Use of a real-time remote data acquisition system to monitor the performance of sand drains at the proposed bridge site near St. Louis, SK

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ABSTRACT

The existing bridge on Provincial Highway No. 2 over the South Saskatchewan River near St. Louis, Saskatchewan has reached the end of its service life. A new bridge will be built on an alignment that is two kilometres downstream of the existing crossing. The presence of the flowing artesian Hatfield Valley aquifer under the South Saskatchewan River at the proposed bridge location creates challenges to install cofferdams for the pier construction because there is a high probability that hydrodynamic instability will develop. The hydraulic heads in the Hatfield Valley Aquifer at the proposed bridge crossing are five to six meters above river elevation at approximately 432 masl.

Spread footings will be used for the bridge foundations, since it will be difficult to install a deep foundation. It is expected that an excavation approximately three meters below the river bed will be required to construct the spread footing. Under current hydraulic conditions, a three meter excavation would be hydraulically unstable because the artesian water pressures will cause high hydraulic gradients in the foundation soils making pier excavation difficult. Dewatering the Hatfield Valley Aquifer is not a practical alternative because a significant amount of pumping would be required to sufficiently lower groundwater pressures. A system of sand drains was implemented to relieve groundwater pressures in the diamicton and till layers beneath the footing. The local stratigraphic variability and uncertainty associated with numerical modelling required a full scale site investigation with instrumentation to monitor existing conditions and accurately quantify the degree of pressure relief that would be accomplished with relief wells. A trial system of low flow sand drains was implemented and their performance was remotely monitored.

Drilling and installing instrumentation and sand drains took place off an ice bridge surface at the proposed Pier 1 location in February 2008. The Pier 1 location is considered to have the most potential for hydrodynamic instability since the top of the Hatfield Valley Aquifer is closest to the surface at this location. Over 30 vibrating wire piezometers and 28 sand drains were installed. A state-of-the-art remote data acquisition system was set-up to continuously monitor the performance of the sand drains. The instrumentation was installed before the sand drains, so that the background hydraulic conditions could be established. Based on previous numerical modelling, the sand drains were spaced four meters apart. The full effectiveness of the sand drains will be evaluated by comparing hydraulic information before and after the sand drains are installed. If effective, these sand drains will be used for construction of the Pier 1 foundation. This paper documents the installation and performance of the sand drains at the Pier 1 location. The unique construction and installation techniques used for the instrumentation and sand drains will also be presented.

RÉSUMÉ

Le pont existant à St Louis, Saskatchewan a atteint la fin de sa durée de vie, et un nouvel alignement de pont a été choisi à deux kilomètres du croisement existant. On a identifié que la nappe phréatique, artésienne de la vallée Hatfield était présente au-dessous l'emplacement entier. L'hydrogéologie de l'emplacement s'est avérée fortement dépendante sur cette nappe phréatique en tant que charges hydrauliques approximatives de 432 mètres au-dessus du niveau de la mer, c'est-à-dire cinq à six mètres au-dessus du niveau du fleuve existant.

Des fondations superficielles distributrices seront mises en place pour la fondation du pont puisqu'une fondation profonde sera difficile à mettre en place. Le site serait hydrauliquement instable si une excavation d'une profondeur de trois mètres est effectuée. Ce sont les pressions artésiennes qui causent de grands gradients hydrauliques dans le sol de la fondation, ce qui rend la construction de pieu difficile. Un système de puits absorbant de sable sera mis en place pour réduire les pressions hydrauliques dans les couches de tillites sous la fondation. Réduire les pressions hydrauliques de la nappe phréatique de la vallée Hatfield n'est pas une option viable puisque cette nappe contient un gros volume d'eau qui se recharge presque immédiatement. Donc beaucoup de pompage serait requis pour effectivement baisser les pressions hydrauliques. L'incertitude de l'analyse du model numérique et de la variation de la stratigraphie font que le site aura besoin d'être équipé d'instruments qui mesurent la réduction des pressions hydrauliques effectuée par les puits de sable. Un test sur lieu du system des puits sable sera construit et surveillé à longue distance.

Le forage et l'installation du système de puits absorbant de sable et des instruments ce fera sur un pont de glace sur la rivière au Pieu 1. Pieu 1 est le pieu le plus vulnérable à l'instabilité hydrodynamique puisque la nappe phréatique de la vallée Hatfield est très proche à cet endroit. Trente-deux nids de piézomètres et 28 puits absorbant seront installés. Un lecteur de données à distance de pointe sera installé pour continuellement surveiller les performances des puits absorbant. Le lecteur de données et les piézomètres seront mis en place avant l'installation des puits de sable pour que les conditions initiales puissent être déterminées. Le compte-rendu de l'analyse numérique propose que les puits de sable soient espacés de quatre mètres. Le performance des puits de sable sera évaluée avant et après l'installation du système de surveillance. Si la performance des puits de sable est suffisante, les puits de sables seront mis en place pour la construction du Pieu 1. Le compte-rendu de ce projet documentera la construction et la performance des puits de sable. La construction et les techniques d'installation sont uniques grâce au lieu de travail et le climat extrême.

1 INTRODUCTION

A site characterization study was initiated in 1997 for Saskatchewan Provincial Highway No. 2, near St. Louis, Saskatchewan (Figure 1), where a new bridge will cross the South Saskatchewan River. The existing bridge has surpassed its design life and the new bridge must cross the river at a different location to satisfy more suitable roadway alignment standards.

Several major geotechnical challenges were identified that will need to be addressed for the design and construction stages of the roadway and associated structures. In particular, hydraulic heads in the Hatfield Valley Aquifer at the proposed bridge crossing are five to six meters above river elevation at approximately 432 masl. Spread footings will be used for the bridge foundations, since it will be difficult to install a deep foundation. It is expected that an excavation approximately three meters below the river bed will be required to construct the spread footing. Under current hydraulic conditions, a three meter excavation would be hydraulically unstable because the artesian water pressures will cause high hydraulic gradients in the foundation soils making pier excavation difficult. Dewatering the Hatfield Valley Aquifer is not a practical alternative because a significant amount of pumping would be required to sufficiently lower groundwater pressures.

A system of sand drains will be implemented to relieve groundwater pressures in the diamicton and till layers beneath the footing. The local stratigraphic variability and uncertainty associated with numerical modelling required a full scale site investigation with instrumentation to monitor existing conditions and accurately quantify the degree of pressure relief that could be accomplished with relief wells. A trial system of low flow sand drains was implemented and their performance was remotely monitored.

Figure 1: Site location map.

2 GEOLOGY / STRATIGRAPHY

Detailed geological and geotechnical investigations for the area began in 1997 with a review of water well records and geophysical logs obtained from the provincial database. Hydraulic rotary drilling was conducted to determine the stratigraphy of the area where possible river crossings could be considered. The stratigraphy was described on numerous geological cross sections. The northern portion of cross section O-O', which trends along the final highway alignment selected, is presented in Figure 2.

The stratigraphic sequence of the area in ascending order includes: (i) Lea Park Formation (1); (ii) unnamed formation (Hatfield Valley Aquifer); (iii) Warman Formation till (4); (iv) Floral Formation (5); (v) Battleford Formation till (6); (vi) lake clay and silt (7); (vii) delta sand and silt (8); and (viii) landslide debris. The Floral Formation at the north bank consists of lower till (5d), diamicton silt (5e), upper till (5i), and fine sand (5j). The landslide debris is composed of diamicton silt and glacial deposits that are mostly upper till and Battleford Formation till and includes lesser amounts of sand and gravel.

3 HYDROGEOLOGY

The aquifers consist of artesian inter-till sands and gravels in the Saskatoon and Sutherland groups, and unnamed unconfined surficial sands and gravels on the terraces. The aquitards consist of the bedrock clay shale, unnamed lower clay and silt of the Sutherland Group, tills of the Floral and Battleford formations, and the diamicton silt of the Floral Formation. Numerous piezometers have been installed near the proposed new highway alignment, some of which are shown on the stratigraphic cross section (Figure 2) along with typical monitoring data (total heads).

3.1 Hatfield Valley Aquifer

The regional and local groundwater flow systems within the study area are dominated by the presence of the Hatfield Valley aquifer. The Hatfield Valley formed as an ice-marginal channel cut into bedrock during the first continental glaciation (Christiansen et al., 1977). The elevation of head in the aquifer near the river is approximately 432 masl (about 6 m above river elevation) and is considerably higher in the uplands approaching the river valley. The rapid decrease in hydraulic head (i.e. “draw-down”) towards the river valley is understood to be the result of natural hydraulic relief. The river thalweg is at an approximate elevation of 424 masl, which results in an upward gradient. Piezometer readings in the aquifer approximately 1 km west of the study area, near the town of St. Louis, have been measured at approximately 430.5 masl, suggesting that a localized east-west hydraulic gradient may exist.

3.2 Lower and Upper Floral Aquifer

A discontinuous sand and gravel unit (5c) at the base of the Floral Formation (lower Floral aquifer) represents a second artesian aquifer at the proposed bridge location. At locations where the Warman and Dundurn Formations are missing, the lower Floral aquifer is either not present or becomes part of the Hatfield Valley aquifer. Sand and gravel units (5f to 5h) overlying the diamicton form the upper Floral aquifer, but are discontinuous over the study area.

4 PIER ONE RELIEF WELL SYSTEM DESIGN

A dewatering system must be utilized to safely construct the piers. Therefore, a design for a dewatering system for the diamicton was required. It was anticipated that a series of sand drains (relief wells) installed in the excavation area could reduce the hydraulic gradients in the diamicton, so that construction could be safely conducted. The hydraulic gradients will increase in the glacial till as a result of the drain installation. However, higher gradients in the glacial till are acceptable, since this layer will be confined. A further benefit of this type of relief well system is that they are low-flow sand drains, designed to relieve pressure at the base of the proposed footing excavation. Therefore, it was anticipated that only a small amount of water would be discharged from the till and diamicton, and no dewatering of the Hatfield Valley Aquifer would be necessary. To determine the number and configuration of sand drains necessary to sufficiently reduce seepage gradients in the diamicton, a seepage model was constructed using input parameters as shown in Figure 3.

The numerical assessment that was conducted included the installation of a cofferdam. Although design considerations for the cofferdam have not been finalized, it is anticipated that sheet pile cofferdams will not be acceptable for this site. This is due to the high piping potential of the silty diamicton. The sand drain layout is shown in Figure 4. For the purpose of this analysis, it was assumed that the cofferdam area has dimensions of 20 m by 20 m (in plan view). A relatively fine finite element mesh was utilized within the cofferdam walls so that 0.25 m diameter sand drains may be implemented. Gradient contours for 4.5 m spaced sand drains within the cofferdam is represented in Figure 5.

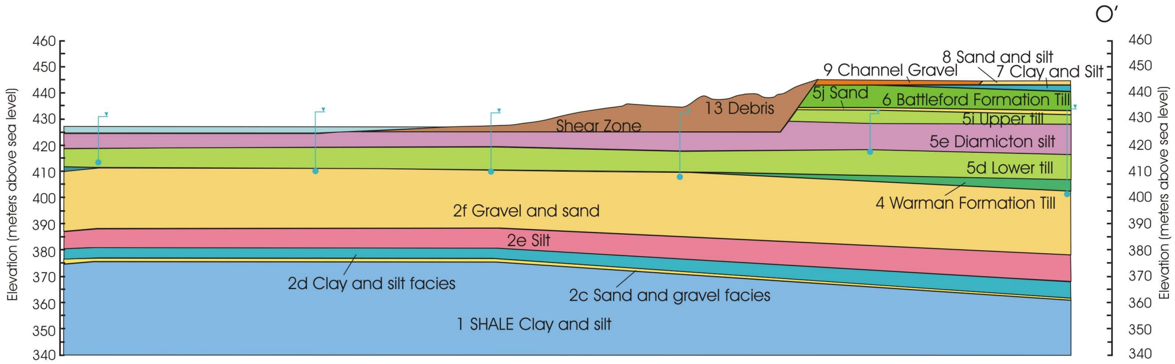

Figure 2: Stratigraphic cross section of the north riverbank location adjacent to the South Saskatchewan River.

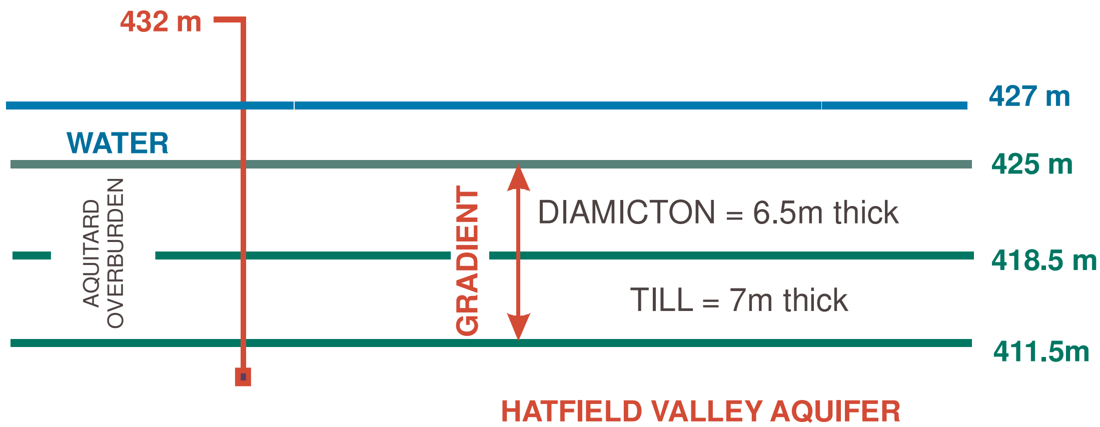

Figure 3: Schematic representation of the geological input parameters for the analysis.

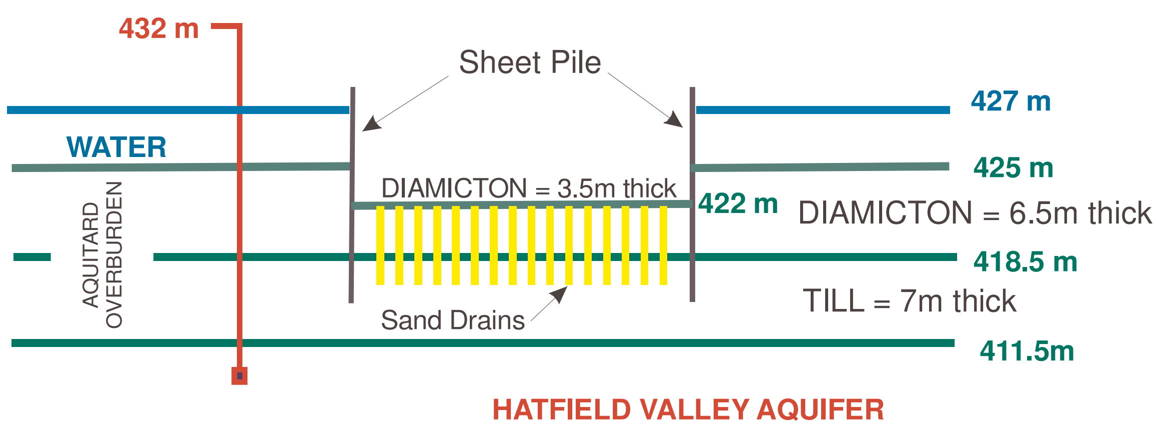

Figure 4: Schematic representation of cofferdam and sand drain configuration.

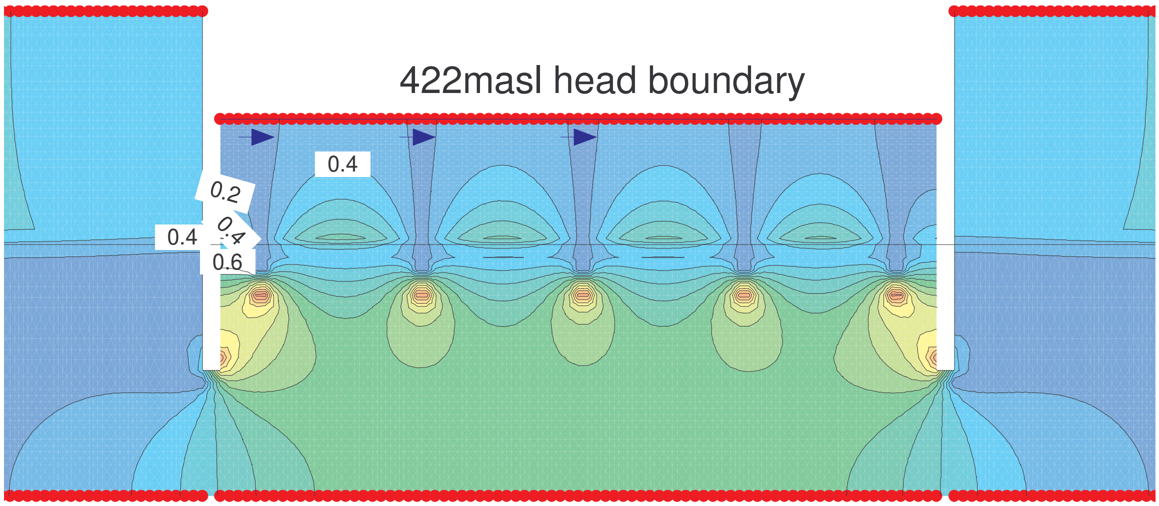

Figure 5: Gradient contours for 4.5 m spacing of sand drains within the cofferdam, following excavation of 3 m into the Diamicton.

5 DRILLING AND INSTALLING INSTRUMENTATION

Drilling and installing instrumentation and sand drains took place off an ice bridge surface at the proposed Pier 1 location in February 2008. Photos showing the drill equipment on the river ice are shown in Figures 6, 7 and 8. The Pier 1 location is considered to have the most potential for hydrodynamic instability since the top of the Hatfield Valley Aquifer is closest to the surface at this location. A total of 32 vibrating wire piezometers and 28 sand drains were installed. The instrumentation was installed before the sand drains, so that the background hydraulic conditions could be established. Based on previous numerical modelling, the sand drains were spaced four meters apart. The full effectiveness of the sand drains was evaluated by comparing hydraulic information before and after the sand drains were installed.

Figure 6: Rotary drill equipment layout

Figure 7: Drilling with air to start a borehole

Figure 8: Installation of steel borehole casing

6 MONITORING

In order to capture the impact of the sand drains on the pore water pressures in the diamicton, a state-of-the-art remote data acquisition system using the ARGUS Monitoring Software was set-up to continuously monitor the performance of the sand drains.

6.1 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's architecture is indicated in Figure 9.

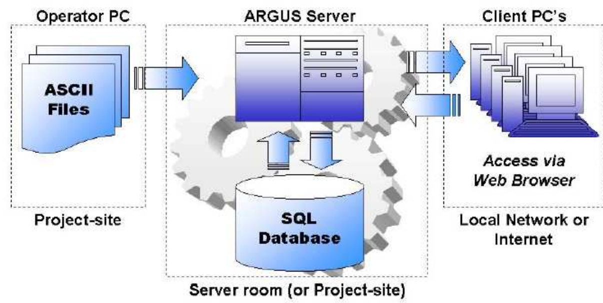

Figure 9: Schematic of ARGUS monitoring software

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 any authorized user with an internet connection.

6.2 Data Collection System

Three collecting stations were installed on the ice to collect data from all the instruments. Each station communicated to a common base station through radio frequency communications, where data was then gathered remotely. The collection stations were removed in April of 2008 to avoid damage due to spring thaw of the river ice. In order to obtain sufficient long term monitoring data, the data collection systems were set up again in the river in May of 2008 for continued summer monitoring (Figure 10).

6.3 Instrumentation Results

The hydraulic response related to the placement of the sand drains occurred over a relatively short period of time. Results showing this rapid sand drain response are presented in Figure 11. The drop in hydraulic head for the piezometers in the diamicton illustrates the potential effectiveness of the low flow sand drain system at the proposed Pier 1 location.

Figure 10: Summer monitoring stations on South Saskatchewan River at proposed Pier 1 location

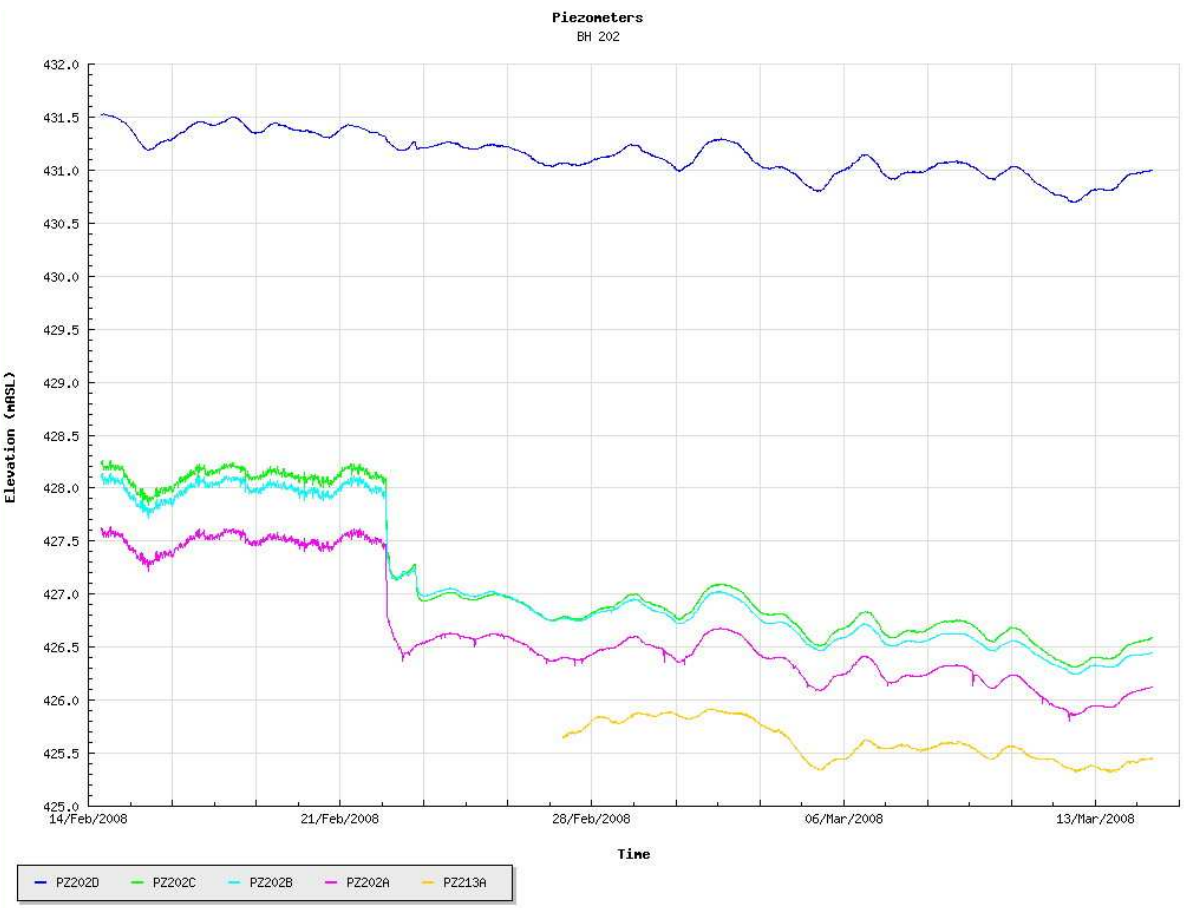

Figure 11: Results of sand drain response

7 CONCLUSION

As the sand drains were installed, the piezometers were able to show a decrease in pore pressures through the diamicton in real-time. The low flow sand drains were able to reduce foundation pressures within design parameters. With the effectiveness of the sand drains established, these sand drains will be used for the construction of Pier 1 foundation. A similar design will be used for the subsequent piers at this bridge location.

Real-time monitoring allowed the ability to capture the performance of the sand drains to assess the effectiveness of foundation pressures. The real time data acquisition system will remain in operation to gather data that supports the long term operation of the low flow sand drains.

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