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FINAL REPORT

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International Resources Group Ltd.
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Leakage Detection Survey of the Qaraoun Dam, Lebanon using Remotely Operated Vehicle

ASLP Project No. RU10-009

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Executive Summary

In April of 2010 a remotely operated vehicle (ROV) inspection was completed on the upstream face of the Qaraoun Dam in Lebanon. The survey was completed under contract with International Resources Group (IRG) of Washington, D.C. with funding from the United States Agency for International Development (USAID) for the Litani River Authority (LRA) who operates the facility. This inspection was for the purpose of identifying leaks between the joints on the face slabs of the dam. To complete the inspection, Aquatic Sciences L.P. of Orchard Park, New York, operated their *Seabotix LBV300XL* ROV equipped with a dye injection system along each joint on the dam face.

While inspecting the dam face general conditions of the concrete slabs were observed. In many areas offsets and misalignments of the slabs were noted. In some areas broken or spalled edges were identified. Silt accumulation at the deep sections of the dam was heavy, thus covering some features on the dam face.

Two areas with large leaks were identified. The first major leak was located at Vertical Joint 24 at 831.3 m elevation. This leak was on a length of the vertical joint below the third horizontal joint. The second area with a large volume leak was detected at Vertical Joint O1 just above the abutment at elevation 847.4 m. It appeared two leaks in the same proximity were identified here. This area had been reported by LRA as repaired in August of 2009. Other smaller leaks were identified at Joint 32 elevation 838 m, Joint 31 at 835 m, Joint 29 at 842 m and Joint O2 at 835 m.

Since the ROV inspection was completed in a timely manner, some additional time was used to inspect the power tunnel inlet, the irrigation tunnels inlet and the spillway structure. During the inspection, the ROV was able to positively identify problems along the face of the dam relating to the source of leaks. The goals of the inspection were completed successfully.

الملخص التنفيذي

في نيسان من العام ٢٠١٠، انتهت عملية الكشف (مسح التسرب) على الواجهة الامامية المحاكية للمياه في سد القرعون، بواسطة جهاز غاطس يمكن التحكم به من خارج المياه، حيث تم تنفيذ هذا المسح من قبل شركة Aquatic Sciences L.P. of Orchard Park, New York بموجب عقد مع شركة مجموعة الموارد الدولية (IRG) و بتمويل من الوكالة الاميريكية للتنمية الدولية (USAID) عبر برنامج دعم إدارة حوض نهر الليطاني (LRBMS) لصالح المصلحة الوطنية لنهر الليطاني التي تدير منشآت القرعون.

ان الهدف من هذا المسح كان تحديد أماكن التسرب من الـــ water stop أو الفواصل الكاوتشوكية التي تمنع دخول المياه إلى جسم السد من البلاطات الخرسانية التي تشكل الواجهة الأمامية المحاكية للمياه ولإنجاز المهمة وتحقيق الهدف قامت شركة Aquatic Sciences بإستقدام غاطس ماركة Seabotix LBV 300XL ROV مجهز بمعدات لحقن المواد الملونة في أماكن التسرب بغية الوقوف على قيمته وحجمه.

بشكل عام استطعنا من خلال هذا المسح ملاحظة نمو بعض الكائنات والطحالب بشكل غير منتظم على الواجهة المذكورة وتكسير في زوايا البلاطات التي تتشكل منها الواجهة. كذلك تم ملاحظة بعض الطمي في الأماكن العميقة من السد.

إن أهم النتائج التي افضى إليها هذا المسح هي اكتشاف نقطتان للتسرب يمكن اعتبارها كبيرة وهي على الفاصل العامودي رقم ٢٤ وهي على ارتفاع ASL ٨٣١,٣ م، أما نقطة التسرب الكبيرة الثانية تم اكتشافها على الفاصل العامودي رقم ٠١ وعلى ارتفاع ٨٤٧,٤ م وفي الواقع هي عبارة عن نقطتين للتسرب ولكنهما متقاربتان لذلك تم اعتبارهما نقطة واحدة وهذه المنطقة أي منطقة التسرب المذكورة قد تم التنويه عنها في تقارير المصلحة الوطنية لنهر الليطاني وخاصةً في تقرير آب ٢٠٠٩، كذلك تم تحديد نقاط تسرب صغيرة كثيرة، لاسيما على الفاصل ٢٣ عامودي وعلى ارتفاع ASL ٨٣٨ م على الفاصل ٣١ ارتفاع ASL ٨٣٥ م، على الفاصل ٢٩ ارتفاع ASL ٨٤٢ م وعلى الفاصل ٠٢ ارتفاع ASL ٨٣٥ م.

كما وقامت الشركة ذاتها بالكشف عن المأخذ الرئيسي للنفق المؤدي إلى معمل إنتاج الطاقة في مركبا ومأخذ مشروع الري القناة ٩٠٠ كذلك منشأة التصريف الـــ spillway.

لقد تمت المهمة بنجاح كبير، وتم تحديد أماكن التسرب بشكل دقيق، لذلك يمكن تقييم عمل الجهاز الغاطس ايجاباً.

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Leakage Detection Survey of the Qaraoun Dam in Lebanon
April 20-26, 2010

1.0 INTRODUCTION

International Resources Group (IRG), of Washington, D.C., contracted Aquatic Sciences L.P. (ASLP) of Orchard Park, New York to assist with the locating and assessment of leaks in the Qaraoun Dam concrete face located in Lebanon. The project was funded by the United States Agency for International Development (USAID) for the Litani River Authority (LRA). The dam is rock filled with a concrete face and is 60 m high, 1,100 m long. Created in 1959, it supplies three hydro electrical stations and provides irrigation water to both the Bekaa and the South regions. ASLP's purpose was to provide on-site inspection services using video equipment to show existing joint conditions along the face and at the bottom of the dam. Additionally, dye injection was undertaken to positively identify leakage through any cracks. The inspection was completed successfully between April 20, 2010 and April 26, 2010.

1.1 Facility Description

The Qaraoun Dam is located at the southern end of Lake Qaraoun, which is located in the southern region of the Bekaa Valley, and is Lebanon's largest man-made lake. The dam is 40 km southeast of Beirut and 30 km east of Saida at geographical location 33° 32.886' North, 35° 41.412' East. At 2 km wide, 5 km long, and 12 km^2 in surface area, this artificial lake was created by the dam in 1959. The lake is located on the Litani River. It starts in the north of Lebanon and rises in the Bekaa Valley, west of Baalbek and naturally empties into the Mediterranean Sea north of Tyre. The dam, which holds back Lebanon's longest river, is 60 m high and 1,100 m long. A gallery 6,400 m carries the water to the first underground hydroelectric station. The dam crest is at 861 m elevation and the maximum water level is at 858 m elevation.

The structure is over 160 m wide (upstream to downstream) at the base and 6 m wide at the top. The sealing surface of the rock filled dam is concrete slabs 40 cm thick. The concrete slabs are made in panels of varying dimensions; most panels are 14 m wide and 12 m high. There is approximately 35,000 m^2 of concrete surface.

The concrete panels are jointed by waterstops with voids above the waterstops filled with sealant. These joints were labeled at the time of the inspection along the length of the dam. The numbering method starts at the center abutment and carries outward. East of the abutment the first joints were labeled D, C, B, A. Beyond this, to the east, the joints were labeled from 1 to 48; Joints 3, 14 and 16 were omitted from the dam crest. To the west of the abutment the joints were labeled from O1 to O33. Horizontal joints were not labeled, so vertical measurements were related to elevation ranging from 800 m to 860 m above sea level.

The dam is operated and maintained by the Litani River Authority (LRA), which was formed in 1954 to manage the Litani River and Watershed water usage and hydro-electric power generation. Three hydro-electric power plants operate using the discharge of the dam.

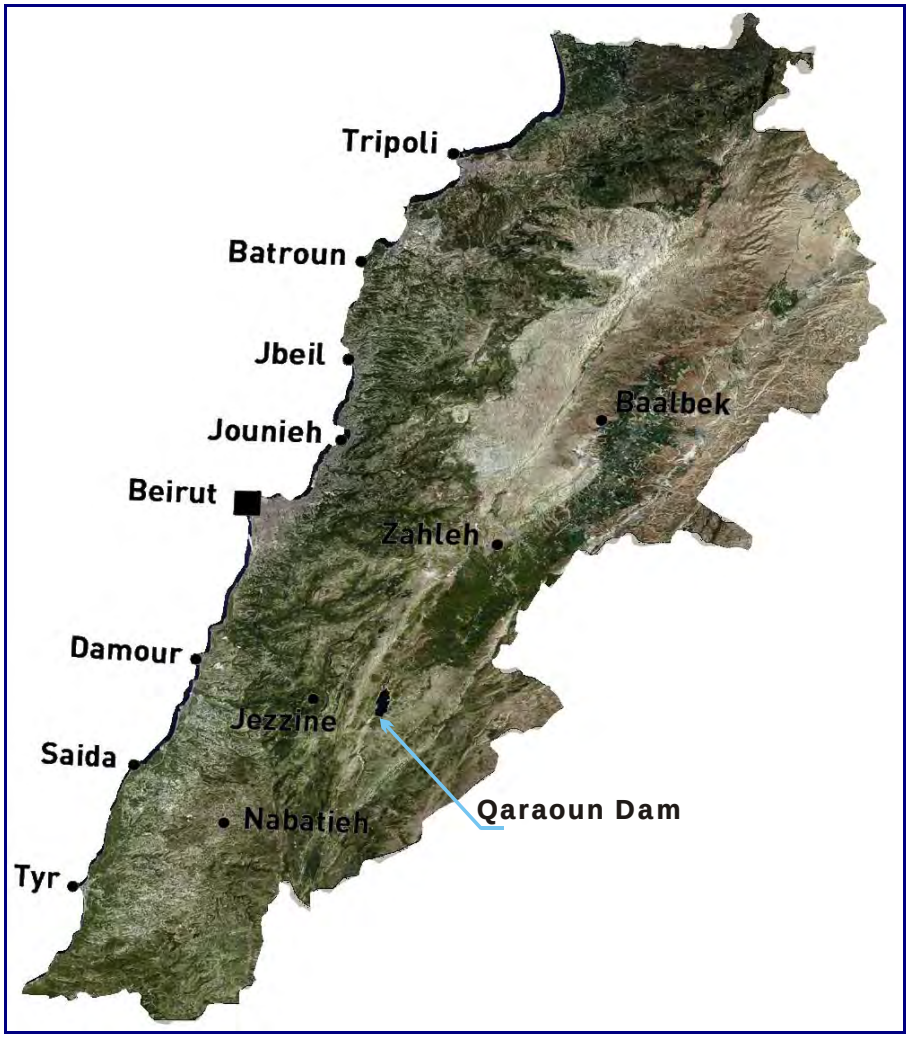


Figure 1: Location of the Qaraoun Dam in Lebanon

2.0 METHODOLOGY

The inspection of the Qaraoun Dam required the use of a specialized remotely operated vehicle (ROV) outfitted with navigation sonar and additional purpose-built equipment.

2.1 ROV Equipment

Aquatic Sciences chose the *Seabotix LBV300XL* ROV due to its capabilities and size. The vehicle was ballasted to be neutrally buoyant in fresh water. The vehicle uses six electric thrusters to propel itself through the water. Four horizontal thrusters are for forward travel capable of pulling long tether lengths. The *Seabotix LBV300XL* has a vertical and a lateral thruster to enable the operator to move vertically and laterally through the water column. The vehicle was equipped with two variable intensity 50W Quartz-halogen lights to illuminate the area of inspection for the high resolution color camera. The ROV was also equipped with a second low-light wide-angle color camera.

The system utilizes 740 m of neutrally buoyant, high visibility umbilical cable. This umbilical houses both signal and power conductors (fiber optic and copper respectively), along with a Kevlar strength member and abrasion resistant protective jacket. The umbilical is neutrally buoyant in water to reduce the drag and allow for longer penetration distances. An ROV pilot controls the vehicle movement, lighting, and camera position from the surface with the use of a handheld control console.

The video signal is routed to the surface through a fiber optic cable in the umbilical; the fiber optic signal is converted in the reel junction box to an analogue video signal which is then fed into a high resolution video monitor for the pilot to view. The video signal is also recorded in real time in digital format. Audio commentary is added to document any points of interest and anomalies as they are seen during the inspection.

The *Seabotix LBV300XL* is approximately 40 cm long, 35 cm wide and 25 cm high weighing 15 kg. The size and weight of the *Seabotix LBV300XL* allows the vehicle to be deployed by hand to difficult access points. Appendix 5 contains a specification sheet for the *Seabotix LBV300XL*.

Figure 2: *Seabotix LBV300XL* Prior to Deployment

2.2 Navigation Sonar

A *Tritech Micron DST* scanning sonar operating at 650 kHz was mounted on the ROV for navigation purposes. The sonar, mounted upright, scans on a horizontal plane generating a plan view image of the surrounding area using an acoustic beam 35 degrees tall and 3 degrees wide.

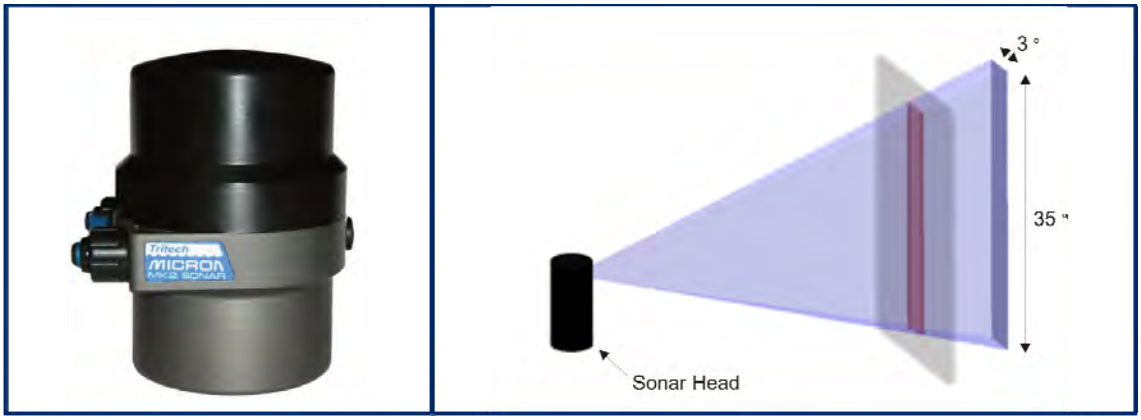


Figure 3: Tritech Micron DST Sonar Beam Pattern

The sonar is positioned so as to provide a full 360 degree view around the ROV. Targets are identified by strong returns (yellow) and shadows (black).

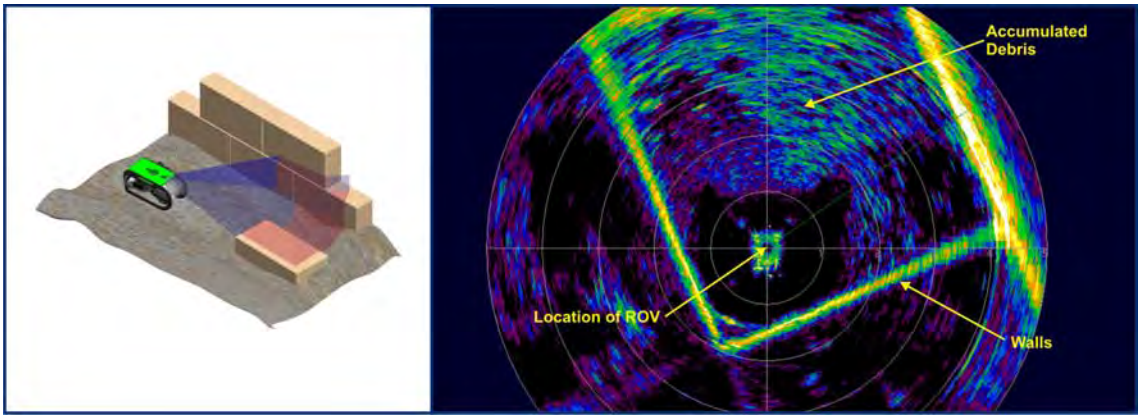


Figure 4: Navigation Sonar

2.3 Additional Equipment

To aid in the detection of leaks along the joints on the dam face bright nylon cords were attached to the front of the ROV to form “telltales”. Upon the presence of flow, the strings are pulled toward the source of the leak, providing a quick visual representation in front of the video camera.

As a further indicator of flow, a dye injection system was integrated onto the ROV. This system uses a bladder of premixed water soluble dye tablets piped to a mini pump coupled to the ROV actuator. The pilot is able to meter out quantities of dye on demand, useful for monitoring for leaks with the color camera.

2.4 Inspection Process

The ROV equipment was mobilized via air freight to Beirut, Lebanon. An open bed truck was used to transfer equipment form the shipping depot to the dam site. Warehouse facilities were provided to help with the mobilization and security of the ROV equipment. The system was setup in the rear of a work vehicle to provide shelter for the equipment and operator from weather and sunlight. The ROV tether and winch were positioned at the back of the work vehicle and were accessible to the tender during operations. The client supplied a 6000 watt generator which was the source of electrical power for all inspections.

During the inspection the support vehicles were positioned near the area being surveyed. The ROV was lowered by its tether down the face of the dam to the water. The ROV then carried out the inspection controlled by the operator, with the tether managed by the tender at the dam crest. Throughout the inspection audio commentary was added to the video detailing conditions. As well, the client provided a drawing that was marked digitally with the progress of the inspection and any faults or areas of interest.

Figure 5: ROV being lowered down the dam face to the water

The inspection initially originated at the west end of the dam and traveled east. On the first day the joints near the water surface were prioritized since water levels were expected to lower over the inspection period. After completing the upper portion of the dam, the inspection proceeded along deeper joints. Due to changing weather conditions the survey shifted from area to area to keep within the schedule. On April 25, 2010 an outage of the Markabi power house was scheduled between 06:00 and 10:00 for inspection of the tunnel inlet and surrounding dam face.

In general, each vertical joint was inspected from top to bottom. On the ascent, horizontal joints were inspected leading off the vertical joint. The ROV then returned to the vertical joint and continued ascending. This approach was required to reduce the risk of entanglement on the artifacts along the dam face.

Following the successful completion of the entire dam face, further inspections were requested by LRA. These inspections took place at one of the irrigation intakes checking for sediment and the overflow structure checking for leaks. For both of the additional inspections a boat was used to aid in tending the ROV away from the dam. Finally, on April 26, 2010 the ROV was used to inject dye into one of the leaks found on the dam face.

Following the additional inspection work, the ROV was demobilized and packed into shipping crates. The crates were then returned to the shipping depot by an open bed truck for return transit. A brief meeting was held with IRG and LRA to discuss the findings and proposed solutions. Additional site photographs are provided in Appendix 4.

3.0 INSPECTION OBSERVATIONS

During the period from April 20, 2010 to April 26, 2010, a remotely operated vehicle (ROV) inspection was completed on the face of the Qaraoun Dam in Lebanon. During the time of the inspection the water level was high, between 856.30 m and 856.84 m. Weather varied over the period from mostly sunny to thunderstorms with rain. Aquatic Sciences L.P. of Orchard Park, New York completed the inspection under contract by International Resources Group (IRG) funded by the United States Agency for International Development (USAID). The Qaraoun Dam is managed and maintained by the Litani River Authority (LRA).

The inspection of the dam started at the west end working east along the upper section. The lower sections of the dam were completed in changing order depending on area. Documentation of the joint conditions were made during the inspection. This information is provided in Appendix 2. All references were labeled with the date and time matching the video and sonar data. Video still images are available in Appendix 1.

3.1 Limitations

The inspection completed by Aquatic Sciences L.P. in April 2010 was intended for the purposes of locating leaks, i.e., identified water flow from upstream to downstream, on the face of Qaraoun Dam. The inspection is based only on visible features/areas of the dam below water on the dates of the inspection. This inspection did not entail structural, stability or hydraulic investigations. General conditions of the concrete panels, their joints and features were noted in video commentary and this report, however are in no way inclusive of all characteristics present. The report does not include the evaluation from a specialist on the general condition, safety or stability of the structure.

3.2 General Findings

During the inspection of the Qaraoun Dam, water elevations were recorded daily from the water level staff mounted on the southwest side of the overflow structure. The water level dropped uniformly over the inspection period from 856.83 m to 856.30 m. Water elevations are used with reference to the ROV depth gauge to determine vertical position on the dam face.

Date	Elevation (m)
2010-04-20	856.84
2010-04-21	856.74
2010-04-22	856.62
2010-04-23	856.55
2010-04-24	856.46
2010-04-25	856.38
2010-04-26	856.30

Table 1: Water elevations during the inspection period

Reporting for the Qaraoun Dam has been divided into seven sections from left to right as viewing from upstream. In general, the conditions were observed to be similar across the face of the dam. Joints were variable in alignment and spacing. In most cases horizontal joints were small and well aligned, vertical joints were larger in separation. The inspection observations map in Appendix 2 provide locations to features documented during the inspection. The maps were drawn with information and measurements collected at the dam, as well as a drawings (dated December 12, 1979) provided by the client/owner.

3.2.1 Section 1

Refer to Appendix 2-1.

Observation Map Sheet 1 covers from vertical mark 49 to 44. The location marked 49 is the end of the dam structure at the east. Between joint marks 49 and 47 no water was present at the base of the slabs at the time of inspection. The ROV had adequate water depth to work from Joint 46 and west. This area was inspected on April 22, 2010. At the junction of Vertical Joint 45 and the upper horizontal joint some spalling on the slab edge was noted. The bottom had little debris and silt accumulation. No leaks were detected in this area.

3.2.2 Section 2

Refer to Appendix 2-2.

Observation Map Sheet 2 covers from Vertical Joint 43 through to Vertical Joint 30. A number of areas were noted with raised offset slab sections. Along the upper horizontal joint between Vertical Joint 43 and 44, at Vertical Joint 38 and at Vertical Joint 32 the greatest offsets were noted. In these areas the upper slabs were lifted.

Some broken concrete edges were noted in this area on the upper horizontal joint between Vertical Joint 37 and 38 and along Vertical Joints 34 and 36. A minimal amount of silt and debris was on the bottom in this area.

Three small leaks were noted in this section; one along Vertical Joint 32 between elevations 837 m and 842 m and the second small leak at elevation 835 m along Vertical Joint 31. The third leak was at elevation 836.1 m along Vertical Joint 33.

3.2.3 Section 3

Refer to Appendix 2-3.

Sheet 3 covers the area from Joint 29 through to Joint 15. At Vertical Joints 27 and 24 offsets were noted at the top of the dam above the water line. Along the upper horizontal joint in this section the upper slabs were generally raised. Numerous areas with shifts and offsets were noted.

Two leaks were identified in this section; one along Joint 29 at elevation 840.1. The second, a large leak at 831.3 m elevation along Joint 24. This second leak was recorded on April 22 at 16:16 and was observed to be less than 1 m in length with an opening 2 cm wide. A high velocity of flow was noted through this opening, evident by the clean concrete surrounding the leak.

3.2.4 Section 4

Refer to Appendix 2-4.

In Sheet 4, the deepest section of the dam is covered from Vertical Joint 13 to Vertical Joint D. The dam appeared to have few offsets and misaligned joints in this area. Across the upper horizontal joint at 851 m a continuous offset where the upper panels were raised above the second row of panels was observed. Near the area east of the abutment at Vertical Joint C, larger offsets were noted where the east panels were lower than those adjacent to the abutment.

In a few areas spalling was noted on joint edges including: Joint 13 at 842 m, Joint 6 at 851 m and Joint 2 below 851 m. In the deeper section of the dam several more rows of scaffold bracketing were observed below each horizontal joint. In some areas ladders were present along the vertical joints. Rope, netting and other debris were attached or present on and around the scaffold sections, shown in Image 1-9 in Appendix 1. On the bottom a thick layer of silt was present generally obstructing a view of the horizontal joints. A variety of natural and artificial debris was present on the reservoir floor.

Along Vertical Joint C and D, both at 855 m elevation a possible leak was observed.

3.2.5 Section 5

Refer to Appendix 2-5.

Sheet 5 covers the area heading west of the abutment from Joints O1 to O16. The vertical joints near the abutment here are raised on the east side, as the west panels move backwards. Along Joint O2 the offset at 840 m was measured at approximately 25 cm. Some other offsets were noted along Joint O5 and at the upper horizontal joint at O9 and O16. In many areas the edges of the concrete slabs were broken.

A large leak was observed at Vertical Joint O1 on April 25 at 14:35. This leak appeared to be present in two locations near the third horizontal joint down. This was an area that had been repaired in August of 2009. Another possible leak was identified just above this large leak on Joint O2 and below at elevation 834.8 m. Some other possible leaks were noted at Joint O8 at 854.6 m and at Joint O10 at elevation 855.7 m.

3.2.6 Section 6

Refer to Appendix 2-6.

In Sheet 6, the area spanning from Vertical Joint O17 to O30 is covered. In general, most offsets were observed along the interface between the upper two rows of slabs where the upper slab is usually raised outwards. Joints O18 and O19 had broken edges along the vertical joints. At Joint O24 and elevation 842 m the slabs were offset with spalled edges.

No leaks were identified in this area.

3.2.7 Section 7

Refer to Appendix 2-7.

Sheet 7 provides coverage of the west end of the dam, from Vertical Joint O31 to O33. This area was shallow with few features noted. No leaks were observed in this section.

3.3 Identified Leaks

At the time of the April 2010 ROV inspection of the Qaraoun Dam, two major leaks and several smaller leaks were identified.

The first major leak was located at Vertical Joint 24 at 831.3 m elevation. This leak was on the vertical joint below the third horizontal joint. The leak had a high volume of flow through an opening 2 cm wide and less than 1 m high, found on April 22 at 16:16. (See Image 1-6 & 1-7 in Appendix 1.)

The second area with a large volume leak was detected at Vertical Joint O1 just above the abutment at elevation 847.4 m. It appeared two leaks in the same proximity were identified here on April 25 at 14:09 and 14:35. This area had been reported by LRA as repaired on August 14, 2009. On April 26, 2010, 1.5 liters of dye was injected here to aid in locating the path of the leak (shown in Image 1-22, Appendix 1).

Other leaks were identified at Joint 32 elevation 838 m, Joint 31 at 835 m, Joint 29 at 842 m and Joint O2 at 835 m. These joints passed less volume than those mentioned above.

3.4 Additional Areas Inspected

In addition to the leak inspection of the dam structure, other locations were also inspected at the Qaraoun Dam. These included the intake for the power tunnel, the intake for the irrigation tunnels and the spillway structure.

3.4.1 Power Tunnel Intake

On April 25 at 07:45 during the scheduled outage, the ROV was used to inspect the opening of the power tunnel intake to observe the general condition and check for accumulation of debris. The intake was located using navigation sonar and inspected while the ROV was tended from the dam face.

Using sonar, the intake opening was measured at 3 m wide. The depth gauge was used to measure the open clearance in elevation of the intake as 4.6 m. Twelve horizontal vanes were counted equally spaced along the openings height. All horizontal surfaces had some silt accumulation present (Image 1-13, Appendix 1). The structure appeared to be in good condition with no signs of deterioration or damage. Additional details are present in Figure 3-2, Appendix 3 in the collected sonar imagery.

3.4.2 Drainage Intakes

Two drainage intakes are present north of Vertical Joint 19 approximately 100 m from the dam. The ROV navigation sonar was used to locate these structures with the ROV from in front of the dam. In order to limit the risk of entanglement, only the west intake structure was observed with the ROV.

The structure was approached from the west side and descended to the top of the inlet. The concrete appeared to be in good condition. Very little silt and debris was present on the structure. The top of the intake was several meters above the silt layer on the reservoir floor.

Using sonar, the structures appeared to be hexagonal in shape with features running south towards the dam. Appendix Figure 3-4 shows three I-beam lengths between the west intake and the dam face. The east intake was also observed by using the navigation sonar.

3.4.3 Spillway Structure

The reservoir spillway structure is north of Vertical Joint 23 about 50 m from the dam. An inspection of this structure was requested by LRA for the locating of leaks. The ROV was tended from the structure while operated from the dam. The south side was inspected, where a notable number of patches of rough concrete forming were observed. The underside edge of the overflow flume was rough with small holes present (Image 1-18, Appendix 1). No leaks were positively identified by the ROV.

The inside of the spillway risers were observed from the top of the structure. Several small leaks were visible. Photographs of the inside of the spillway are provided in Appendix 4.

4.0 SUMMARY

From April 20, 2010 to April 26, 2010, a remotely operated vehicle (ROV) inspection was completed on the upstream face of the Qaraoun Dam in Lebanon. This inspection was for the purpose of identifying leaks between the joints on the face slabs of the dam. To complete the inspection, Aquatic Sciences L.P. of Orchard Park, New York, operated their *Seabotix LBV300XL* ROV equipped with a dye injection system along each joint on the dam face.

While inspecting the dam face, general conditions of the concrete slabs were observed. In many areas offsets and misalignments of the slabs were noted. In some areas broken or spalled edges were identified. Silt accumulation at the deep sections of the dam was heavy covering some features on the dam face.

Two areas with large leaks were identified. The first major leak was located at Vertical Joint 24 at 831.3 m elevation. This leak was on the vertical joint below the third horizontal joint. The second area with a large volume leak was detected at Vertical Joint O1 just above the abutment at elevation 847.4 m. It appeared two leaks in the same proximity were identified here. This area had been reported by LRA as repaired in August of 2009.

Other smaller leaks were identified at Joint 32 elevation 838 m, Joint 31 at 835 m, Joint 29 at 842 m and Joint O2 at 835 m.

Since the ROV inspection was completed in a timely manner, additional time was used to inspect the power tunnel inlet, the irrigation tunnels inlet and the spillway structure.

During the period of the inspection the ROV was able to positively identify problems in the face of the dam relating to the source of leaks.

APPENDIX 1:

Video Images

Image 1-1: 2010-04-20-1703 - Joint offset at joint O9 and upper horizontal joint.

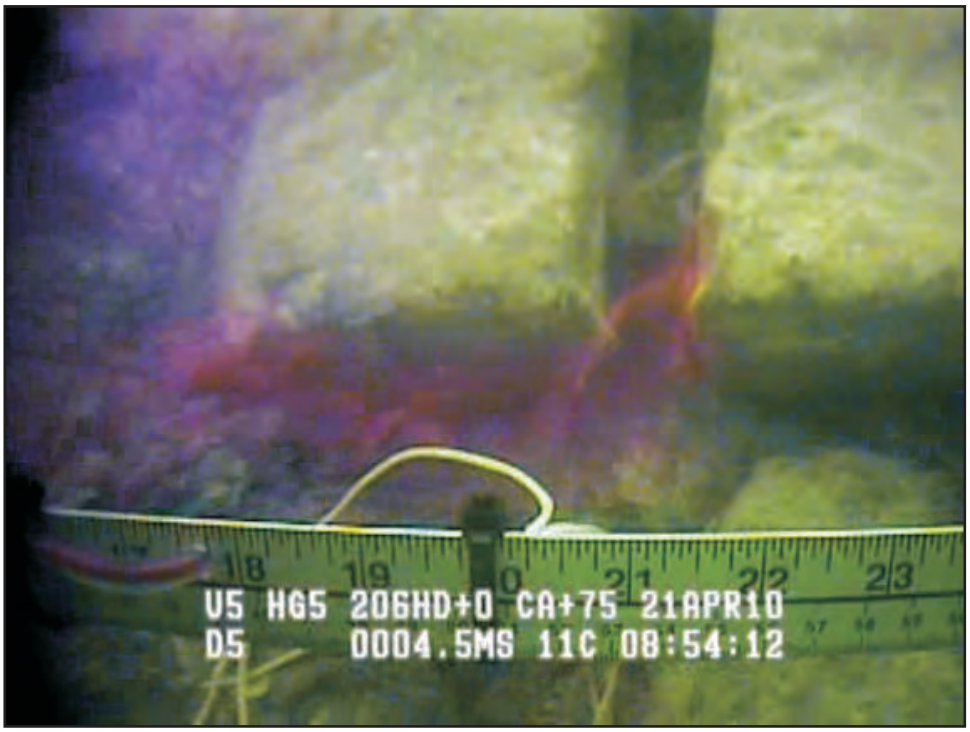


Image 1-2: 2010-04-21-0854 - Joint intersection at joint O6 and upper horizontal joint.

Image 1-3: 2010-04-21-1440 - Vertical joint 25.

Image 1-4: 2010-04-21-1737 - Leak in vertical joint 29.

Image 1-5: 2010-04-22-0955 - Ladder at vertical joint 21.

Image 1-6: 2010-04-22-1617 - Large leak closeup at joint 24.

Image 1-7: 2010-04-22-1618 - Large leak in vertical joint 24 at 831.3 m elevation.

Image 1-8: 2010-04-24-1545 - Raised slab at joint O2.

Image 1-9: 2010-04-24-1706 - Net, ropes and debris hanging on platform near joint 10 at elevation 815 m.

Image 1-10: 2010-04-25-0635 - Debris at bottom of abutment.

Image 1-11: 2010-04-25-0635 - Raised slab along joint C.

Image 1-12: 2010-04-25-0731 - Silt at floor of power tunnel inlet.

Image 1-13: 2010-04-25-0734 - Horizontal vanes in power tunnel inlet.

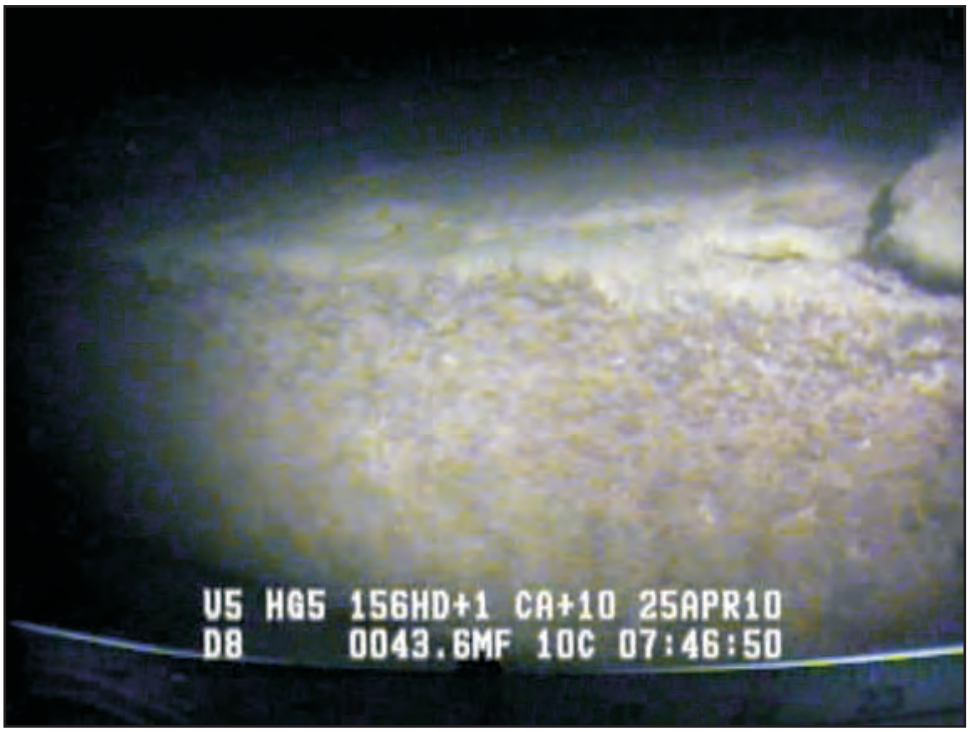


Image 1-14: 2010-04-25-0746 - Silt on vane in inlet.

Image 1-15: 2010-04-25-0903 - Broken edges of slab at joint 2.

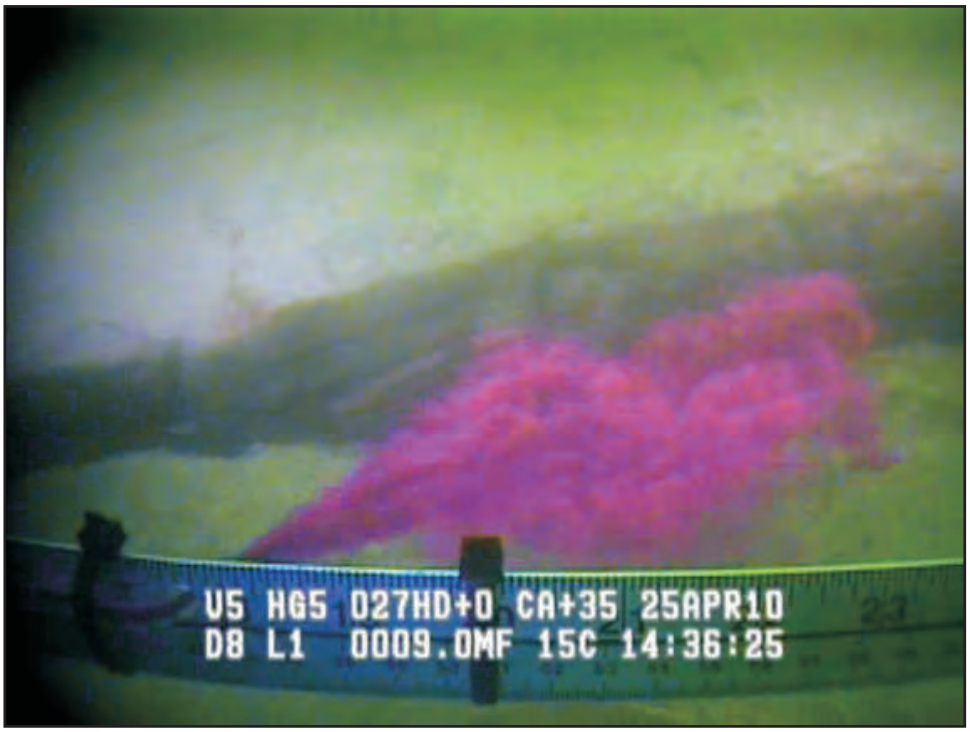


Image 1-16: 2010-04-25-1436 - Dye being pulled in to large leak in joint O1

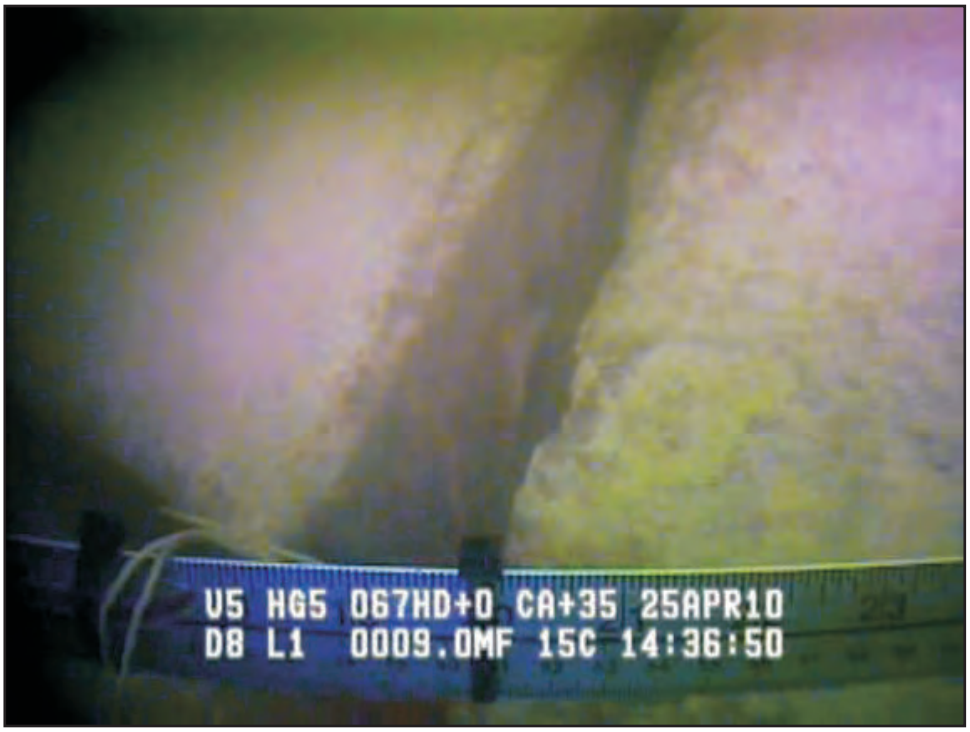


Image 1-17: 2010-04-25-1436 - Leak at joint O1.

Image 1-18: 2010-04-26-1052 - Porous concrete interface on spillway.

Image 1-19: 2010-04-26-1209 - Irrigation intake structure.

Image 1-20: 2010-04-26-1209 - Top of irrigation intake.

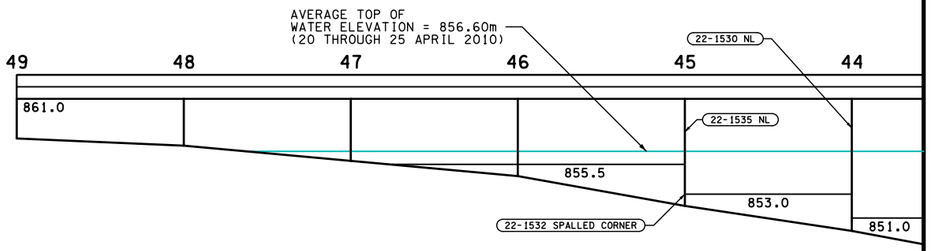
Image 1-21: 2010-04-26-1214 - I-Beams leading south from intake.

Image 1-22: 2010-04-26-1254 -Injecting dye into large leaks at O1.

APPENDIX 2:

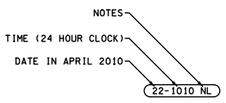
Inspection Observations Maps

East to West



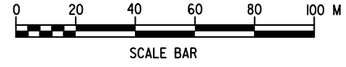
KEY:

NL - NO LEAK
PL - POSSIBLE LEAK
SL - SMALL LEAK
LL - LARGE LEAK
OJ - OPEN JOINT
SC - SILT COVERED JOINT
JO - JOINT OFFSET
RS - RAISED SLAB
BE - BROKEN EDGES

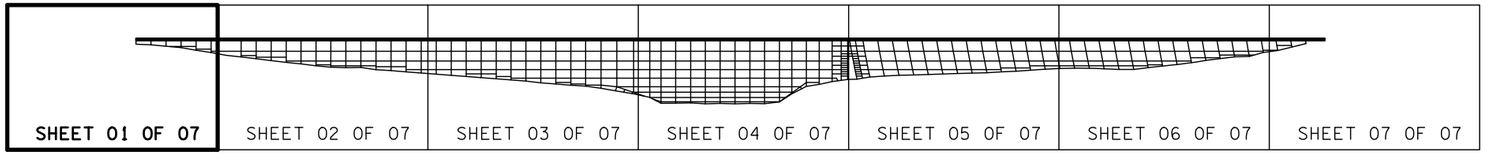


NOTES:

1. THE INFORMATION DEPICTED ON THIS MAP ONLY REPRESENTS THE GENERAL CONDITION EXISTING ON THE DATES AND AT THE TIMES INDICATED.
2. ELEVATIONS SHOWN HEREON ARE EXPRESSED IN METERS.
3. EQUIPMENT UTILIZED TO AQUIRE DATA:
   ROV: SEABOTIX LBV300XL



SCALE BAR



IRG an AECOM company

REV.	DESCRIPTION	DATE

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CHECKED BY: C. JOHNSON	PLOT DATE: 14 MAY 2010	DRAWING FILE NAME: APPENDIX 1 OF 7.DGN	

ROV INSPECTION OF THE QARAOUN DAM

INSPECTION OBSERVATIONS MAP

VERTICAL JOINTS 49 THROUGH 44

APPENDIX REF. NUMBER:
2 - 1
SHEET 01 OF 07

East to West

AVERAGE TOP OF WATER ELEVATION = 856.60m (20 THROUGH 25 APRIL 2010)

43 42 41 40 39 38 37 36 35 34 33 32 31 30

861.0

851.0

847.0

845.0

842.0

838.5

837.5

836.7

834.0

22-1524 NL
22-1519 NL
22-1514 NL RS EAST
22-1526 NL RS UPPER
22-1516 NL
22-1502 NL
22-1510 NL RS UPPER
22-1506 NL DEEP FILLER
22-1454 NL
22-1448 NL
22-1451 NL
22-1442 NL
22-1434 NL
22-1426 REBAR
22-1418 NL
22-1412 NL
22-1422 NL RS UPPER
22-1327 NL SOME SPALLING
22-1420 NL
22-1320 NL
22-1325 NL
22-1313 NL
22-1305 NL
22-1316 NL
22-1303 NL
22-1308 NL
22-1257 NL
22-1300 NL BE
22-1249 NL
22-1247 NL
22-1254 NL DEEP FILLER
22-1237 NL
22-1242 PSL 154.4m
22-1231 NL
22-1205 NL
22-1158 NL
22-1234 NL BE
22-1148 NL
22-1141 SL
22-1153 NL
22-1026 NL RS UPPER 4cm
22-1139 NL JO SMALL
22-1113 PSL
22-1115 SL 2cm
22-1121 NL
22-1023 NL OJ 4cm
22-1027 NL
22-1020 NL OJ 2.5cm
22-1129 NL
22-1019 NL
22-1016 NL OJ 2cm X 17cm
22-1013 NL
22-1012 SL
22-1008 NL
22-1010 NL
22-0933 NL
22-1002 NL
21-1743 NL
22-0953 NL LADDER
22-0950 NL OJ 2cm
22-0943 NL

KEY:

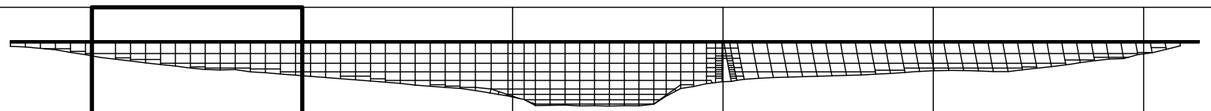
NL - NO LEAK
PL - POSSIBLE LEAK
SL - SMALL LEAK
LL - LARGE LEAK
OJ - OPEN JOINT
SC - SILT COVERED JOINT
JO - JOINT OFFSET
RS - RAISED SLAB
BE - BROKEN EDGES

NOTES
TIME (24 HOUR CLOCK)
DATE IN APRIL 2010
22-1010 NL

NOTES:

1. THE INFORMATION DEPICTED ON THIS MAP ONLY REPRESENTS THE GENERAL CONDITION EXISTING ON THE DATES AND AT THE TIMES INDICATED.
2. ELEVATIONS SHOWN HEREON ARE EXPRESSED IN METERS.
3. EQUIPMENT UTILIZED TO AQUIRE DATA:
   ROV: SEABOTIX LBV300XL

0 20 40 60 80 100 M
SCALE BAR



SHEET 01 OF 07 | SHEET 02 OF 07 | SHEET 03 OF 07 | SHEET 04 OF 07 | SHEET 05 OF 07 | SHEET 06 OF 07 | SHEET 07 OF 07

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SCALE: 1 : 50
PLOT DATE: 14 MAY 2010
DATE(S) OF SURVEY: 20 - 26 APRIL 2010
AQUATIC SCIENCES JOB NO.: RJ10-309
DRAWING FILE NAME: APPENDIX 1 OF 7.DGN

VERTICAL JOINTS 43 THROUGH 30

ROV INSPECTION OF THE QARAOUN DAM

INSPECTION OBSERVATIONS MAP

APPENDIX REF. NUMBER:
2 - 2
SHEET 02 OF 07

East to West

AVERAGE TOP OF WATER ELEVATION = 856.60m (20 THROUGH 25 APRIL 2010)

29 28 27 26 25 24 23 22 21 20 19 18 17 15

861.0
851.0
842.0
834.0
830.0
827.5
826.0
822.0
820.6
819.5
818.0

21-1745 NL
21-1723 NL DEEP FILLER
21-1659 NL
21-1605 NL
21-1421 NL
21-1330 NL RS UPPERS
21-1326 NL RS UPPER 5cm
21-1319 NL RS UPPER 5cm
21-1312 NL RS IN SPOTS
21-1305 NL JO UPPER 5cm WEST
21-1302 NL
21-1300 NL
21-1244 NL
21-1237 NL
21-1234 NL
21-1702 NL
21-1610 NL
21-1424 NL JO UPPER 10cm
21-1314 NL
21-1252 NL
21-1203 NL
21-1222 NL
21-1243 NL
21-1716 NL
21-1652 NL JO
21-1614 NL
21-1454 NL
21-1428 NL JO
23-0910 NL SPALLED EDGES
23-0936 NL
22-0956 NL REPAIRED AREA
23-1012 NL
22-1041 NL
23-1218 NL SC
23-1238 NL BROKEN CORNER
23-0929 NL
23-0932 NL
23-0947 NL
23-1007 NL
23-1024 NL
21-1624 NL
21-1626 NL
21-1625 NL 4cm
22-1058 NL
23-1237 NL
23-1256 NL
21-1739 LEAK
21-1713 NL OJ 2.5cm
21-1650 NL OJ 4cm
23-0921 NL
23-0945 NL SC
23-1022 NL
23-1214 NL
23-1216 NL
23-1234 NL
21-1711 NL
21-1734 NL
21-1645 NL TIGHT JOINT
21-1639 NL
21-1430 NL
23-1004 NL
23-1213 NL
25-1247 NL LADDER OVER JOINT
23-1053 NL
23-1210 NL
22-1616 LARGE LEAK 2cm X 1m
23-1249 NL

KEY:

NL - NO LEAK
PL - POSSIBLE LEAK
SL - SMALL LEAK
LL - LARGE LEAK
OJ - OPEN JOINT
SC - SILT COVERED JOINT
JO - JOINT OFFSET
RS - RAISED SLAB
BE - BROKEN EDGES

NOTES
TIME (24 HOUR CLOCK)
DATE IN APRIL 2010
22-1010 NL

NOTES:

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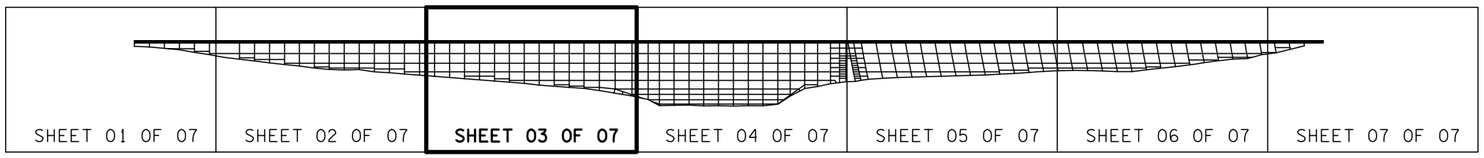
2. ELEVATIONS SHOWN HEREON ARE EXPRESSED IN METERS.
3. EQUIPMENT UTILIZED TO AQUIRE DATA:
   ROV: SEABOTIX LBV300XL

0 20 40 60 80 100 M
SCALE BAR



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DATE(S) OF SURVEY: 20 - 26 APRIL 2010
AQUATIC SCIENCES JOB NO.: AU10-309
PLOT DATE: 14 MAY 2010
DRAWING FILE NAME: APPENDIX 1 OF 7.DGN

VERTICAL JOINTS 29 THROUGH 15

ROV INSPECTION OF THE QARAOUN DAM

INSPECTION OBSERVATIONS MAP

APPENDIX REF. NUMBER: 2 - 3
SHEET 03 OF 07

AVERAGE TOP OF
WATER ELEVATION = 856.60M
(20 THROUGH 25 APRIL 2010)

13 12 11 10 9 8 7 6 5 4 2 1 A B C D

861.0
21-1232 NL
21-1225 NL
21-1219 NL
21-1210 NL
21-1202 NL
21-1157 NL
21-1150 NL
21-1143 NL
21-1131 NL
21-1119 NL
21-1113 NL
21-1053 NL
21-1017 NL LARGE OFFSET
21-1028 PL 1M TO 2M
21-1019 NL
21-1023 PL
21-1228 NL
21-1227 NL
21-1214 NL RS UPPERS
21-1203 NL RS UPPER
21-1213 NL
21-1200 NL
21-1204 NL
21-1155 NL
21-1149 NL
21-1140 NL BROKEN CORNERS
21-1138 NL
21-1132 NL
21-1127 NL
21-1051 NL
21-1057 NL
25-1004 NL OJ
21-1048 NL
21-1043 NL
856.0

851.0
23-1320 NL
21-1224 NL
23-1457 NL
24-1700 NL
21-1206 NL SPALLING EDGE
25-1216 NL
21-1133 NL RS UPPERS 4CM
21-1129 NL OFFSET
21-1121 NL RS UPPERS
25-0903 NL BE
21-1117 NL RS UPPERS 4CM
21-1059 RECTANGULAR FRAME
21-1026 NL RS WEST
25-0616 NL RS WEST
851.0
846.5
23-1413 NL
23-1451 NL
24-1727 NL
25-1204 NL
25-1136 NL
25-1020 NL
25-0950 NL
25-0925 NL
25-0855 NL
25-0853 NL
25-1701 NL
25-0628 NL LARGE RAISE

842.0
23-1258 NL
23-1410 NL SPALLED CORNERS
23-1442 NL
23-1334 NL
24-1724 NL
25-1234 NL
25-1201 NL
25-1133 NL SC TIGHT
25-0947 NL SC
25-0849 NL SC
25-0916 NL SC
25-0713 NL OJ
25-0821 NL SC
25-0658 NL SC
25-0657 NL
842.0
838.0
25-0655 NL
25-0653 NL

834.0
23-1324 NL PLATFORM
24-1711 NL
25-1017 NL
25-1131 NL SC
25-0835 NL
25-0650 NL SC
25-0643 NL
834.0
25-0633 NL
25-0649 NL
25-0646 NL

826.0
23-1504 NL PLATFORM PARTIALLY DISMANTLED
25-1232 NL SMALL PLATFORM
25-0945 NL LADDER ALONG JOINT
25-0913 NL SC
25-0839 NL PLATFORM
25-0819 NL SC
822.0
818.0
25-0717 NL PLATFORM
25-0641 NL
25-0636 NL

818.0
23-1251 NL
24-1705 NL PLATFORM DEBRIS & NETS
25-1330 SC
25-1230 NL PLATFORM W/ LADDER
25-1158 NL
25-1129 NL SC
25-1012 NL

813.0
23-1437 NL
24-1710 HEAVY SILT IN THIS AREA
25-1225 NL
26-1326 NL FISHING OR FALL NET
808.0
25-1124 NL HEAVY SILT
25-1010 NL SC
804.0

KEY:

NL - NO LEAK
PL - POSSIBLE LEAK
SL - SMALL LEAK
LL - LARGE LEAK
OJ - OPEN JOINT
SC - SILT COVERED JOINT
JO - JOINT OFFSET
RS - RAISED SLAB
BE - BROKEN EDGES

NOTES
TIME (24 HOUR CLOCK)
DATE IN APRIL 2010
22-1010 NL

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3. EQUIPMENT UTILIZED TO AQUIRE DATA:
   ROV: SEABOTIX LBV300XL

0 20 40 60 80 100 M
SCALE BAR

SHEET 01 OF 07 | SHEET 02 OF 07 | SHEET 03 OF 07 | **SHEET 04 OF 07** | SHEET 05 OF 07 | SHEET 06 OF 07 | SHEET 07 OF 07

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CHECKED BY: C. JOHNSON
SCALE: 1 : 50
AQUATIC SCIENCES JOB NO.: RJ10-009
DRAWING FILE NAME: APPENDIX 1 OF 7.DGN
PLOT DATE: 14 MAY 2010

VERTICAL JOINTS 13 THROUGH D

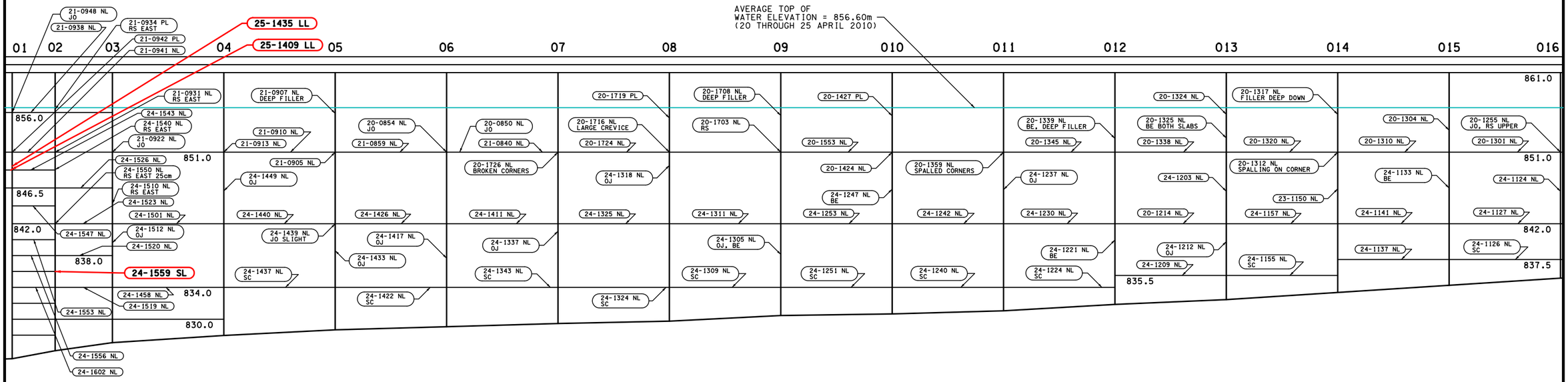
ROV INSPECTION OF THE QARAQUN DAM

INSPECTION OBSERVATIONS MAP

APPENDIX REF. NUMBER:
2 - 4
SHEET 04 OF 07

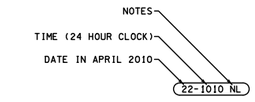
East to West

AVERAGE TOP OF
WATER ELEVATION = 856.60m
(20 THROUGH 25 APRIL 2010)



KEY:

NL - NO LEAK
PL - POSSIBLE LEAK
SL - SMALL LEAK
LL - LARGE LEAK
OJ - OPEN JOINT
SC - SILT COVERED JOINT
JO - JOINT OFFSET
RS - RAISED SLAB
BE - BROKEN EDGES



NOTES:

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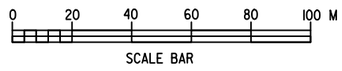
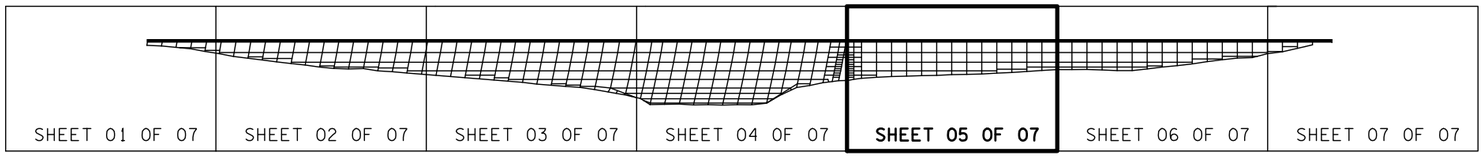
2. ELEVATIONS SHOWN HEREON ARE EXPRESSED IN METERS.
3. EQUIPMENT UTILIZED TO AQUIRE DATA:
   ROV: SEABOTIX LBV300XL



SCALE BAR



IRG an AJ company

REV.	DESCRIPTION	DATE	APPD

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FIELD BOOK(S):
DATE(S) OF SURVEY: 20 - 26 APRIL 2010
DRAWN BY: S. WHITE
SCALE: 1 : 50
AQUATIC SCIENCES JOB NO.: AQ10-009
CHECKED BY: C. JOHNSON
PLOT DATE: 14 MAY 2010
DRAWING FILE NAME: APPENDIX 1 OF 7.DGN

VERTICAL JOINTS
01 THROUGH 016

ROV INSPECTION OF THE QARAOUN DAM

INSPECTION OBSERVATIONS MAP

APPENDIX REF. NUMBER:
2 - 5
SHEET 05 OF 07

East to West

AVERAGE TOP OF WATER ELEVATION = 856.60m (20 THROUGH 25 APRIL 2010)

LADDER DOWN TO FIRST JOINT

017 018 019 020 021 022 023 024 025 026 027 028 029 030

861.0

20-1247 NL
20-1252 NL
20-1238 NL
20-1238 NL RS UPPER 5cm
20-1225 NL
20-1236 NL FILLER
20-1218 NL
20-1222 NL FILLER
20-1214 NL RS, JO TOP RIGHT CORNER
20-1159 NL WIDE OJ
20-1202 NL FILLER
20-1148 NL
20-1155 NL
20-1136 NL
20-1145 NL
20-1124 NL
24-0839 NL
20-1128 NL FILLER
20-1108 NL
23-1734 NL
23-1737 NL
20-1103 NL
23-1720 NL
23-1727 NL
20-1100 NL
23-1707 NL
23-1741 NL
20-1047 NL
23-1659 NL
23-1704 NL
20-1030 NL
23-1645 NL
23-1648 NL

851.0

24-1112 NL
24-1118 NL
24-1018 NL BE
24-1029 NL
24-1003 NL BE
24-1013 NL
24-0950 NL
24-0957 NL
20-1206 NL
24-0938 NL
24-0944 NL
24-0925 NL
24-0932 NL
24-0911 NL JO UPPERS WEST
24-0917 NL
24-0906 NL
24-0848 NL
845.0
24-0903 NL RS, BROKEN CORNERS
24-0846 NL
23-1724 NL
23-1711 NL
847.5
23-1702 NL
23-1654 NL SC

842.0

24-1116 NL SC
24-1024 NL SC
24-1011 NL SC
24-1006 NL OJ
24-0928 NL SC
24-0927 NL SC

838.5

837.5

24-0954 NL
24-0942 NL SC

KEY:

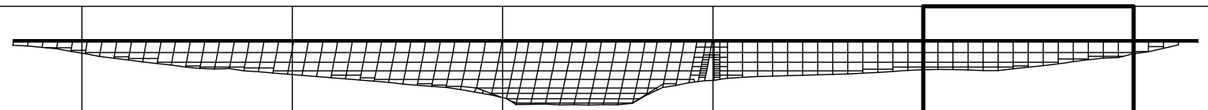
NL - NO LEAK
PL - POSSIBLE LEAK
SL - SMALL LEAK
LL - LARGE LEAK
OJ - OPEN JOINT
SC - SILT COVERED JOINT
JO - JOINT OFFSET
RS - RAISED SLAB
BE - BROKEN EDGES

NOTES
TIME (24 HOUR CLOCK)
DATE IN APRIL 2010
22-1010 NL

NOTES:

1. THE INFORMATION DEPICTED ON THIS MAP ONLY REPRESENTS THE GENERAL CONDITION EXISTING ON THE DATES AND AT THE TIMES INDICATED.
2. ELEVATIONS SHOWN HEREON ARE EXPRESSED IN METERS.
3. EQUIPMENT UTILIZED TO AQUIRE DATA:
   ROV: SEABOTIX LBV300XL

0 20 40 60 80 100 M
SCALE BAR



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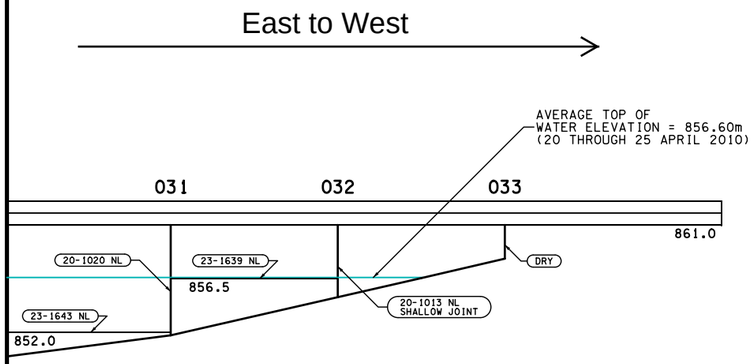
SCALE: 1 : 50
AQUATIC SCIENCES JOB NO.: RU10-309
CHECKED BY: G. JOHNSON
PLOT DATE: 14 MAY 2010
DRAWING FILE NAME: APPENDIX 1 OF 7.DGN

VERTICAL JOINTS 017 THROUGH 030

ROV INSPECTION OF THE QARAOUN DAM

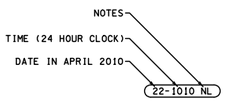
INSPECTION OBSERVATIONS MAP

APPENDIX REF. NUMBER:
2 - 6
SHEET 06 OF 07



KEY:

NL - NO LEAK
PL - POSSIBLE LEAK
SL - SMALL LEAK
LL - LARGE LEAK
OJ - OPEN JOINT
SC - SILT COVERED JOINT
JO - JOINT OFFSET
RS - RAISED SLAB
BE - BROKEN EDGES



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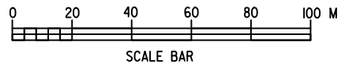
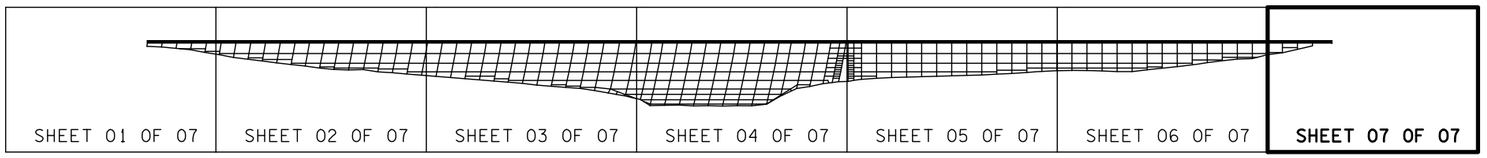
3. EQUIPMENT UTILIZED TO AQUIRE DATA:
   ROV: SEABOTIX LBV300XL





IRG an AECOM company

REV.	DESCRIPTION	DATE	APPD.

Aquatic Sciences
40 CENTRE DRIVE
ORCHARD PARK, NY 14127
TEL: 716.667.3500 / FAX: 716.667.3509
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CHECKED BY: G. JOHNSON
FIELD BOOK(S):
SCALE: 1 : 50
PLOT DATE: 14 MAY 2010
DATE(S) OF SURVEY: 20 - 26 APRIL 2010
AQUATIC SCIENCES JOB NO.: RU10-309
DRAWING FILE NAME: APPENDIX 1 OF 7.DGN

VERTICAL JOINTS 031 THROUGH 033

ROV INSPECTION OF THE QARAOUN DAM

INSPECTION OBSERVATIONS MAP

APPENDIX REF. NUMBER:
2 - 7
SHEET 07 OF 07

APPENDIX 3:

Sonar Images

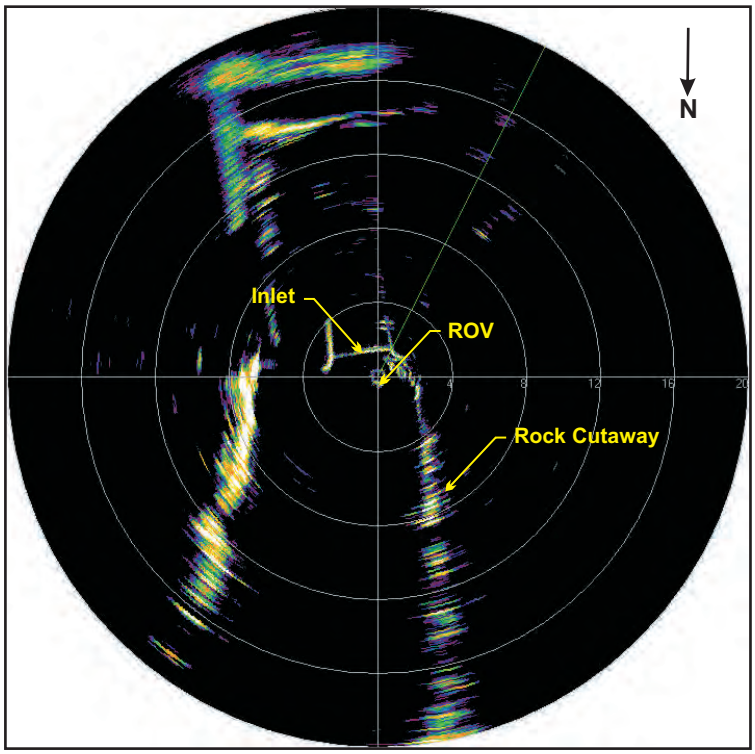

Figure 3-1: 2010-04-25 07:32:20 - Power tunnel intake overview with rock cutaway

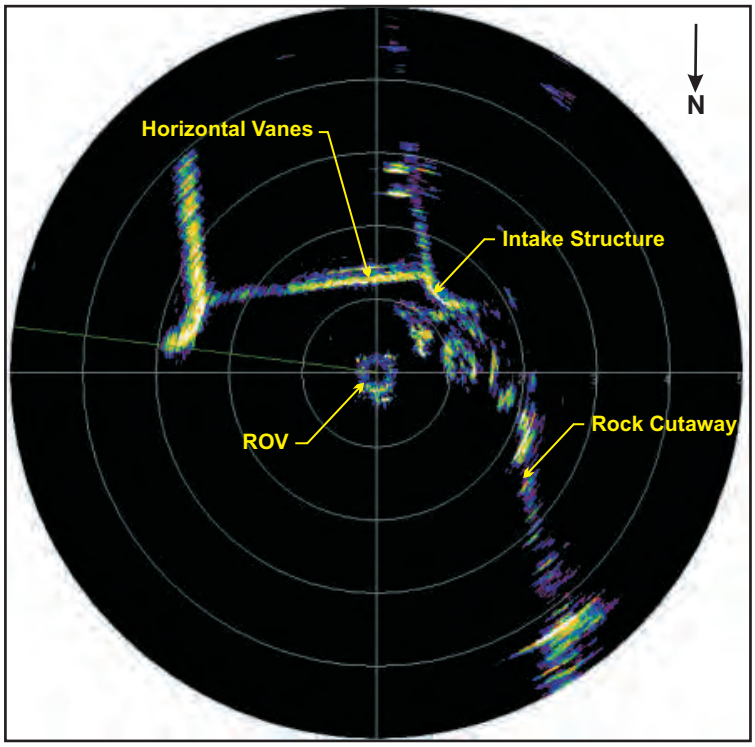

Figure 3-2: 2010-04-25 07:32:51 - Power tunnel intake closeup

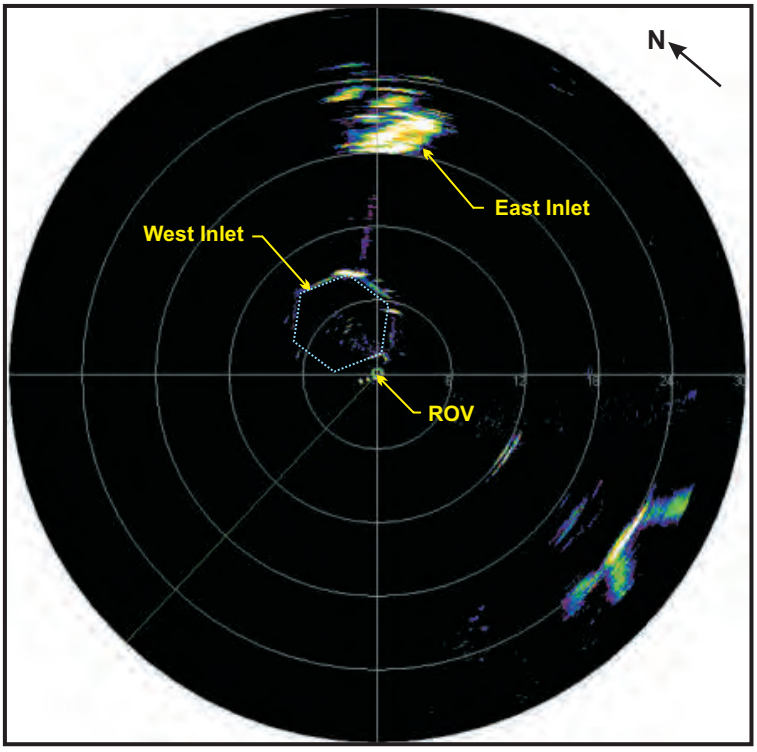

Figure 3-3: 2010-04-26 12:12:24 - Irrigation tunnel inlets, presumed hexagonal shape.

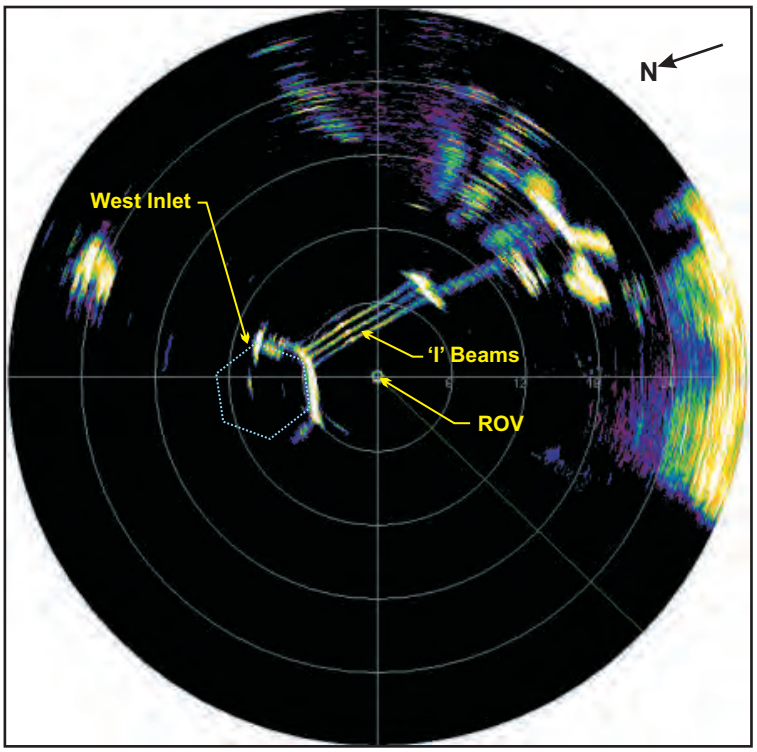

Figure 3-4: 2010-04-26 12:19:59 - West irrigation tunnel inlet showing 3 'I' Beams heading towards dam.

APPENDIX 4:

Site Photographs

Image 4-1: ROV being lowered through surface debris.

Image 4-2: ROV near vent pipe.

Image 4-3: System setup in rear of work vehicle.

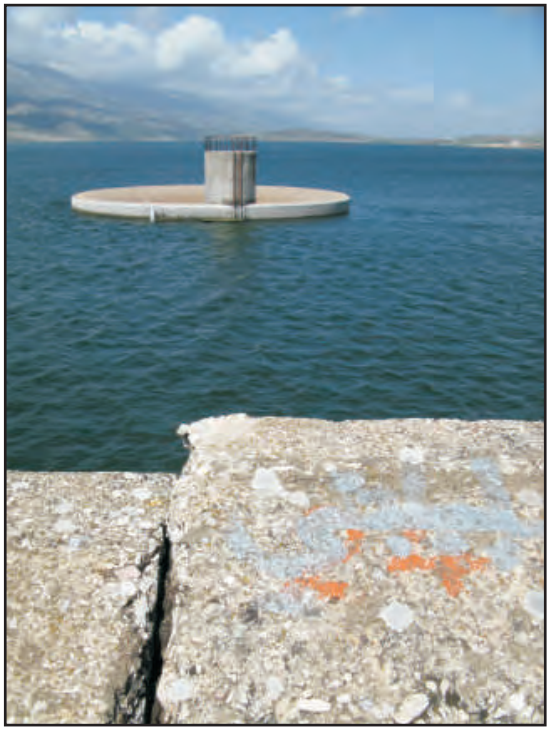

Image 4-4: Spillway and offset at joint 24.

Image 4-5: View looking west along dam face showing bend to south.

Image 4-6: Boat used to aid in recovering ROV tether from leak.

Image 4-7: Drainage outlets with combined leaks in small conduit.

Image 4-8: Accessing the spillway structure.

Image 4-9: View down small spillway riser.

Image 4-10: View looking down large spillway riser.

APPENDIX 5:

Equipment Description

REMOTELY OPERATED VEHICLE

LBV300XL

INSPECTION SERVICES

Aquatic Sciences provides umbilicals of 250m (820 ft.),750 m (2,460 ft.), 1100 m (3,600 ft.), and 2,500m (8,200 ft.) for the *LVB300XL,* which is unique in the world for this class of inspection vehicle. This vehicle operates with increased forward thrust and provides superior quality video images. This Remotely Operated Vehicle (ROV) is approximately 53 cm (21 in.) long, 24 cm (10 in.) wide and will operate in a 41 cm (16 in.) diameter pipe.

LBV300XL is depth rated to 304 m (1,000 ft.) and weighs less than 15.8 kg (35 lbs.). This inspection class ROV features compact size, powerful thrusters, and maximum manoeuvrability.

The system provides on screen information overlay to aid in navigation, setup and control. Information displayed includes heading, depth, water temperature, camera angle, date/time, trim, light level, and user text.

CAMERAS & FUNCTIONS

The high resolution colour camera requires minimal light, has a 3.6 mm lens, auto iris, manual focus and is mounted on a rotating chassis to provide 270 degree field of vision. The camera itself has full tilt capabilities, allowing extreme close-ups of tunnel and pipeline surfaces. A secondary forward camera features low light colour format for use when water conditions are turbid. This camera is a Videology CCD camera with a wide dynamic range (64 db). Hi resolution (450 TVL), low light (0.3 lux), DC auto Iris. The wide-angle 2.8 – 6mm lens offers a 118-degree horizontal field of view. The ROV is fitted with compact sonar for navigation purposes. A single function manipulator is standard on the ROV.

All camera functions, array of LED and halogen variable intensity control lights and a single function manipulator are controlled from the surface. Approximate dimensions are 53 cm (21 in.) in length and 24 cm (10 in.) wide.

ACCESSORIES

The ROV can be retrofitted to include profiling sonar, probe for metal thickness measurement, scrub brush and a manipulator.

THRUSTERS

Six brush-less DC thrusters: four forward, one vertical and one lateral. The vehicle features modular thruster configuration and has a high thrust to weight capability enabling extended excursion capacity.

UMBILICAL CABLE

The fiber optic umbilical cables ASI provides are 250m (820 ft.),750 m (2,460 ft.), 1100 m (3,600 ft.), and 2,500 m (8,200 ft.) in length and 8 mm (0.31 in.) in diameter with a Kevlar strength member and a buoyant floatation jacket which counters the negative buoyancy of the internal leads. An electronic sheave counter measures the distance of penetration.

CONTROLS

All thruster, camera, light and manipulator functions are controlled from the surface via joystick box. Topside control of all functions allows clients to participate in the inspection process, directing the ROV pilot to areas of concern and adding real time audio commentary to the video document.

MOBILIZATION & DEMOBILIZATION

For shoreside access inspections, the service is completely self sufficient and operates from a specially outfitted cube van complete with genset, spool ramps, communications equipment and heaters.

Aquatic Sciences

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APPENDIX 6:

Inspection Video DVDs

The DVDs included with this report contain the complete video collection from the Qaraoun Dam inspection in April 2010 in Windows Media Video (.wmv) format. This media is not viewable in standard DVD set top players.

The Highlights DVD is playable in NTSC DVD set top players. As well, the Highlights disc contains a Windows Media Video (.wmv) version of the video and this report in Adobe Acrobat (.pdf) format.