TWO TRACER TESTS AT THE LOS ALAMOS CANYON WEIR

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ABSTRACT

Following the May 2000 Cerro Grande fire at the Los Alamos National Laboratory, concerns arose regarding increased sediment transport from denuded areas at the Laboratory to offsite locations. In order to mitigate potential increased offsite sediment transport, a low-head weir was constructed in the lower reaches of Los Alamos Canyon to collect the sediment load from runoff waters. During construction of the weir, surficial alluvial deposits were removed and the underlying fractured basalt bedrock was exposed. Although the weir was designed to allow for runoff through-flow, ponding was observed behind the weir on the exposed fractured basalt surface following heavy precipitation events. Therefore, the potential for enhanced subsurface infiltration from the weir ponding became a concern. Tracer tests were designed to evaluate the potential for increased hydrologic transport to subsurface perched water zones below the weir site. Potassium bromide and potassium iodide tracer tests were conducted at the weir site in April 2002 and June 2003, respectively, to evaluate the connectivity of surficial ponded waters with intermediate perched zones. Two angled and one vertical monitoring well were installed and instrumented to investigate the connection between surface water and perched waters. The tests revealed that the ponded surface water and the perched zones are well-connected. Bromide tracer was encountered down to a depth of 82 m, although the concentrations attenuated with depth. Infiltration can be rapid and travel times varied from 2 weeks to 2 months in the fractured basalt bedrock. Water level measurements obtained from four sampling ports in the vertical well indicated a response time between 1 day and 2 weeks for the intermediate perched water zones from the ponding events.

INTRODUCTION

In May 2000, a prescribed burn at Bandelier National Monument, approximately 6 km south of Los Alamos National Laboratory (LANL), went out of control and spread across the western Pajarito Plateau in northern New Mexico. This fire was named the Cerro Grande fire and approximately 30 km^2 of forested areas at LANL were burned [1]. The lack of vegetative cover in the wake of the fire created concerns regarding increased sediment transport from LANL to offsite locations. As a preventive measure, the U.S. Army Corps of Engineers constructed a low-head weir in Los Alamos Canyon to prevent sediment transport past the eastern boundary of LANL. The weir itself consists of a rock-and-mesh gabion constructed across the stream bed in Los Alamos Canyon downstream of a flat-floored area (Fig. 1). The structure is classified as "low-head" because water can pass through the gabion and significant long-term ponding behind the weir should not occur. It was designed to cause particles larger than 80 μm in diameter to settle in a flat area graded in the channel behind the weir.

Fig. 1 Photograph of the Los Alamos Canyon low-head weir with ponded runoff

However, the project neglected to consider potentially enhanced subsurface hydrologic transport from temporary ponding of water behind the weir in an area where fractured bedrock is exposed at the surface. Alluvium along the Los Alamos Canyon floor was removed in order to install the weir, thereby exposing the fractured basalt bedrock. Although the weir was designed to allow for rapid flow-through and little ponding, standing water did develop after heavy precipitation events or during spring snow melt.

Therefore, tracer tests were designed to evaluate the influence of ponded water at the weir on several thin perched water zones in the subsurface beneath Los Alamos Canyon. One vertical (Los Alamos Weir Study [LAWS]-01) and two angled monitoring wells (LAWS-02 and LAWS-03) were installed adjacent to the weir. Groundwater (perched) sampling ports were installed in LAWS-01, and moisture sensors were installed in LAWS-02. Tracer tests were conducted with potassium bromide and potassium iodide to evaluate the influence of ponded water on the subsurface perched zones. Other reports also summarize the field work and the results of the tracer tests and water level measurements in the perched water zones [2, 3].

HYDROGEOLOGIC SETTING

Geology

The weir site is underlain by fractured basaltic sequences that are part of the Cerros del Rio volcanic field that range in age from 2.15 to 2.45 Ma [4]. The basalts consist of fractured vesicular basalt to a depth of approximately 29 m that are underlain by more massive basalt and interbedded tephra. A thin clay layer is present at approximately 41 m below ground surface (bgs). The clay zone is underlain by massive basalts, vesicular basalts, interbedded tephra, and breccia that extend to approximately 86 m bgs. A thicker clay layer underlies this sequence. Refer to Fig. 2 for a geologic cross-section of the weir site.

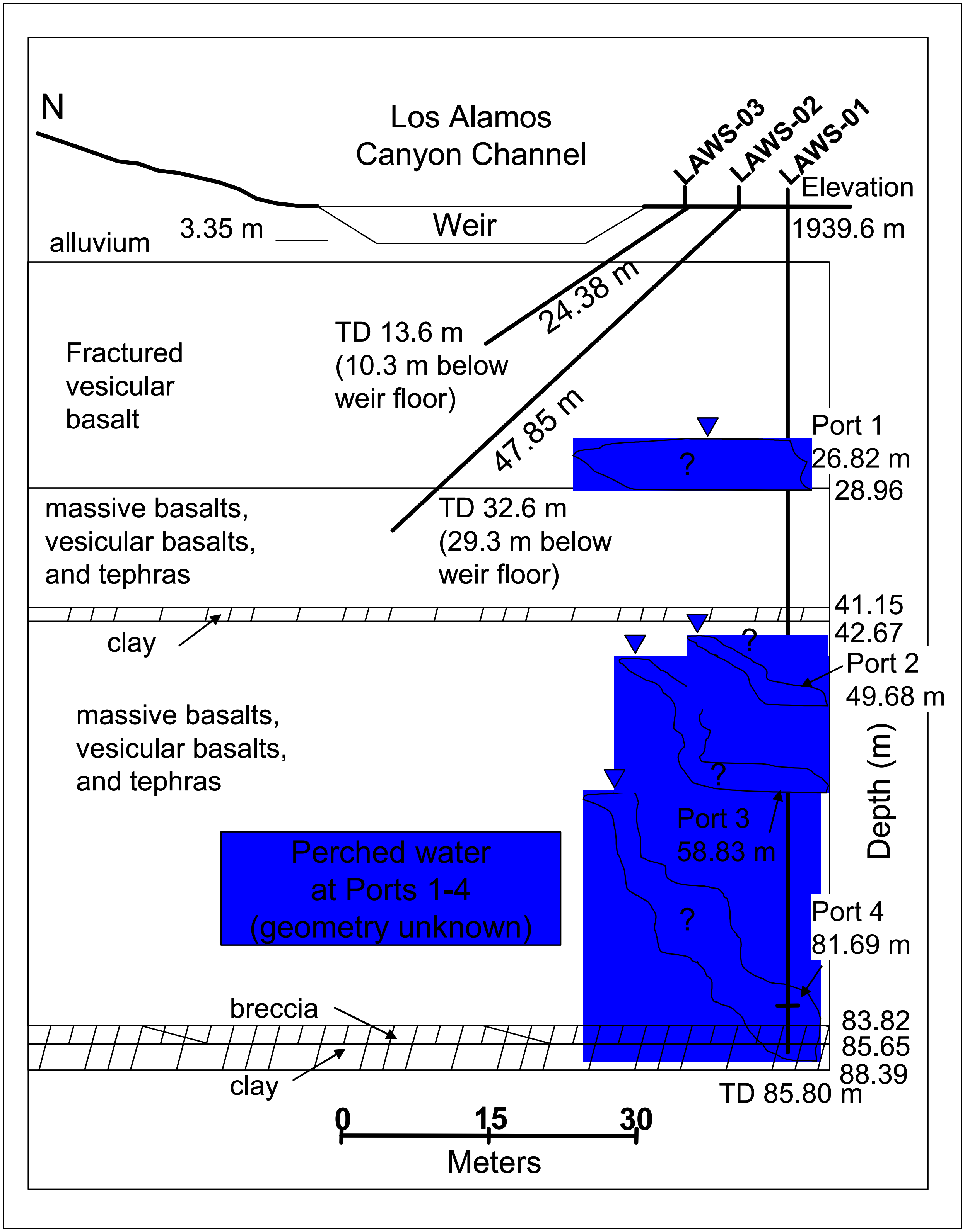

Fig. 2 Hydrogeology and locations of boreholes and groundwater sampling ports at the weir site

Hydrogeology

Streamflow in Los Alamos Canyon is ephemeral. Runoff in the lower reaches of Los Alamos Canyon near the weir is derived from the fire-impacted upper reaches of the Canyon or from a nearby tributary that discharges storm water runoff from the town of Los Alamos. Most runoff in Los Alamos Canyon occurs in response to snowmelt in the spring or to thunderstorms during the summer monsoon season. Average annual precipitation at LANL is approximately 45 cm per year, with much of the precipitation occurring during intense rain showers in July and August [4]. The rainstorms can be very localized and create runoff at a weather station where no precipitation is recorded.

Intermediate perched water zones are known to occur within the Cerros del Rio basalt beneath the LANL site. These perched water zones are known as intermediate perched water zones because the regional aquifer is normally encountered at a depth of 210 m within canyon systems at the eastern periphery of LANL [5]. During the installation of the vertical boring at the weir site, three intermediate perched water zones were encountered at depths between 24 and 30 m, 42 and 64 m and 80 to 85 m. These perched water zones are encountered within fractured zones in the Cerros del Rio basalt. The middle zone is perched upon more massive portions of the basalt and the lower zone is perched above a clay layer. The two lower perched zones were also encountered in a well approximately 300 m to the west of the weir site; the upper zone was not encountered.

INSTALLATION AND INSTRUMENTATION OF MONITORING WELLS

In April 2001, one vertical and two angled monitoring wells were installed at the weir site (Fig. 2). The vertical well, LAWS-01, is located approximately 15 m south of the weir. It was completed as an 84-m deep monitoring well that penetrates the perched water zones in the Cerros del Rio basalts. A Flexible Liner Underground Technology, Inc. (FLUTe^{TM}) rubberized membrane was installed in the well that allowed four discrete zones to be isolated and equipped with sampling ports. One sampling port was installed in the 24 to 30 m perched zone, two sampling ports were installed in the 42 to 64 m zone and one sampling port was installed in the 80 to 85 m zone. Pressure transducers were also installed in each isolated zone to record water level measurements.

LAWS-02, drilled at an angle of 43° from horizontal, is 48 m long with a vertical depth of 33 m bgs. The shallow perched water observed in Port 1 of LAWS-01 was not encountered in LAWS-02 or LAWS-03. The borehole was initially instrumented with a color-reactive liner to locate water-producing fractures. That liner was later replaced by an absorbent liner to collect water from the vadose zone. Electrical-wire pairs were installed with the FLUTe^{TM} liner to indicate relative moisture content. Normally the liner can be installed in an uncased hole, but because of borehole instability, the liner was deployed through PVC casing in which 76 cm long scallops had been cut at 15 cm intervals to permit liner access to the borehole wall.

The third hole, LAWS-03, was drilled at an angle of 34° from horizontal to a length of 41 m. However, because of borehole instability during construction, the completed borehole was only

24 m long with a vertical depth of 10.3 m below the weir floor. Because of installation problems LAWS-03 was not able to be used in the tracer test monitoring.

TRACER TEST METHODOLOGY

Tracer tests were conducted at the weir using potassium bromide in April 2002 and potassium iodide in June 2003. In both instances, the tracers were mixed with 1900 liters of Los Alamos tap water in a large trailer-mounted tank and evenly sprayed on the dry surface of the pond area with a fire hose. After the water carrier evaporated, bromide and iodide remained on the surface until mobilized by the next ponding event.

A solution of the bromide tracer, equivalent to 16,725 ppm, was used. A 1,685 ppm solution of the iodide tracer was prepared. Background perched water samples collected from LAWS-01 sampling ports 3 and 4 reported bromide concentrations of less than 1 ppm and iodide concentrations less than the detection limit of 0.05 ppm. Therefore, following a ponding event, concentrations of bromide and iodide in excess of those values in the perched water zones would indicate that the tracer had been mobilized from the pond floor.

Tracer transport was monitored via the absorbent FLUTe^{TM} liner in LAWS-02 for the bromide test and through weekly water samples collected from the four sampling ports in LAWS-01 for both tracers. Because it was faster to collect samples from LAWS-01 than to remove and replace the liner repeatedly from LAWS-02, sampling from LAWS-01 was the primary means of data collection.

DATA COLLECTION

In order to quantify precipitation, surface water flow and tracer arrival times in the vicinity of the weir, data were collected for precipitation, runoff, depth of ponded water, wetting fronts, tracer arrival times and perched water levels. Table I summarizes the types of data, the sources and the frequency of data collection. Data were collected between June 2002 and September 2003.

Table I Overview of data collection for the weir project.

Data	Purpose	Source	Frequency
Precipitation	Document storms	Weir and two nearby locations	Continuously
Runoff	Document storms, collect samples	Above and below weir	Continuously
Standing Water	Document ponding	Gage E049 at weir	Continuously
Moisture	Identify moisture and detect tracer	Wire pairs; absorbent liners	Continuously; and as warranted
Perched water	Monitor water levels, detect tracer, and determine transport time	LAWS-01 sampling ports	Water level sampled weekly

RESULTS

Results are presented for the tracer test data from LAWS-01 and the water level measurements from the four sampling ports in LAWS-01.

Tracer Tests

The results of the bromide tracer test are provided in Fig. 3. It shows the concentrations of bromide detected in the four ports in LAWS-01 over time in relation to key precipitation or ponding events. Bromide concentrations detected in ports 1, 2 and 3 ranged between 7 and 22 ppm; concentrations in Port 4 were generally below background (4 ppm) except for two sampling events with approximately 7 ppm. Water was rarely present in Port 1, at 27 m bgs for the first 4 months of measurements and was fist detected in September 2002, approximately 3 weeks after a ponding event in August 2002. From that point on, bromide concentrations were highest in Port 1. From approximately April 2003 until June 2003, water was not present in ports 1 or 2, and bromide concentrations dropped in Port 3 to around 4 ppm. Following a large runoff event in June 2003, water was again present in ports 1 and 2 and bromide concentrations ranged between 10 and 12 ppm in all four ports. Bromide concentrations gradually decreased after that event to less than 5 ppm when the last measurements were taken in September 2003, indicating that bromide had likely been flushed from the system.

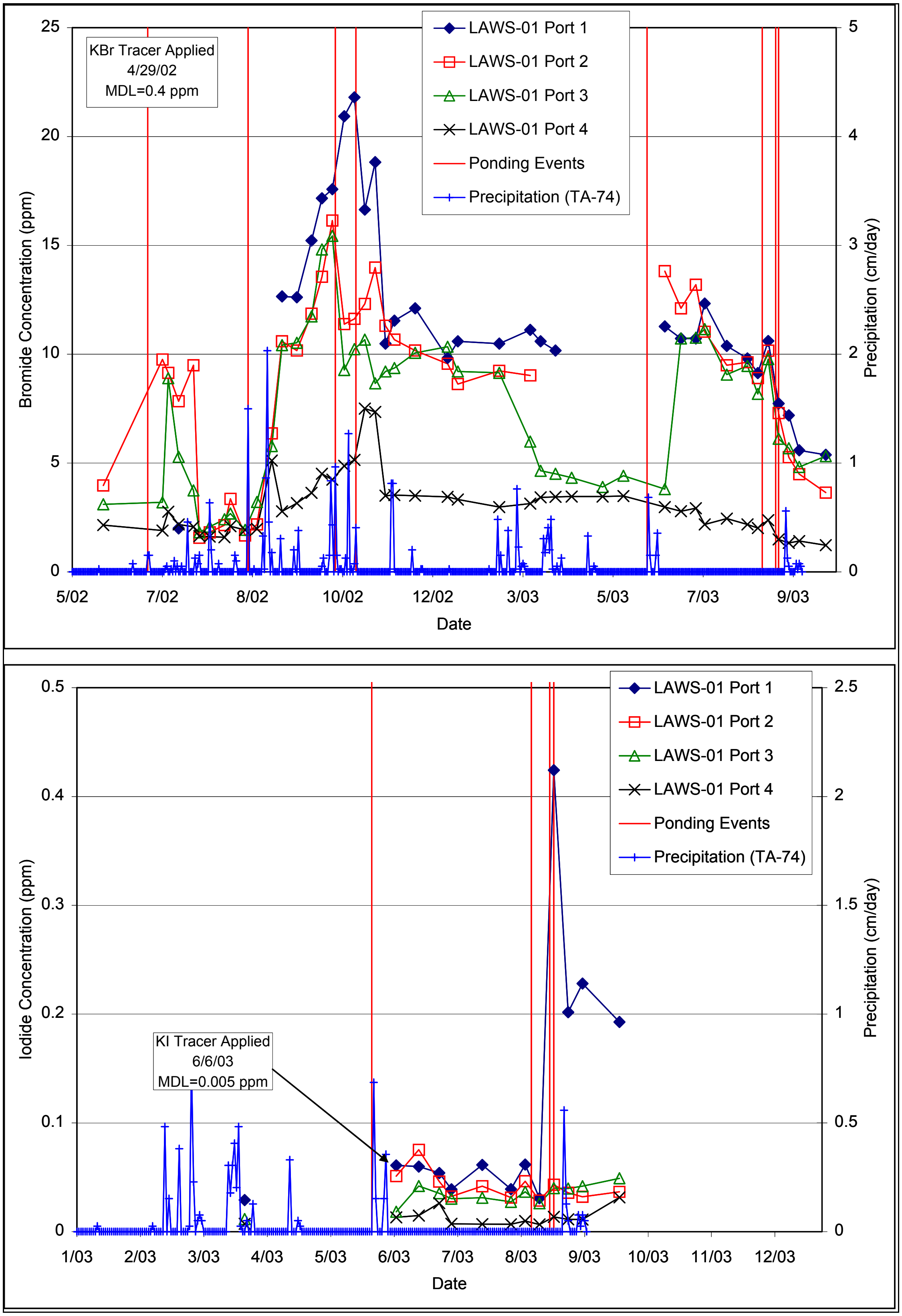

Fig. 3 Bromide (top) and iodide (bottom) concentrations at LAWS-01

The results of the iodide tracer test are presented in Fig. 4. It shows the concentrations of iodide detected in the four ports in LAWS-01 over time in relation to key precipitation or ponding events. Because of the lower levels of iodide present in the background water sampling from LAWS-01, a lower concentration of potassium iodide was applied to the pond floor than for bromide. Consequently, much lower overall concentrations were detected in the perched water zone at LAWS-01. The iodide concentrations generally ranged between approximately 0.03 and 0.07 ppm in ports 1, 2 and 3; the concentrations in Port 4 were barely detectable in all but one reading. Again, when water was present in Port 1, the iodide concentration was highest in that port for all put one sampling period, when Port 2 contained a slightly higher concentration. Following a large ponding event in August 2003, iodide concentrations in Port 1 rapidly increased to 0.42 ppm and then quickly returned to 0.2 ppm while the concentrations at the other ports remained below 0.05 ppm. Travel times for the bromide tracer varied greatly and ranged between 2 weeks to 2 months for the two middle sampling ports.

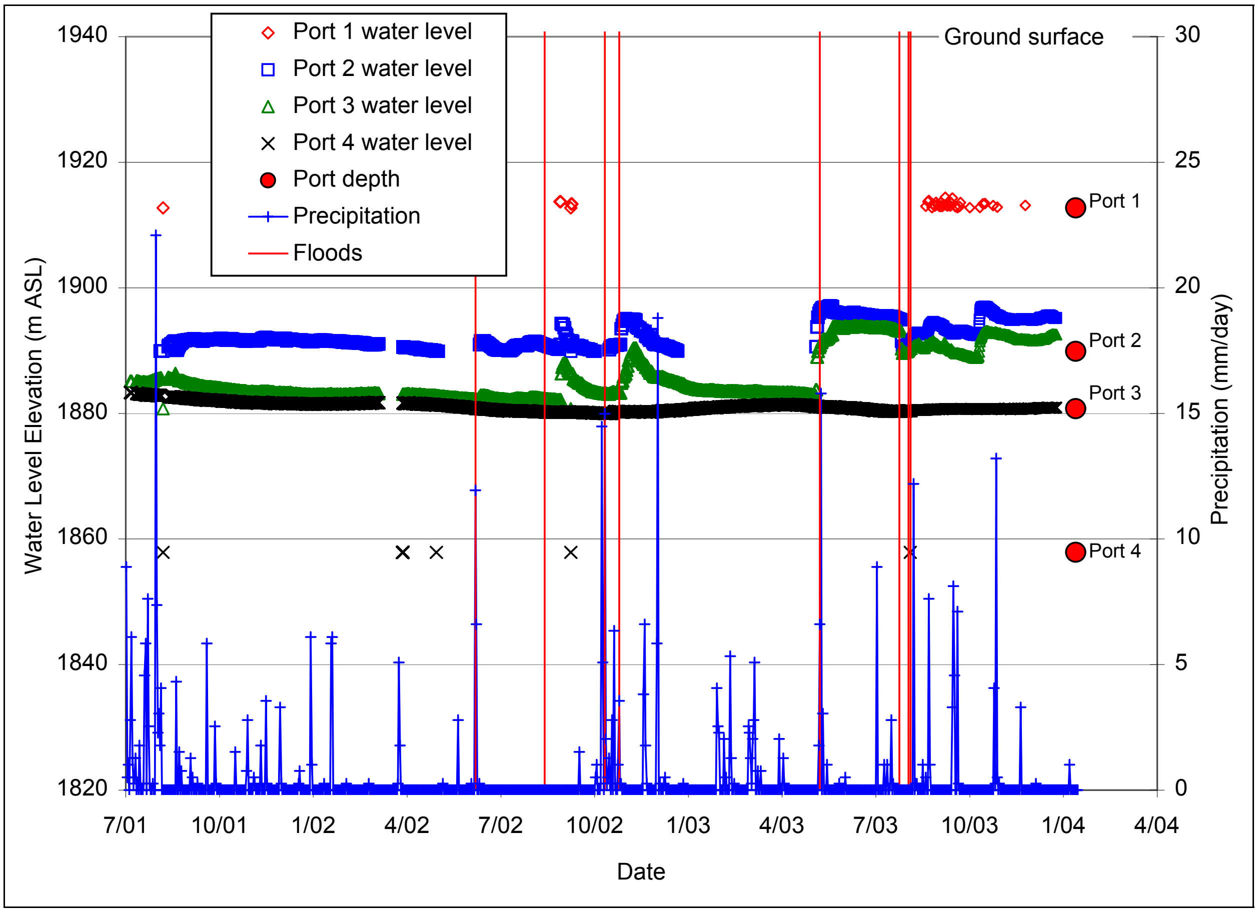

Fig. 4 Groundwater elevations measured in the four ports at LAWS-01

Water Levels

The water level measurements recorded at the four sampling ports also give an indication of connectivity between surface water at the weir and the subsurface perched zones. Water was periodically present in Port 1 and, when present, there was very little change in water level over the course of the tracer tests. In Port 4, the deepest port, water levels essentially remained the same throughout the 1.5 yr period of the test.

The most dramatic and sometimes rapid changes in water levels were observed in ports 2 and 3, at 50 and 59 m bgs, respectively. It should be noted that these two sampling ports were installed in a larger perched zone interval that extends from 42 to 64 m in LAWS-01. Therefore, it is reasonable to assume that the water levels in these ports would respond in a similar manner. However, it should be noted that water was not present in Port 2 between January and May of 2003, whereas it was present in Port 3 for the entire monitoring period. Water levels in Port 2 showed increases ranging between 2 and 7 m in response to ponding events in 2002 and 2003. Water levels in Port 3 increased between 0.3 and 13 m as a result of the same four ponding events. Sometimes the responses were immediate, e.g. within 24 hours, and other times there was a delayed reaction of up to 2 weeks. Refer to Figure 4 for water level data from the four ports.

CONCLUSIONS

The results of the bromide tracer test indicate that ponded water associated with the weir do in fact reach the three perched water zones underlying the site. Travel times range between 2 weeks to 2 months, with no clear correlation to the amount of ponding at the weir. The results also indicate that the bromide concentrations attenuated with depth and were only present above background at the lowest perched zone in two sampling events. The zones where the highest concentrations were recorded were the two shallowest zones at 27 m and at 50 and 59 m bgs.

The results of the iodide tracer test are inconclusive, pending data collection following future ponding events, because iodide concentrations recorded in the perched water zones were essentially slightly above background concentrations. One exception is the August 2003 concentration in Port 1, clearly indicating that the iodide tracer was detected in that zone.

The water level measurements indicate that the intermediate perched zone between 42 and 64 m below grade showed the most changes over the 1.5 year period of data collection. The complicated results indicate a complex network of fractures systems underlies the weir site and that differing runoff rates and ponding depths likely influence the direction and degree of infiltration into the subsurface.

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