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HAZARDS AND SAFETY EVALUATION OF EXISTING DAMS

by
V. Jairaj

Abstract

Hundred of dams are dotted across Sri Lanka varying in size and age. Often little attention is paid to regular maintenance or monitoring of the conditions of these dams to ascertain the safety of these structures. The reason perhaps remains in the relatively stable geological land formation coupled with the inadequate finances, insufficient exposure to the modern 'state of art' design and maintenance of dams. Nevertheless these structures should be considered as potential high hazard structures by their threat to human lives below them. This paper attempts to highlight the concept of 'Safety Evaluation of Existing Dams' (SEED) as applied to a developing nation such as Sri Lanka.

1.0 Introduction

1.1 Dams are an essential element of the national infrastructure but the public risk in case of failure is great. Although there may be many downstream residents who may be unaware of the dam safety procedures, legal and moral responsibility essentially rests with the dam owners such as the Irrigation Department, Mahaweli Authority, Sri Lanka Electricity Board and eventually on the government itself. Dam owners serve the society by meeting important national needs such as food production, generation of electricity and water supply. Nevertheless these reasons do not justify the utilities and effectiveness of ownership if the owner cannot provide safety for people downstream of the dam.

1.2 Sri Lanka, rich in its ancient history and civilisation, is dotted with rehabilitated dams of varying sizes and age especially in the dry zone. Most of these are dams rehabilitated in the 'recent past' from the ancient breached ruins covered in thick jungle. Limited finances and an on going civil disturbance would make regular maintenance of these structures generally inadequate.

1.3 This paper will deal with some basic philosophies in the containment of catastrophic natural failures of dams and the elements that need to be considered. A dam operating satisfactorily for many years could fail due to either of these two phenomena :

* Extreme natural events for which the dam has not been adequately designed.

* Failure due to aging of dam resulting in piping type failure.

2.0 Natural Hazards

Natural hazards that threaten the safety of the dam are as follows :

a) Flooding due to high intensity rainfall with or without cyclonic winds.

b) Flooding from dam failures from upstream catchments - a 'domino effect'.

c) Earthquakes

d) Landslides into the reservoir that may trigger a wave over the dam.

e) Instability of the dam embankment leading to earth slides, especially during rapid draw down conditions or high water level in the reservoir.

f) Piping failures.

g) Decaying of dams through aging.

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Apart from earthquake, the topics listed above are relevant to a typical dam in Sri Lanka and they will be discussed here.

2.1 Failures due to flooding

2.1.1 Failure of a dam as a result of flood puts more people and property at risk than during a natural flood in the absence of the dam. Floods are a frequent, costly and almost an annual natural disaster in Sri Lanka. Most spillways of village reservoirs to medium scale reservoirs are designed to perform safely for a flood of up to 1 in 200 year return period (the author has based this information from his knowledge as at 1981). In such dams when floods of lower magnitude/return periods are encountered with cyclonic winds the wave height generated (in the direction of fetch) would often overtop the dam. Such repeated overtopping would erode the downstream shoulder of the dam. In such instances it would seem prudent to increase the free board of the dam and thereby reduce the damage to the (upstream) U/S and (downstream) D/S shoulders of the dam.

2.1.2 Spillways of major reservoirs should be designed to discharge a Probable Maximum Flood (PMF) (approx return period of 1 in 10,000 years). Due consideration is also given to "Murphys law" in the operation of the spillways in such freak storms. Spillway blockages through floating debris or inability to operate some of the spillway gates should be considered. In such cases auxiliary spillways are provided to safely discharge the flood waters and thereby increase the safety of the population D/S of the dam.

It is not economically feasible to build every dam to withstand a PMF especially in a developing country like Sri Lanka. However, when designing spillways for major reservoirs, due consideration should be given to this situation especially when village reservoirs are situated in the U/S catchment.

However, village reservoirs should be designed to withstand a flood of 'Economically Acceptable Return Period' (EARP). EARP may be determined on a national level taking account of the catchment and rainfall characteristics and the population at risk below the reservoir.

2.1.3 The consequence of such a philosophy would mean that millions of rupees would be required to widen spillways or to raise dams. None of these would be an easy task, even if the money could be found. However by providing suitable auxiliary spillways to existing dams a compromise can be found to discharge the enhanced design spillway flows. These can be in the form of natural or fuse plug spillways designed to washout during such catastrophic events. Although in theory provision of such spillways may seem easy, in reality it is not so, especially when the downstream area is developed and populated.

2.1.4 Dam break studies should be undertaken as part of the flood risk analysis for medium and large scale dams. Such studies would show the population at risk for various scenarios downstream of these dams. Typical examples of the scenarios are illustrated as follows :

* Flooding by over topping and erosion failure of the dam during a PMF event.

* Flooding due to piping failure of the dam when the reservoir is full.

There are various software packages on the market that can be utilised to do dam break studies, some of these are listed below as reference only:

a) Dam break - By US Weather Bureau.
b) HEC-2 - By US Army Corp of Engineers
c) MIKE 11 - Danish Hydraulic Laboratory.

(The author has found MIKE 11 to be reasonably user-friendly Dynamic software).

2.2 Landslides

2.2.1 Landslides and rockslides may impact dams directly by blocking a spillway or by eroding and weakening the abutments. Indirectly a large landslide that occurs within the reservoir basin and behind the dam can cause an overflow wave that exceeds the spillway flows. Such a wave could over top the dam and flood the D/S settlements. Vaiont dam in Italy (1963) is an extreme example where 2300 lives were lost.

The damage to the dam can vary according to the type of construction, location and type of landslide or rockslide. A concrete dam similar to Vaiont may suffer little damage following such an incident. However an earth dam could suffer considerable damage and even failure depending on the circumstances. The possibilities of such disasters occurring in Sri Lankan dams would be minimal and would be confined to those dams in the central highlands.

2.2.2 Stability of an earth embankment dam is critical on the first filling of the reservoir and under rapid draw-down conditions. In either case the consequence can be disastrous depending on the severity of the failure and the population at risk below the dam. However such failure situations have been well documented in the field of geomechanics, and can be avoided provided the dam is designed and adequately monitored for such conditions.

2.3 Embankment and foundation piping

2.3.1 Piping or progressive erosion of concentrated leaks has caused a larger number of catastrophic failures than any other action except over-topping, and many of the modern techniques of earth dam design and construction have been developed to prevent it. For example, the present stringent requirements (for uniformly compacted embankments with emphasis on control of construction water content and density) have developed to provide dense homogeneous cores which reduce the incidence of concentrated leaks and resist piping when leaks to develop. Because of such requirements, and the introduction of graded filters in the D/S section of the dams, there have been extremely few piping failures in important modern dams.

2.3.2 When water seeps through the compacted soil of an embankment or the natural soil of a foundation, the pressure head is dissipated in overcoming the viscous drag forces which resist the flow through the small pores. Conversely, the seeping water generates erosive forces which tend to pull the soil particles with it in its travel through and under the dam. If the forces resisting erosion are less than those which tend to cause it, the soil particle would be washed away and piping would commence. The resisting forces depend on the cohesion, the interlocing effects, and the weight of the soil particle, as well as on the action of the downstream filter, if any.

At steady state, the filter medium within the dam initiates the formation of particle filters through the various flow paths within the dam and thereby prevents further particle migration through the dam. However in practice the lake level is never static and the viscosity of water is variable with temperature. These variations break down such fine natural filter media. Breaking down and building of these filter media within the flow paths is an on-going dynamic process that eventually ages the dam.

3.0 Regular Monitoring

3.1 Failure histories of dams

Carefully documented failure histories of dams world-wide (under normal operating conditions) show that dams do not fail suddenly without sufficient warning. Whatever the mode of failure, there would have been sufficient signals prior to such catastrophic events. Unfortunately often these have not always been noticed or they have been ignored. The symptoms prior to failure have been pieced together well after such events, in an attempt to determine the cause of failure - 'Post-mortems will not revive the dead but it can be a lesson for the future'.

3.2 Monitoring of performance of dams

3.2.1 The objectives of monitoring of dams can be summarised as follows :

* to provide confirmation of the design assumptions and predictions of performance during construction and operation phases.
* to provide an early warning of the development of unsafe trends in behaviour in the normal course of operation of the dam.
* to provide data on behaviour of dams to conform with modern criteria. If found to deviate from such criteria the intensity of monitoring may be increased to ascertain remedial measures to improve the condition of the dam.

When setting up a surveillance programme it is vital to ensure that the monitoring data is received and analysed by qualified dam engineers and engineering geologists in an ordered manner, so that unusual behaviours can be identified and appropriate action taken.

3.2.2 Dams are structures with a long life span. The type of monitoring needed, the frequency, and the type of instrumentation will depend on the type of dam, condition of the dam, and the standards adopted for design and construction. Instruments installed to monitor the performance of the dam should have the following qualities:

* Reliability with a similar life span to the dam
* They must be accessible, verifiable, and replaceable.
* They should be simple so that frequent readings can be made quickly by site operating staff without the need for specialist attention.

Some of the important items for a monitoring check list are given below :

- reservoirs levels
- rainfall
- seepage eg. main drains, abutments, spillways
- crest settlement
- deformation eg. slips, cracks
- pore water pressure in the dam, abutments and foundation.

Also visual inspection of the surroundings by people who know the dam, is very important because even the best instrument will not find fissures, leakages, damp spots etc. The choice of parameters to be measured and the positioning of instruments cannot always be optimal at design stage. The first filling of a reservoir is a critical stage in its life that is both important and delicate. It is in fact the proof that a dam can fulfil its design functions.

3.3 Visual observations

Visual observations should be carried out by the reservoir operator and at less frequent intervals by the dam engineer. The visual inspections should consist of a minimum of walking along the dam alignment and looking for any signs of distress or unusual conditions at the dam. The inspection should be carried out to check list as given in Table 1.

3.4 Seepage in dams

All dams leak. An acceptable level of leakage (seepage) will vary from dam to dam, depending on the method of construction, the foundation and the materials of construction of the dam. However, if seepage from various components of the dam i.e. toe drain, abutments, spillways etc. are monitored regularly with other varying factors such as the lake level, rain fall a data base of the characteristics of the dam may be built-up. Should any of these show significant variation or a rising trend over a period of time then it could alert the dam owner of the need for further investigation. The above mentioned monitoring could be done at intervals varying from fortnightly to monthly depending on the amount of data required and the variability of the inter-related parameters such as lake level, and rainfall.

3.5 Installation of piezometers

3.5.1 The main purpose of installation of piezometers is to furnish reliable confirmation that the pore pressures which actually develop in a given dam do not exceed appreciably the values assumed by the designer. Piezometers are installed in both embankments and foundations. On operating dams these are installed in pre-drilled holes. Piezometers should be located so that they will provide information on the magnitude and distribution of pore water pressures in critical areas. In most dams a main battery of piezometers is set into one or more transverse sections of the dam to give a general picture of the pore pressure distribution. Additional piezometers are then located where specific information is needed, such as long abutment contacts or along the contact between the embankment and the concrete structures.

The following are the commonly used types of piezometers :

a) well piezometer
b) Casagrande type piezometer
c) twin tube hydraulic piezometer
d) pneumatic piezometer
e) vibrating wire piezometer

This paper will be limited to item (b) above because of its simplicity of installation, reliability and cost effectiveness for Sri Lankan Conditions. It is suggested that those interested in seeking detailed information of the other types could look up the references given in this paper.

3.5.2 The Casagrande type piezometer consists of a plastic pipe of 20 mm diameter (a common size) with a porous tip which is embedded in a sand filter, and sealed into a borehole with a short length of bentonite. The hole is back filled with cement grout or soil excavated from the hole. Slotted PVC pipe could be used instead of the porous tip at the base of the piezometer and this variation is called the Standpipe piezometer (see inset in Fig. 1). The height of water in the piezometer tube is measured by a dipmeter and the reading may be tabulated as shown in Table 2. Fig. 1 illustrates the positions of bore holes (in PLAN) on a dam and Fig. 2 shows the locations of piezometers in each hole, pore water pressure, and flow net diagrams on an exaggerated and real scale. Fig. 3 shows the variation in piezometric elevations relative to time, rainfall and lake levels. This figure illustrates that piezometric pressure in this instance is sensitive to lake level.

3.5.3 Internal displacements and deformations are often monitored on large earth, earth and rockfill, and concrete face rockfill dams. This allows confirmation of the design assumptions, particularly relating to long term settlement of the earthfill and foundation.

There are various types of instruments that could be used to measure deformation on a dam. However the discussion here will be limited to the detection of surface movements through precision surveying. Surface movement devices commonly consists of monuments installed on the surface of embankments dams or abutments. The devices are used to measure total horizontal, vertical displacement at a specific point on the dam. They are generally installed along the crest and one or more cross sections of the dam. Comparison of precision surveying results of these monuments over a period of time would detect surface movements both horizontally and vertically. Normally the bench marks from which these precision surveys are originated should be kept well away from the dam and at locations where land is stable. Fig. 4 illustrates the installation of a monument in an embankment dam.

The frequency of measurement will depend on factors such as, age, condition, design and construction standards adopted in building the dam.

4.0 Conclusions

Monitoring the performance of dams should form an integral part of the maintenance and operation of dams. Hazard potential of these dams should not be under-estimated given the fact that D/S of most of these dams are well populated and often careful site inspection and regular monitoring can signal an impending danger.

5.0 Acknowledgement

The Author's thanks goes to the Watercare Services Ltd for allowing the use of existing monitoring data to illustrate some of the text in this report.

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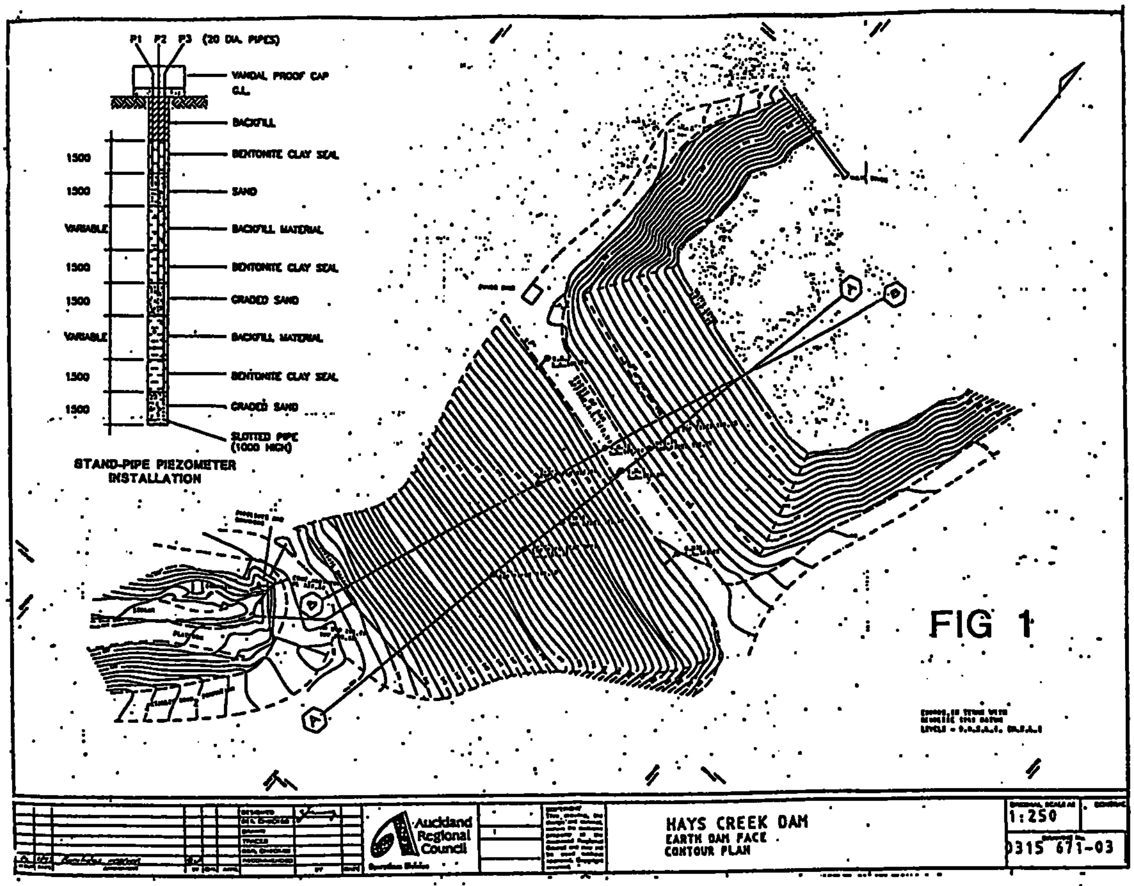
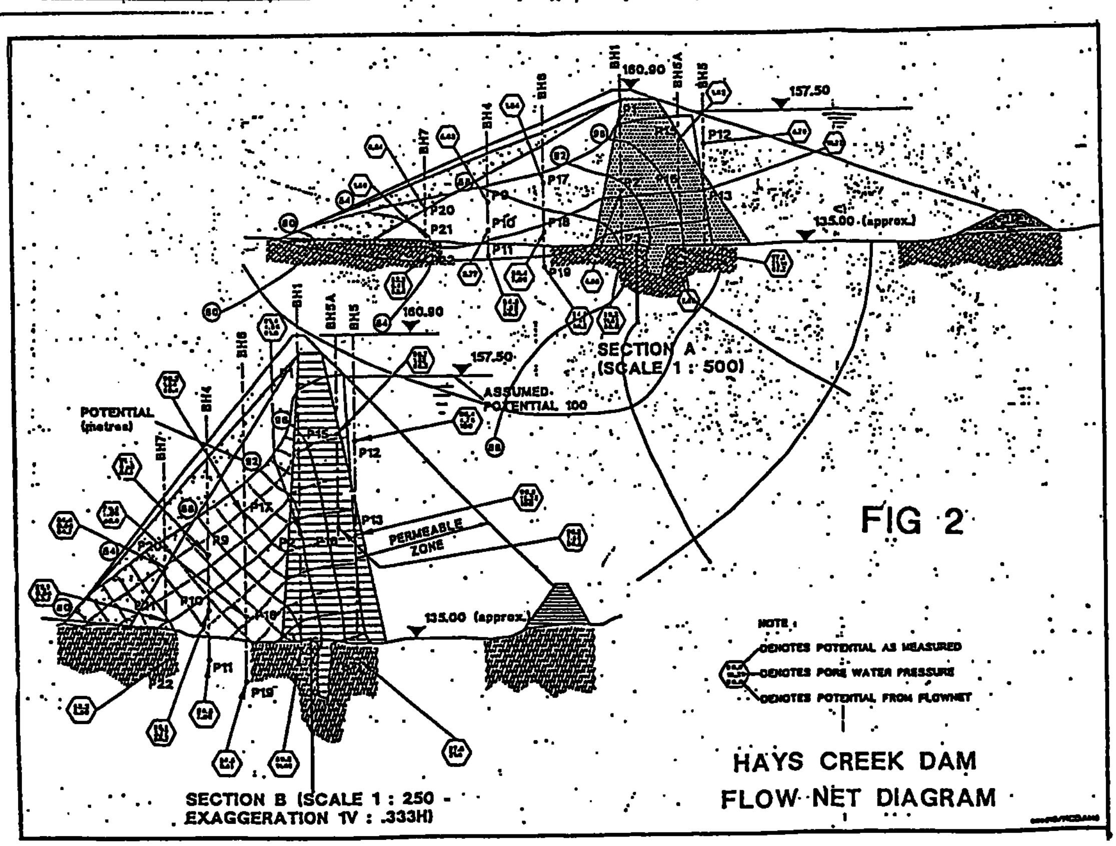

P1 P2 P3 (20 DIA. PIPES)
VANDAL PROOF CAP
G.L.
BACKFILL
BENTONITE CLAY SEAL
SAND
BACKFILL MATERIAL
GRADED SAND
SLOTTED PIPE (1000 HIGH)
1500
VARIABLE
STAND-PIPE PIEZOMETER INSTALLATION
FIG 1
Auckland Regional Council
HAYS CREEK DAM
EARTH DAM FACE
CONTOUR PLAN
1:250
315 671-03


BH1
BH5A
BH5
BH4
BH6
BH7
160.90
157.50
135.00 (approx.)
P12
P13
P17
P20
P21
P9
P10
P18
P11
P19
P22
SECTION A (SCALE 1 : 500)
160.90
157.50
ASSUMED POTENTIAL 100
POTENTIAL (metres)
P15
P14
PERMEABLE ZONE
FIG 2
NOTE:
DENOTES POTENTIAL AS MEASURED
DENOTES PORE WATER PRESSURE
DENOTES POTENTIAL FROM FLOWNET
HAYS CREEK DAM
FLOW NET DIAGRAM
SECTION B (SCALE 1 : 250 - EXAGGERATION 1V : .333H)

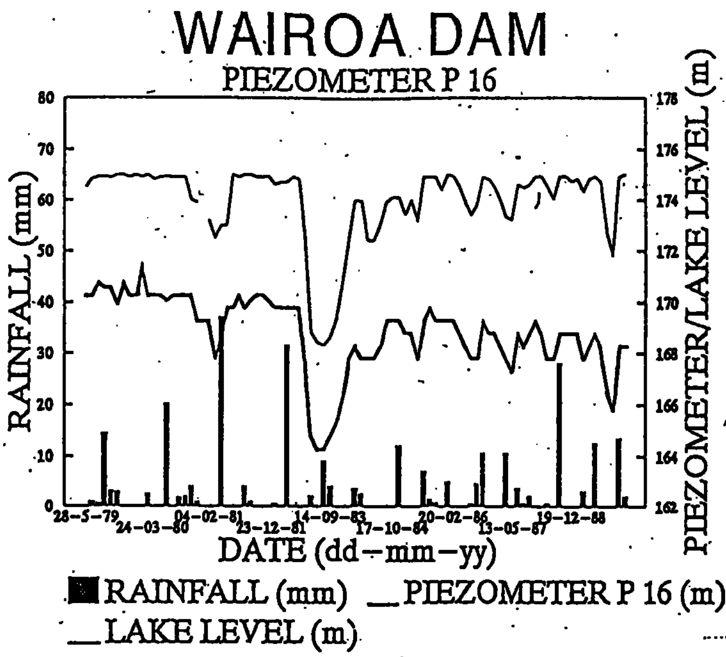


FIG 3

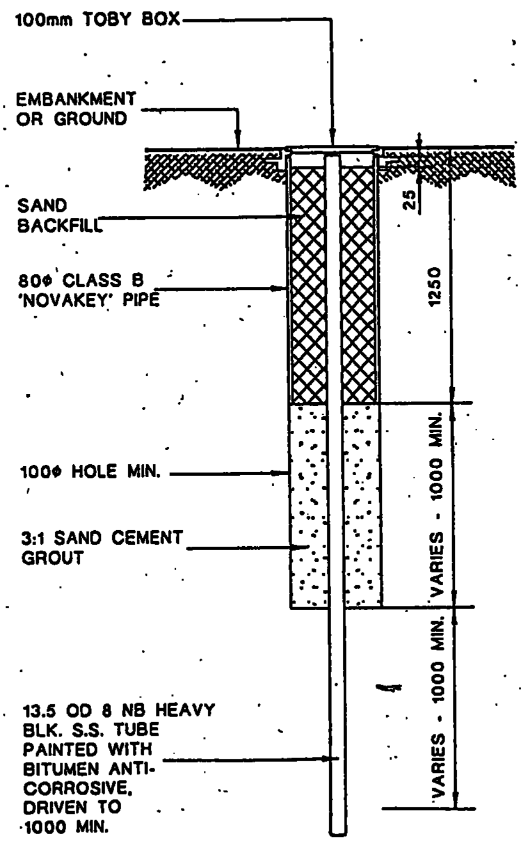


FIG 4

GROUND MOVEMENT MARKERS.

TABLE 1

NAME OF DAM: ______________________ INSPECTION DATE: ____________

EMBANKMENT
1 of 2

CHECK (✓) ACTION NEEDED

AREA INSPECTED	ITEM NO.	CONDITION	OBSERVATIONS	MONITOR	INVESTI-GATE	REPAIR
CREST	1	SURFACE CRACKING				
	2	CAVE IN, ANIMAL BURROW				
	3	LOW AREA(S)				
	4	HORIZONTAL ALIGNMENT				
		RUTS AND/OR PUDDLES				
	6	VEGETATION CONDITION				
	7					
	8					
UPSTREAM SLOPE	9	SLIDE, SLOUGH, SCARP				
	10	SLOPE PROTECTION				
	11	SINKHOLE, ANIMAL BURROW				
	12	EMB.-ABUT. CONTACT				
	13	EROSION				
	14	VEGETATION CONDITION				
	15					
	16					

ADDITIONAL COMMENTS: REFER TO ITEM NO. IF APPLICABLE.

EMBANKMENT
2 of 2

CHECK (✓) ACTION NEEDED

AREA INSPECTED	ITEM NO.	CONDITION	OBSERVATION	MONITOR	INVESTI-GATE	REPAIR
DOWNSTREAM SLOPE	17	WET AREA(S) (NO FLOW)				
	18	SEEPAGE				
	19	SLIDE, SLOUGH, SCARP				
	20	EMB.-ABUT. CONTACT				
	21	CAVE IN, ANIMAL BURROW				
	22	EROSION				
	23	UNUSUAL MOVEMENT				
	24	VEGETATION CONTROL				
	25					
	26					
INSTRUMENTATION	27	PIEZOMETERS/OBSERV. WELLS				
	28	STAFF GAUGE AND RECORDER				
	29	WEIRS				
	30	SURVEY MONUMENTS				
	31	DRAINS				
	32	FREQUENCY OF READINGS				
	33	LOCATION OF RECORDS				
	34					
	35					

ADDITIONAL COMMENTS: REFER TO ITEM NO. IF APPLICABLE.

TABLE 2

UPPER NIHOTUPU DAM

PIEZOMETER READINGS

		PIEZOMETRIC ELEVATIONS (m)							DIPMETER READINGS (m)					LAKE LEVEL	
	DATE	P1	P2	P3	P4	P5	LAKE LEVEL (m)	RAINFALL (mm)	P1	P2	P3	P4	P5	(ft)	(in)
JAN'91	02-01-91	208.14	209.27	171.51	173.37	179.00	214.04	1.20	10.36	9.23	8.65	6.50	0.00	100.00	6.00
	04-01-91	208.05	209.15	171.51	173.37	179.00	213.89	0.00	10.45	9.35	8.65	6.50	0.00	100.00	0.00
	07-01-91	207.86	208.83	171.49	173.38	179.00	213.66	0.00	10.64	9.67	8.67	6.49	0.00	99.00	3.00
	09-01-91	207.75	208.62	171.48	173.38	179.00	213.46	1.00	10.78	9.88	8.68	6.49	0.00	98.00	7.00
	14-01-91	207.48	208.17	171.45	173.39	179.00	212.95	0.00	11.04	10.33	8.72	6.48	0.00	98.00	11.00
	16-01-91	207.33	208.00	171.44	173.40	179.00	212.72	6.60	11.17	10.50	8.73	6.47	0.00	96.00	2.00
	18-01-91	207.22	207.83	171.42	173.40	179.00	212.57	0.00	11.28	10.67	8.75	6.47	0.00	96.00	0.00
	21-01-91	207.11	207.64	171.42	173.41	179.00	212.42	0.00	11.39	10.86	8.75	6.46	0.00	95.00	2.00
	23-01-91	206.99	207.50	171.41	173.41	179.00	212.21	0.00	11.51	11.00	8.76	6.46	0.00	94.00	6.00
	25-01-91	206.88	207.37	171.41	173.41	179.00	212.01	8.00	11.62	11.13	8.77	6.46	0.00	93.00	10.00
	28-01-91	206.72	207.17	171.39	173.41	179.00	211.45	1.50	11.78	11.33	8.79	6.45	0.00	92.00	0.00
	30-01-91	207.07	207.05	171.38	173.42	179.00	211.15	28.00	11.43	11.45	8.80	6.44	0.00	91.00	0.00
FEB'91	01-02-91	208.74	207.02	171.37	173.43	179.00		49.50	9.76	11.48	8.81	6.43	0.00		
	04-02-91	213.13	207.92	171.37	173.44	179.00	211.78	0.80	5.37	10.58	8.81	6.42	0.00	93.00	0.00
	06-02-91	211.68	208.48	171.38	173.44	179.00	211.45	0.00	6.82	10.02	8.82	6.42	0.00	92.00	0.00
	08-02-91	210.70	208.71	171.35	173.44	179.00	211.10	0.00	7.60	9.79	8.83	6.42	0.00	90.00	10.00
	11-02-91	209.58	208.78	171.35	173.45	179.00	210.54	1.00	8.92	9.74	8.83	6.41	0.00	89.00	0.00
	13-02-91	208.99	208.71	171.36	173.45	179.00	210.13	0.00	9.51	9.79	8.82	6.41	0.00	87.00	6.00
	15-02-91	208.42	208.82	171.34	173.48	179.00	209.72	0.00	10.08	9.88	8.84	6.40	0.00	86.00	4.00
	18-02-91	214.18	208.48	171.36	173.47	179.00	209.70	65.00	4.32	10.02	8.82	6.38	0.00	88.00	3.00
	20-02-91	214.34	209.08	171.38	173.48	179.00	210.31	3.00	4.18	9.44	8.82	6.37	0.00	88.00	3.00
	22-02-91	212.30	209.49	171.35	173.48	179.00	210.08	0.00	6.20	9.01	8.83	6.37	0.00	87.00	8.00
	25-02-91	210.55	209.59	171.36	173.31	179.00	209.47	0.00	7.95	8.91	8.82	6.57	0.00	85.00	8.00
	27-02-91	209.80	209.56	171.37	173.49	179.00	209.14	0.00	8.70	8.94	8.81	6.38	0.00	84.00	6.00
MAR'91	02-03-91	208.75	209.36	171.36	173.49	179.00	208.58	0.50	9.75	9.12	8.82	6.36	0.00	82.00	7.00
	04-03-91	208.81	209.18	171.35	173.51	179.00	208.28	2.80	9.89	9.34	8.83	6.34	0.00	81.00	7.00
	06-03-91	208.35	209.01	171.36	173.50	179.00	207.90	0.00	10.15	9.49	8.82	6.35	0.00	80.00	4.00
	08-03-91	207.84	208.80	171.38	173.51	179.00	207.59	0.00	10.66	9.70	8.82	6.34	0.00	79.00	4.00
	11-03-91	207.13	208.42	171.38	173.52	179.00	206.98	0.00	11.37	10.08	8.82	6.33	0.00	77.00	4.00
	13-03-91	206.71	208.15	171.36	173.52	179.00	206.70	0.00	11.79	10.35	8.82	6.33	0.00	76.00	6.00
	15-03-91	206.65	207.74	171.37	173.54	179.00	206.40	6.50	11.85	10.78	8.81	6.31	0.00	75.00	6.00
	18-03-91	206.18	207.74	171.36	173.54	179.00	206.63	5.60	10.32	10.76	8.82	6.30	0.00	76.00	10.00
	20-03-91	207.49	207.66	171.37	173.54	179.00	206.80	0.00	11.01	10.84	8.81	6.30	0.00	76.00	9.00
	22-03-91	206.90	207.50	171.37	173.54	179.00	206.75	0.00	11.60	11.00	8.81	6.30	0.00	78.00	7.00
	25-03-91	206.22	207.20	171.37	173.55	179.00	206.57	0.50	12.28	11.30	8.81	6.29	0.00	76.00	0.00
	27-03-91	214.17	207.14	171.38	173.57	179.00	207.72	38.50	4.33	11.38	8.80	6.27	0.00	79.00	9.00
APR'91	01-04-91	209.39	208.06	171.39	173.58	179.00	207.95	0.00	9.11	10.44	8.79	6.26	0.00	80.00	6.00
	03-04-91	208.08	208.38	171.39	173.58	179.00	207.90	0.00	10.44	10.12	8.79	6.26	0.00	80.00	4.00
	05-04-91	208.16	211.54	171.40	173.60	179.00	207.95	0.50	10.34	8.96	8.78	6.24	0.00	80.00	6.00
	08-04-91	212.52	208.78	171.41	173.60	179.00	208.56	0.50	5.98	9.74	8.77	6.23	0.00	82.00	8.00
	10-04-91	214.38	209.17	171.41	173.60	179.00	208.51	5.00	4.14	9.33	8.77	6.23	0.00	82.00	4.00
	12-04-91	213.84	209.60	171.41	173.61	179.00	208.71	0.80	4.66	8.90	8.76	6.22	0.00	83.00	0.00
	15-04-91	210.71	209.75	171.43	173.62	179.00	208.71	0.00	7.79	8.75	8.74	6.21	0.00	83.00	0.00
	17-04-91	209.42	209.68	171.45	173.62	179.00	208.88	2.80	9.06	8.82	8.72	6.21	0.00	82.00	10.00
	19-04-91	214.70	209.77	171.45	173.63	179.00	208.98	20.50	3.80	8.73	8.72	6.20	0.00	83.00	10.00
	22-04-91	212.94	210.06	171.46	173.64	179.00	209.06	0.50	5.56	8.42	8.71	6.19	0.00	84.00	2.00
	24-01-91	214.89	210.17	171.47	173.65	179.00	209.57	34.00	3.61	8.33	8.70	6.18	0.00	85.00	10.00
	26-04-91	214.68	210.39	171.49	173.66	179.00	212.21	4.20	3.82	8.11	8.67	6.17	0.00	94.00	8.00
	29-04-91	214.70	210.64	171.54	173.67	179.00	212.49	4.00	3.80	7.88	8.61	6.15	0.00	93.00	8.00
MAY'91	01-05-91	214.73	210.77	171.56	173.67	179.00	212.59	4.00	3.77	7.73	8.59	6.15	0.00	95.00	9.00
	03-05-91	213.35	210.65	171.57	173.67	179.00	212.62	0.00	5.15	7.65	8.56	6.15	0.00	95.00	10.00