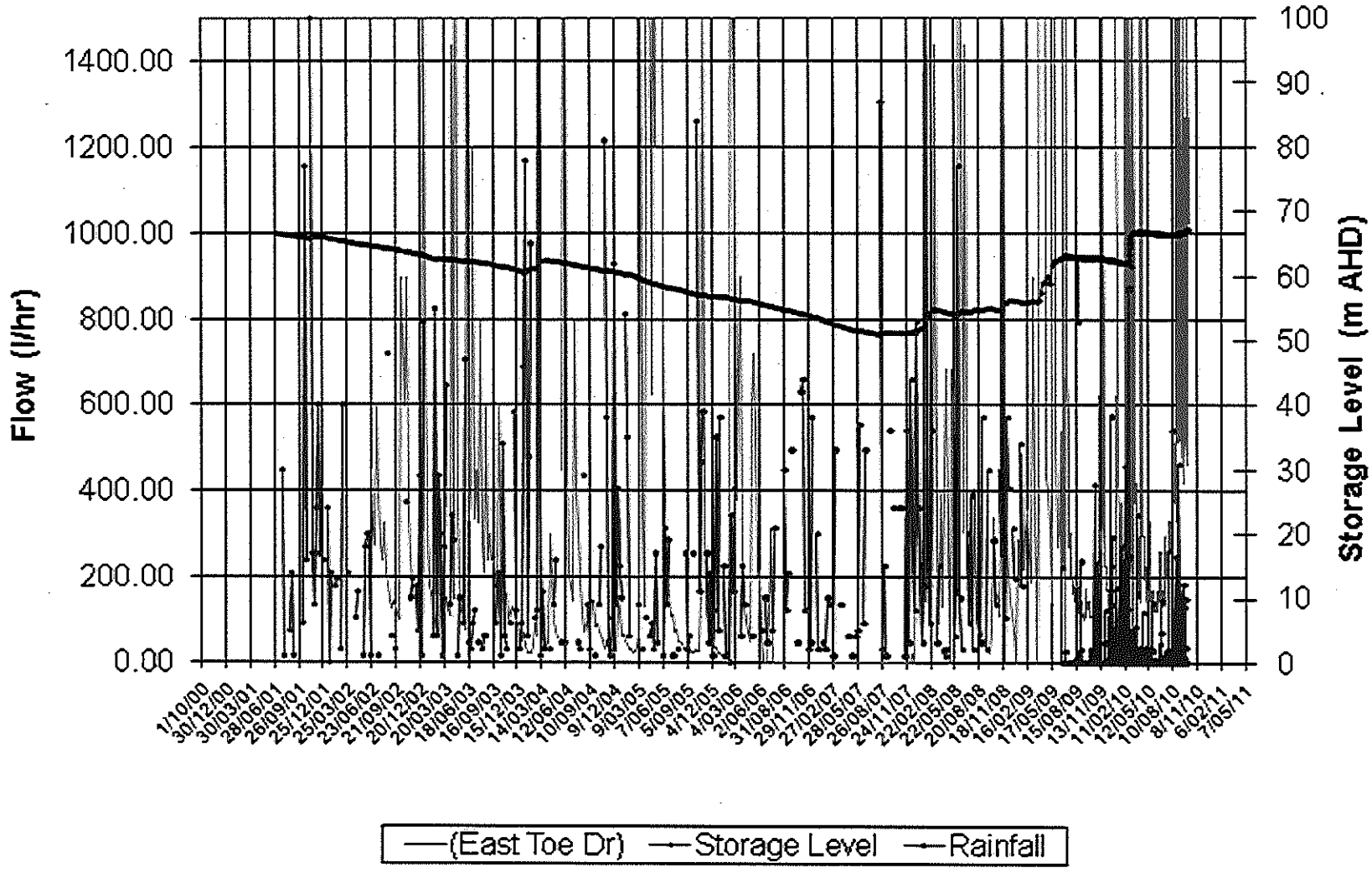
(All distances and elevations are in metres. All levels to AHD.)



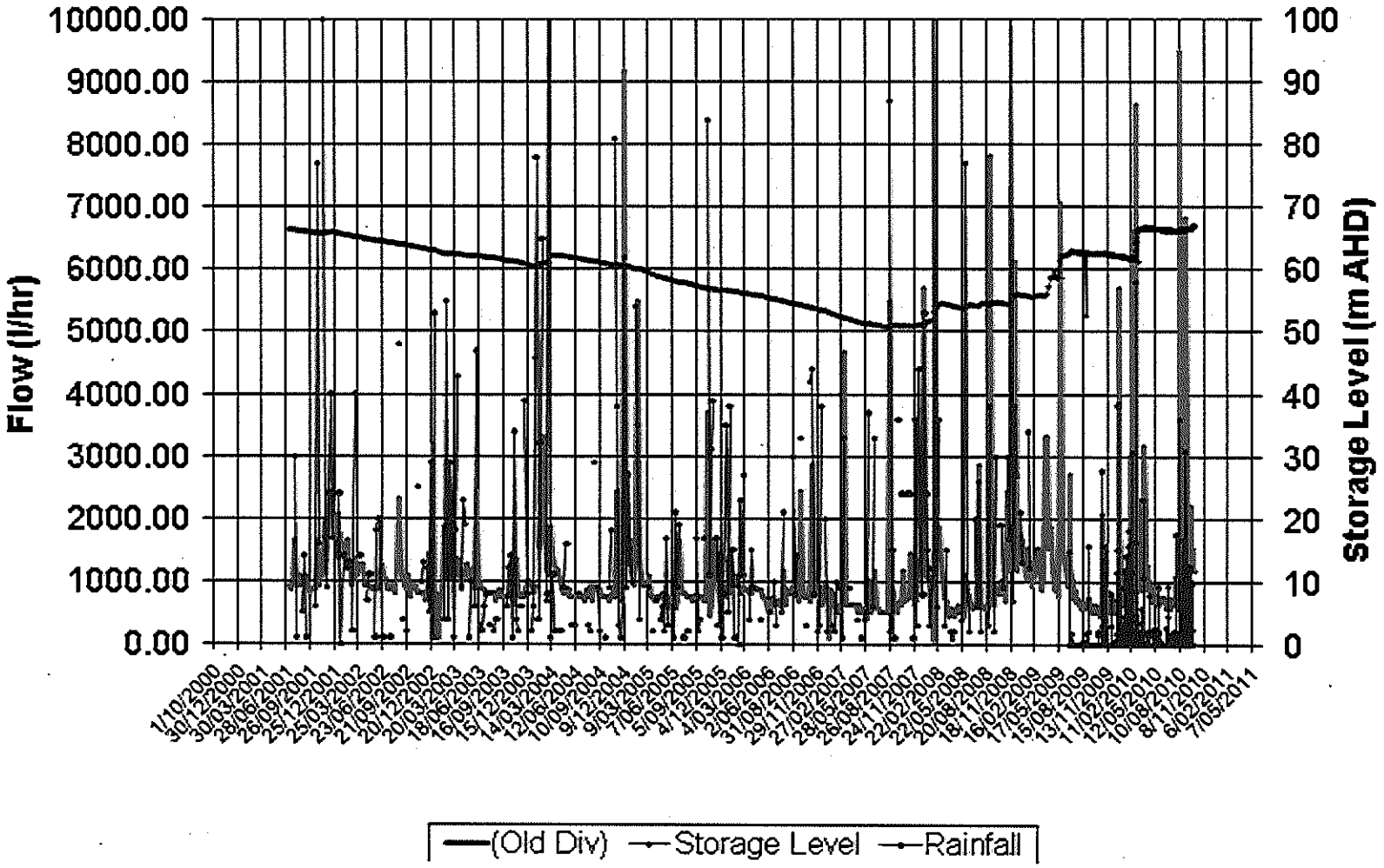
Wivenhoe Leakage - Gallery Weirs



Wivenhoe Leakage - LHS Embankment



Wivenhoe Leakage - RHS Embankment Old Diversion Channel



APPENDIX C HYDRAULIC SYSTEM ASSESSMENT

WIVENHOE DAM HYDRAULIC SYSTEMS REPORT

Complied by:

Queensland Hydraulics Pty Ltd

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PO Box 379 Salisbury QLD 4107

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CONTENTS:

OVERVIEW

The maintenance and testing regime currently in place is sound and should, through regular oil sampling and testing, give adequate warning of any impending equipment failures.

From the information supplied it would be a reasonable to assume that neither unit has run more than 1000 hours including original shop testing and commissioning. These low hours along with the good maintenance and testing procedures should rule out any equipment failure due to wear, fatigue or contamination.

There are several points we believe should be included in the inspection and testing procedures to increase the likelihood of early detection of potential problems. These points are referred to in the recommendations below.

An inherent design problem was identified in that the case drain line, from the motors, drains back to tank over a period of time when the units are not in operation. Some suggestions to improve or eradicate this problem are listed in the recommendations.

SYSTEM EQUIPMENT

Common Equipment and Components in the system such as O-Rings and seals.

The major cause of failures we would anticipate, and as has been experienced, would be form elastomeric components.

These components range from ORings seals in the tube connections, valve flanges, valve internal seal and almost any other component subjected to pressure, also pump and motor rotary shaft seals, flange gaskets, brake actuator seals, accumulator bladders and motor/pump coupling rubbers and others.

The cost of the ORing and shaft seals is small however the labour required to replace them would be prohibitive. The consequence of these seals starting to fail is generally a minor leak which we believe should be addressed on a needs basis. This should maintain the integrity of the system if the problem is addressed punctually.

Accumulators fall under the pressure vessel legislation and as such need to be inspected on a regular basis. Please find attached a section of AS/NZS 3788:2001 with the relevant inspection frequency highlighted in red. It is likely that normal bladder failure in the accumulators would require the bladders to be replaced more frequently than the inspection period for the accumulator shell. This would be the logical time to have the inspection completed.

Pump/Motor couplings should be inspected on a regular basis, no less than every two years.

Pumps. Our investigations could not find any current supplier or the manufacturer of the axial piston pumps on the power units. This would suggest they either no longer make these pumps or the manufacturer has been taken over and the pump range deleted. We would not expect the pumps to have any major failures with so few hours of running, however it would be fair to expect the pump seals e.g. shaft seals, to be nearing the end of there running life purely due to their age.

The pump mountings are not standard and as such no replacement unit could be fitted into the existing configuration without changing bell housings/couplings and the pressure and suction hose setups. This would take an amount of down time, possibly several days.

Directional Control Valves, with the service life of these valves, would be most unlikely to fail as long as a regular exercising routine is maintained. The only failures we would expect would be O-Ring seals and coils. The seals could be replaced on a needs basis and as long as a sufficient quantity of coils was kept on hand there should be no problems. Worst case scenario would require replacement of the valve which would generally be ex-stock Brisbane even if the manufacture was not the same the mounting interface is standard across most ranges.

Relief, Flow and Pressure Control Valves would only be subject to O-Ring failure and replaced on a needs basis.

As with the seals in the other components should a failure occur this would result in an oil leak that in the short term should not be detrimental to the operation of the system.

Springs in relief valves have been known to fail under extreme operating conditions. This would be most unlikely in this system.

Hydraulic Motors of the type in operation should have a service life of many thousands of hours. Our opinion and seconded by Hagglunds is that the only failure that should be experienced in the foreseeable future would once again be rubber components which should be evidenced by minor leaks in advance of a complete seal collapse in which case a considerable amount of oil could be lost, however the system would still operate if oil reservoir levels were maintained.

Winch Brake Hydraulic Cylinders should be removed and serviced on a regular rotating basis. This is one area where a major seal collapse could compromise the operation of the system.

Cam Operated Hydraulic Directional Valves should also be removed and serviced on a regular rotating basis. Having moving parts with quite fine tolerances exposed to the elements could result in the valve sticking in one position or the other.

Pressure Switches should also be serviced and tested on a regular basis. This is one item that over the years has gained a reputation in hydraulic circuits as being a high maintenance item. We have no feedback as to the reliability of the switches in this system however experience tells us that these items should be serviced regularly regardless of duty cycle.

Reservoir Breathers should be cleaned or replaced on a regular basis. Since the manufacture of these hydraulic power units a range of breathers has been introduced onto the market, which deliver a higher quality of air to the reservoir. These breathers are dealt with below.

Mobile Power Unit has the same maintenance regime as the stationary units. Again this unit has relative low operating hours and as such would not be subject to mechanical failure, however some recommendations regarding the units have made below. It was noted that the unit had no filtration either pressure or return line. Should there be a component failure, particularly a pump failure, considerable contamination could be introduced into the system prior to shutting down.

It was also noted that some of the hydraulic hoses had considerable deterioration and cracking of the outer rubber covering.

RECOMMENDATIONS

Common Equipment and Components

Apart from dismantling the system and replacing all the seals there is little that can be done to address this problem. We would suggest maintaining a reasonable supply of the known O-Ring seals and any other seals that can be identified. Storing these seals correctly will extend there shelflife; however they should be replaced every 10 years.

Information attached.

Accumulators

Accumulator gas charge should be checked every year. As mentioned above they fall under the pressure vessel code and as such should be checked in accordance with the attached information.

Pump/Motor couplings

We believe the couplings have not been checked on a regular basis and would recommend this be carried out. With the length of time since the couplings were installed it may be more economical to replace the coupling rubbers regardless of condition, considering the labour required to remove and replace the pump.

Pumps

We were unable to find any reference to the seal sizes in the information supplied to us however we would expect the seals to standard sizes, as they are in most pumps of this design. This would suggest the pumps could have minor repairs, such as seals, carried out. This process would obviously take the time required to remove the pump, dismantle and identify the seals, procure the seals, replace and re-install the pump. We would estimate a minimum of several days. Considering the age of the pumps, or more importantly the seals, we would recommend that consideration be given to replacing the pump seals one by one whilst the coupling rubbers are being addressed.

Directional Control Valves

As long as a reasonable amount of seal kits and spare coils are kept on hand there should no problems with the directional control equipment.

Relief, Flow and Pressure Control Valves

As with the DCV's if some seal kits were kept in case of a seal failure, we would envisage no problems with these valves.

Hydraulic Motors

The only failure we would expect would be seals and as mentioned this should not prevent the system from operating in an emergency, all be it that hydraulic fluid may be lost during operation. These seals would best be replaced on a needs basis.

The hydraulic motors, we believe, were originally supplied as matched sets and as such should remain so.

Hagglunds recommend that a rust preventative be added to the hydraulic oil if the motors should not be run for periods longer than one month. If this were to be employed Hagglunds should be consulted on the type of additive to be used, however we believe that running the motors at a more frequent period than one month would be a better alternative.

Winch Brake Hydraulic Cylinders

These cylinders should be resealed and tested in a regular maintenance program. We would recommend they be resealed no less than every 10 years. This could be done on a basis where no more than one gate was out of operation at any one time. We would expect turn around on repairs to be a matter of days, assuming there is no mechanical damage. Alternatively a spare set of cylinders could be kept and rotated into service in a regular routine.

Cam Operated Hydraulic Directional Valves

We are aware that problems have arisen with these valves in the past due to the exposure to the elements. We would recommend that the valves be serviced and tested at least every two years.

The company that manufactured the original valves has been bought out and closed so these valves are no longer available, however Queensland Hydraulics did have access to the hydraulic range, when they were on the market, and due to demand from customers, have manufactured and could supply an interchangeable valve. Due to the service conditions we feel this may be a consideration to allow servicing on a rotational basis.

Pressure Switches

Being a relative in-expensive component, having one of each pressure setting as a spare to be rotated on a regular basis may be a simple method of ensuring the switches are in good working order at all times. As mentioned above, due to the nature of there construction (pistons with seals, springs, orifices and small working parts.

Reservoir Breathers

The reservoir breathers currently in use provide a positive pressure within the reservoir however rely on a simple strainer to filter the entering air.

Please find attached information regarding a range of breathers we currently recommend for these applications. They rely on a 3 micron mechanical filter element and incorporate a desiccant charge to remove moisture from the incoming air. This has the obvious benefit of reducing the moisture available for condensation within the reservoir and in turn entering the hydraulic oil.

To this end we would recommend the reservoir be drained, inspected and cleaned if this has not been done in the past 10 years or so.

Motor Case Drain Line

In consideration of the motor case drain line draining its contents back to the reservoir over a period of time several alternatives as listed below were discussed. The draining obviously occurs because the reservoir is lower than the motors. It appears as though attempts have been made to place siphon breaks in the line with no success.

One remedy would be to seal the reservoir and introduce a header pipe to connect to a small reservoir at a height above the motors. Although this would solve the problem by supplying positive head pressure on the drain line the practicality of this remedy would be questionable in as much as other modifications would have to be made such as moving oil level switches along with other alterations to filling points and the like. We do not believe this to be a viable option.

An auxiliary reservoir of a volume equal or greater than the drain line volume could be interconnected with the current reservoir at the same height to reduce the overall fluctuations in the reservoir. This would address the problem but not the cause.

The final option discussed would be installation of a soft, positive seated check valve to act as a resistance valve in the drain line. The resistance offered by the valve would have to be calculated to be something in excess of the pressure produced by the head of oil, however not sufficiently high to introduce back pressure above the rating for case pressure on the hydraulic motors. Size would also be critical to ensure no additional back pressure was exerted on the motors, due to pressure drop across the resistance valve, during operation. This proposal would have to be acceptable to Hagglunds.

Mobile Power Unit should have the motor/pump coupling checked on a regular basis. As with the stationary units it may be prudent to replace the coupling rubber at inspection time considering the replacement cost.

We would strongly recommend the fitting of pressure filtration as a minimum and return line filtration would also be worth consideration.

The deterioration in the hydraulic hoses is most likely due to the hoses being exposed to the elements. This may not have affected the capacity of the hose to date, however over a period of time moisture will start to corrode the wire braiding of the hose causing a failure. We would recommend a careful inspection of the hoses with a view to replacing them. If the unit is stored outdoors, covering the hoses from direct exposure to the elements, particularly sunlight, would increase their life.

SUMMARY

The system is obviously in good condition and well maintained.

We have assumed that the diesel power pack has the regular servicing recommended by the manufacturer.

With regular oil sampling and analyses and the current regime of filter changes and exercising the system we can see no reason for a system failure due to worn equipment of fatigue failure.

We would recommend consideration of the above suggestions as it will more likely be some minor component that would prevent the system running than any major component failure.