

## APPLICATION OF A REAL TIME MONITORING SYSTEM TO A LANDSLIDE ON THE SASKATCHEWAN HIGHWAY NETWORK

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### ABSTRACT

Saskatchewan Department of Highways and Transportation (SDHT) implemented a Risk Management System for the provincial highway network in 2003. The Risk Management System was developed to prioritize sites for investigation and allocate resources for construction and maintenance. The Risk Management System identified Provincial Highway No. 302-02 at Prince Albert, Saskatchewan as an urgent site requiring immediate investigation and monitoring. A 650 m section of Provincial Highway No. 302-02, approximately 4.5 km west of the Saskatchewan Penitentiary, was dropping as a result of large retrogressive landslides along the North Saskatchewan River.

Investigation and slope stability analysis indicated the remediation options were limited to the re-alignment of the highway. However, re-alignment of the highway would be costly and require time to design and construct. Daily inspection and monitoring of the site instrumentation were recommended until remedial measures could be implemented but the remote location of the site and high speed of landslide movement were not amenable to traditional means of inspection and monitoring. As a result, an automated real time monitoring and warning system consisting of in-place inclinometers, vibrating wire piezometers, barometer and temperature sensors was installed in the summer of 2005. The instrumentation was installed in two nests, one located on the river bank and the other adjacent to the highway. Data was collected by two data loggers and transmitted by cell phone modem to a server where the data was uploaded to the ARGUS Monitoring Software System on the internet. Data provided by the instrumentation included movement at the shear zone (at the river bank and at the highway), piezometric pressures (above, below and at the shear zone at both monitoring locations), the depth of water in the river and atmospheric pressure and temperature. Alarm levels for the data were set so that risk on the impacted section of highway could be managed until remedial measures were enacted. This paper documents the site conditions and how the real time monitoring system has assisted in characterizing the landslide movement and managing risk at the site.

### RÉSUMÉ

Le Ministère de Routes et Transports de la Saskatchewan (MRTS) a rendu effectif un système de la gestion du risque pour le réseau d'autoroute provincial en 2003. Le système de la gestion du risque a été développé donner la priorité aux sites pour enquête et allouer des ressources pour construction et maintenance. Le système de la gestion du risque a identifié l'Autoroute 302-02 à Prince Albert, Saskatchewan comme un site urgent exiger l'enquête et mesure immédiate. Une section de 650 m d'Autoroute 302-02, approximativement 4.5 kms ouest de la Prison Centrale de la Saskatchewan, laissait tomber par suite de grands glissements de terrain rétrogressifs le long de la Rivière Saskatchewan Nord.

L'enquête et analyse de la stabilité des talus ont indiqué les options pour les mesures remédiables ont été limitées au déménagement de l'autoroute. Cependant, le déménagement de l'autoroute serait cher et exiger le temps du dessiner et construire. Inspection journalière et mesure de l'instrumentation de site a été recommandé jusqu'à ce que les mesures remédiables puissent être rendues effectif. Que cependant, l'emplacement éloigné du site et haute vitesse de mouvement écrasant ne soit pas responsable à moyens traditionnels d'inspection et mesure. En conséquence, un system en temps réel pour diriger et prévenir a été installé en été de 2005. Le système consiste en inclinomètres dans-place, piezomètres du fil vibrant, baromètre et sondes de la température. L'instrumentation a été installée dans deux emplacements, on a localisé sur la rive et l'autre adjacent à l'autoroute. Les données ont été rassemblées par deux bûcherons de la donnée et ont transmis par modem du téléphone portable à un serveur. Les données ont été téléchargées à l'ARGUS Moniteur Système du Logiciel sur l'internet. Les données fournies par l'instrumentation ont inclus le mouvement à la zone du ciseau (à la rive et à l'autoroute), les niveaux hydrauliques (au-dessus, au-dessous d'et à la zone du ciseau aux deux emplacements de l'écoute), la profondeur d'eau dans la rivière, pression atmosphérique et température. Les niveaux de l'alarme pour les données ont été mis afin que risque sur la section encastrée d'autoroute pourrait être dirigé jusqu'à ce que les mesures remédiables aient été décrétées. Ce papier documente le site conditionne et comme le système en temps réel a aidé dans caractériser du glissement de terrain et la gestion du risque au site.

1. INTRODUCTION

Saskatchewan Department of Highways and Transportation (SDHT) required a landslide risk management system to prioritize sites for monitoring and remediation and provide recommended response levels based upon risk level. In 2003, SDHT took the first step in landslide management by implementing a landslide risk management system based upon the Alberta Transportation model (Kelly et al. 2004 & Kelly et al. 2005a).

Multiple retrogressive landslides along the North Saskatchewan River are impacting Provincial Highway No. 302-02, 4.5 km west of Prince Albert, Saskatchewan

(Kelly et al. 2005b). Figure 1 shows the location of the landslide site where Provincial Highway No. 302-02 approaches within 250 m of the river. The surface geometry of the slide mass shows a number of individual slide blocks, indicative of a multiple retrogressive mechanism, Figure 2. The landslide appears to be triggered by severe river bank erosion and high pore water pressures from poor drainage. A risk assessment assigned the landslide to the urgent risk category as there were threats to public safety and a significant impact on infrastructure. Figures 3, 4 and 5 show the landslide impacts on the highway.

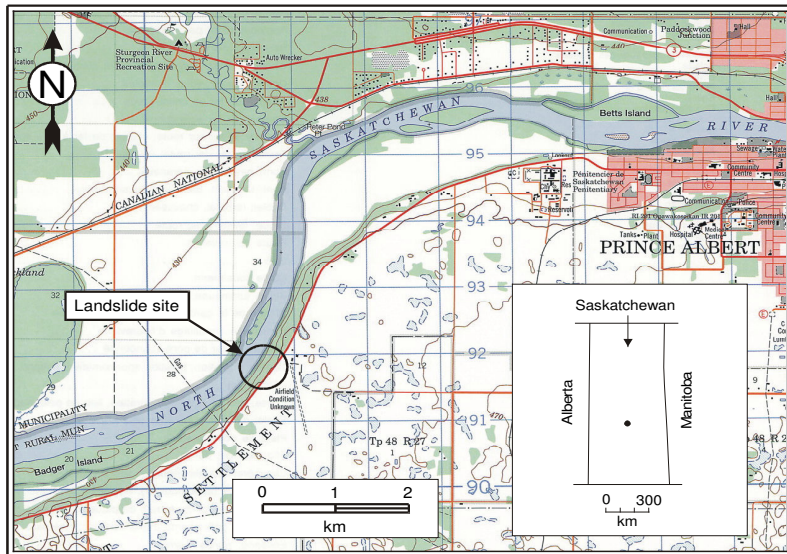


Figure 1. Location map showing the land slide (National Topographic System map sheet 73 H/4).



Figure 2. Aerial oblique showing multiple landslide blocks.



Figure 3. Landslide headscarp in south ditch looking west.



Figure 4. Landslide headscarp in south ditch disrupting ditch drainage with a ditch level higher than the road.



Figure 5. Cracking of the highway shoulder near the west limit of failure.

## 2. FIELD INVESTIGATION AND INSTRUMENTATION

Between October 2002 and May 2004 four boreholes were drilled and electric-logged to determine site stratigraphy, locate the failure plane, monitor the rate of slope movement and define the site pore water pressures. Two of the bore holes, SI001 and SI002, were completed with slope inclinometers adjacent the road and the river bank and a third bore hole near the river bank was completed with a piezometer nest. Both slope inclinometers indicated a well defined shear plane with high rates of movement. Location of the boreholes and instrumentation are shown in Figures 6 and 7.

SI001 readings from April 2003 to June 2005 showed a shear zone at a depth of 44.3 m (elevation 406.5 m) with 13 mm of cumulative movement to the north, or a rate of movement of 6 mm per year. The readings taken from SI002 between May 2004 and June 2005 indicated a zone of movement at a depth of 41.5 m (elevation 393.95 m) with 45 mm of cumulative movement to the northwest.

A stability analysis of the landslide indicated that relocation of the highway was the best remedial option for this highway section (Kelly et al. 2005b). Because relocation of the highway is expensive and will take several years to implement, the risk to the public from a catastrophic failure will be managed in the interim through an automated monitoring and warning system. The instrumentation was installed to provide daily assessments of the site stability and provide timely warnings to SDHT of increased instability.

Two locations were recommended for automated instrumentation, one for the lower landslide block (SI002) and the second for the upper landslide block where Highway No. 302-02 is located (SI003). The lower block moves the greatest and fastest in response to the triggering mechanism of river erosion. The

movement at the upper block is time lagged and reduced, as the movement in the lower block translates back into the upper blocks. Determining the time lag and predicting the amount of movement in the upper block with two automated locations will provide a means to manage risk at the site. Early warning systems built into the automated instrumentation will identify high pore water pressures or anomalous movement in the lower block which may lead to deformation of the highway in the upper block. Advanced notice of accelerated movement of the upper block will allow Saskatchewan Highways to allocate appropriate maintenance resources and place signage in a timely manner.

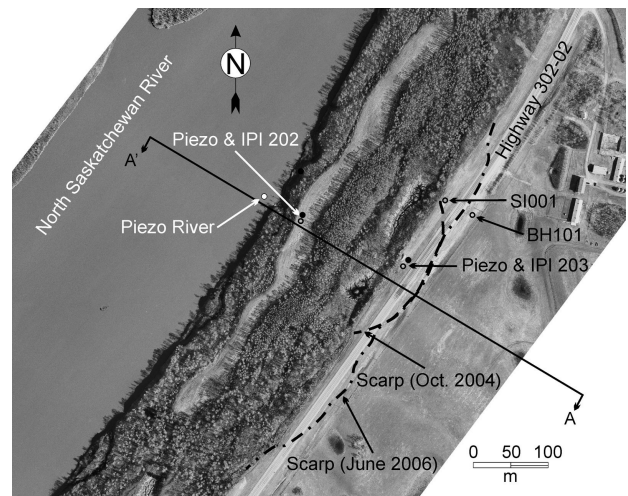


Figure 6. Location of inclinometers, piezometers, cross section A-A', and landslide features.

## 3. INSTRUMENTATION OVERVIEW

### 3.1 Introduction

An automated real time monitoring and warning system was installed in the summer of 2005. The system

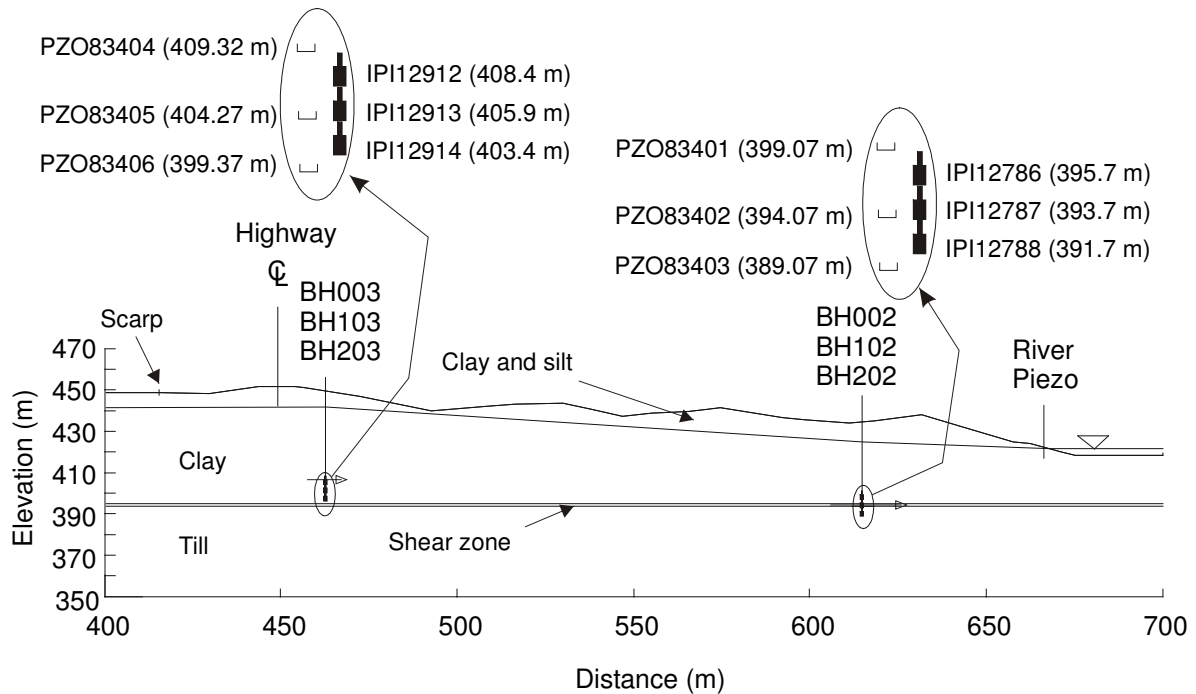


Figure 7. Cross section A-A' showing stratigraphy and instrumentation locations.

consists of in-place inclinometers (IPI), vibrating wire (VW) piezometers, barometer and temperature sensors. The instrumentation was installed in two locations, one located on the river bank and the other adjacent to the highway (Figures 6 and 7). At the highway location the original IPI (BH103) was destroyed on 15 March 2006 by on going movement; therefore, a second IPI (BH203) was installed on 26 May 2006. Table 1 presents a summary of the instruments installed at both locations. All real time monitoring equipment was purchased from Durham Geo Slope Indicator.

### 3.2 In-Place Inclinometers

The in-place inclinometer system consists of inclinometer casing and a string of electrolytic inclinometer sensors. The inclinometer casing is installed in a vertical borehole that passes through a suspected zone of movement. The string of sensors is positioned inside the casing to span the zone of movement. The sensors measure the inclination of the casing. Changes in the inclination readings indicate that the casing has been displaced by ground movement. The amount of displacement is calculated by finding the difference between the current inclination reading and the initial reading and then converting the result to a lateral distance. The sensors are connected to a data acquisition system that continuously monitors movements and can trigger an alarm when it detects a change, or rate of change, that exceeds a preset value.

### 3.3 Vibrating Wire Piezometers

A VW piezometer was required for real-time monitoring because it offered a rapid response to changes in pore water pressure and has the ability to be connected to the automatic data acquisition system. The VW piezometer converts water pressure to a frequency signal via a diaphragm, a tensioned steel wire, and an electromagnetic coil. The piezometer is designed so that a change in pressure on the diaphragm causes a change in tension of the wire. When excited by the electromagnetic coil, the wire vibrates at its natural frequency. The vibration of the wire in the proximity of the coil generates a frequency signal that is transmitted to the readout device. The readout device processes the signal, applies calibration factors, and displays a reading in the required engineering unit.

### 3.4 Other Instrumentation

Because temperature can affect the response of the VW piezometer and IPI; all VW piezometers and IPI are equipped with temperature sensors. For the piezometers and IPI installed at the site, temperature corrections were not useful because the temperature of the sensors remains relatively constant at about 5°C.

One barometer was installed at the site to monitor barometric pressure. Since one of the VW piezometers was used to measure the river water level, which is open to atmosphere; a barometric correction may be required to eliminate measurement uncertainty introduced by barometric pressure.

**Table 1**  
**Summary of instrumentation installation**

Location	Instrument	Name	Elevation (m)	Measurement
Highway (BH103 & 203)	Data Logger	CR10X103	Surface	Data acquisition
	Voltmeter	CR10X103	Surface	Battery Voltage
	In-Place Inclinator	IPI12783	406.40	Movement Above Shear Zone
	(IPI103) Destroyed 15	IPI12784	404.40	Movement At Shear Zone
	March 2006	IPI12785	402.40	Movement Below Shear Zone
	In-Place Inclinator	IPI12912	408.40	Movement Above Shear Zone
	(IPI203) Installed 26 May	IPI12913	405.90	Movement At Shear Zone
	2006	IPI12914	403.40	Movement Below Shear Zone
	Vibrating Wire	PZO83404	409.32	Head Above Shear Zone
	Piezometer (Piezo 103)	PZO83405	404.27	Head At Shear Zone
River Bank (BH202)		PZO83406	399.37	Head Below Shear Zone
	Data Logger	CR10X202	Surface	Data acquisition
	Voltmeter	CR10X202	Surface	Battery Voltage
	In-Place Inclinator	IPI12786	395.70	Movement Above Shear Zone
	(IPI203)	IPI12787	393.70	Movement At Shear Zone
		IPI12788	391.70	Movement Below Shear Zone
	Vibrating Wire	PZO83401	399.07	Head Above Shear Zone
	Piezometer (Piezo 103)	PZO83402	394.07	Head At Shear Zone
	PZO83403	389.07	Head Below Shear Zone	
	PZO83513	River	Depth of River Water	

### 3.5 Data Logger

The CR10X data logger from Campbell Scientific Inc. was used. CR10X has a multi-tasking operating system that allows it to simultaneously interrogate sensors, perform control functions, and transmit data. CR10X collected transmitted data by cell phone modem to a server where the data was uploaded to the ARGUS Monitoring Software System on the internet. Figure 8 shows a photograph of the data logger together with the solar panel of the instrumentation nest near the highway. Monitoring data at the site are recorded hourly; the frequency of data scan can be varied according to the actual conditions at the site.



Figure 8. Instrumentation and data logger near the highway.

### 3.6 ARGUS Monitoring Software

The ARGUS monitoring software is a web-based data management, calculation and presentation tool. The development of ARGUS started in the summer of 2003 in Germany. It was initially created to monitor stability instrumentation at a Soccer Stadium in Portugal (Boart Longyear Interfels 2005).

ARGUS handles all data processing requirements, starting with storage of data into a MySQL database, performing the required calculations on the data, presenting the results in graphical and numerical format; generating alarm messages and creating automated PDF reports. Since ARGUS works on the internet, distribution of the processed data is immediate. Users anywhere can log on to view data and graphs with only their web browsers (Boart Longyear Interfels 2005). A schematic of the ARGUS monitoring software is indicated in Figure 9.

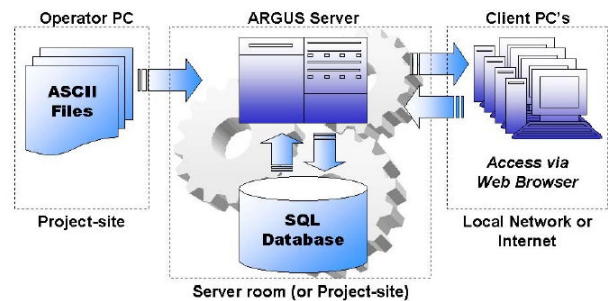


Figure 9. Schematic of ARGUS monitoring software

ARGUS processes the readings collected from sensors at the project site, making the resulting data available on the internet. Users access the data and graphs via their web browsers. Data files from the project site are forwarded to ARGUS. ARGUS scans the files for alarm conditions and then stores the data in a project database. The data is available immediately to anyone who has an internet connection.

ARGUS presents data in the following ways. Plan views show the location of sensors at the site, their current readings, and their alarm status. Plan views are updated in near real time and can show alarms, as required. Figure 10 presents a plan view showing location of sensors and their current readings. Figure 11 presents a photograph showing instrumentation nest adjacent to the highway and their current readings.

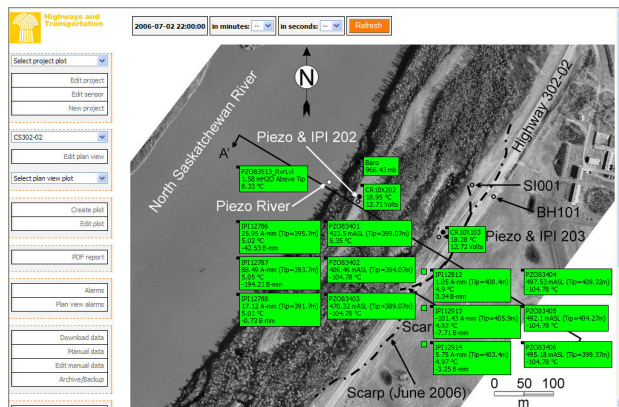


Figure 10. Plan view showing location of sensors and their current readings.

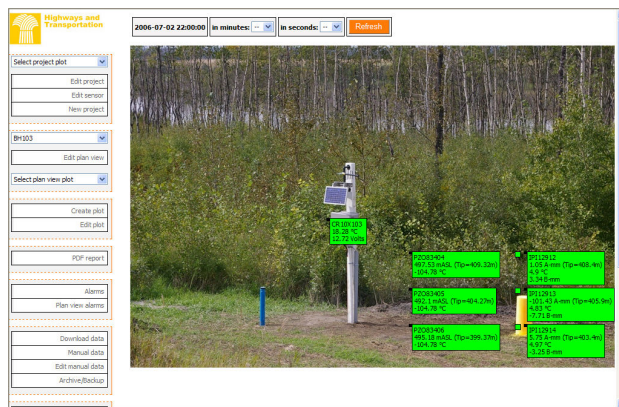


Figure 11. Instrumentation nest adjacent to the highway and their current readings.

Trend plots including time plots, profile plots, and correlation plots, can be printed or included in reports. Example of the trend plots are shown in Figure 12.

Reports are generated automatically and e-mailed to users on a user defined daily, weekly, or monthly schedule.

Data downloads provide access to raw or processed data required for further analysis in spreadsheets.

Alarms appear on screen and alarm notifications are sent out by email and can be forwarded by fax, Short Message Service (SMS) text messaging or pager.

#### 4. INSTRUMENTATION RESULTS

This site provides continuous data from multiple sites which can be compared across a long term timeline. Figure 12 displays plots of river level, piezometer head and IPI deflection versus time.

A time lag of 2 days between movement at the river bank IPI202 and the highway IPI203 was observed between 21 November and 23 November 2005. After 23 November the deflection in both IPIs remained relatively constant until early February 2006. IPI103/203 showed a rapid rate of movement in the order of 5 mm per day for the period of February to June, 2006. The movement was constant and resulted in the destruction of IPI103. IPI103 was replaced by IPI203 on 26 May 2006. During this period of rapid movement, VW piezometer PZO83405 at the shear zone of Piezometer nest 103 showed a rapid increase in pore water pressure by approximately 2 m of head before the piezometer sheared off. The piezometers 5 m above and below the shear zone did not show the same increase in pore water pressure; therefore, the increase in pore water pressure may be related to shear induced pore water pressures.

Previous measurements of the landslide movement with periodic monitoring of the slope inclinometers did not provide information on the variability of the landslide rate of movement. However, real time monitoring of the instrumentation recorded the details of the landslide movement over time. It was assumed that the landslide moved along at a constant rate. However, the real time data indicated that the landslide movement occurred in short periods of time of less than an hour followed by days of relatively inactivity where strain built up for the next movement event. The plots of IPI202 deflection for 28 October and 18 November 2005 show the large jump in deflection between hourly readings.

It can be seen from these plots, that following the flood cycle in May 2006, IPI202 at the river bank began movement of approximately 1 mm per day. This is likely due to the rapid drawdown effects of the river following the flood cycle. This rapid drawdown destabilized the lower landslide block and allowed the movement shown in IPI202.

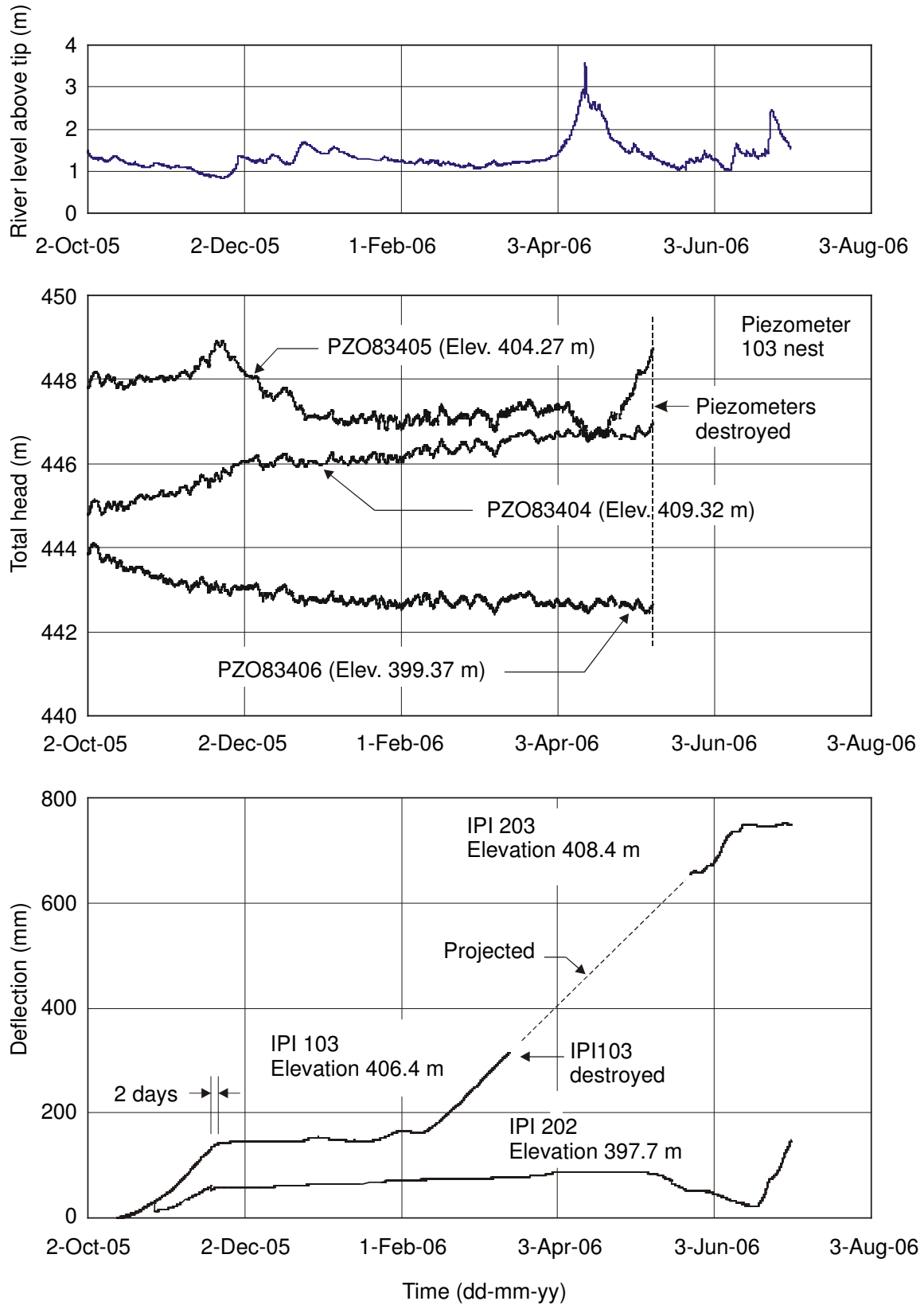


Figure 12. River level, piezometer head and IPI deflection versus time plots.

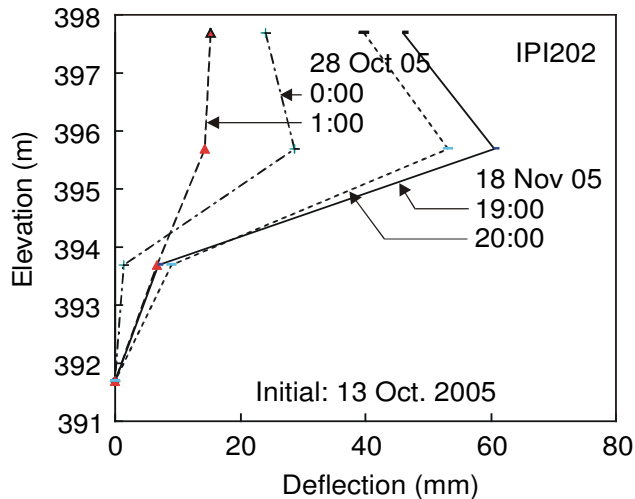


Figure 13. Rapid deflection in IPI202 over a period of one hour on 28 October and 18 November 2005.

## 5. DISCUSSION

The data indicated that there may be as little as a two day lag between movement measured at the river bank and the highway 250 m away; however, there is not enough data available yet with less than 1 year of data to define a lag time. High rates of movement observed in either the riverbank or highway IPIs have provided SDHT with advanced warning of potential hazards on the highway and allowed appropriate measures to be implemented.

We had expected the lower landslide block by the river to move faster and greater than the upper landslide block at the highway in response to river erosion. However, the data to date has indicated the opposite with the upper block moving faster and greater than the lower block. It is difficult to draw long term conclusions from this data, due to the fact that the data is only for less than one annual cycle.

The data from this site is currently being analyzed by C. Salewich (M.Sc. Candidate, University of Saskatchewan).

This M.Sc. thesis will attempt to further explain the relationship between the river level, piezometers and IPI movement.

## 6. CONCLUSION

The real time monitoring system was successfully installed at the Provincial Highway No. 302-02 landslide and provided the basis for risk management at the site. Installation of real time monitoring instrumentation is recommended for other remote sites or where public safety is an issue.

Additional data collection over several annual cycles is required to define the relationship between river bank erosion, movement of the lower landslide block and deformation of the highway.

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