LITANI RIVER BASIN MANAGEMENT SUPPORT (LRBMS)

QARAOUN DAM SAFETY MONITORING PLAN

March 2011

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ACRONYMS

D/S	Downstream
FERC	Federal Energy Regulatory Commission
LRA	Litani River Authority (also called Office National du Litani)
LRBMS	Litani River Basin Management Support (USAID-funded program)
PFM	Potential Failure Mode
PFMA	Potential Failure Modes Analysis
PSHA	Probabilistic Seismic Hazard Analysis
U/S	Upstream
USAID	United States Agency for International Development

EXECUTIVE SUMMARY

BACKGROUND

Qaraoun Dam is the largest dam in Lebanon, both in terms of reservoir capacity (220 Mm3) and size (60 m high). It is also a key asset of the Litani River Authority (LRA). The dam provides income through the production of electricity (a total of 190 MW in three hydroelectric power plants) and supplies irrigation water to agricultural lands. Built in 1960, the dam is aging well but requires close monitoring to keep providing benefits to the country for years to come and remain safe for downstream populations and properties. Qaraoun Dam is also located close to the Yammouneh fault, one of three major fault lines in Lebanon which has suffered from several large earthquakes in the past.

Since the completion of construction of Qaraoun Dam in the early 1960s, monitoring of the performance of the dam's has included the basic elements of a sound program for this type of dam:

- Surveys of dam deformation;
- Measurements of seepage or leakage flows (through dam and foundation); and
- Piezometric measurements downstream of the dam.

Due to uncertain times in Lebanon (Civil War 1975-1990, conflicts with neighboring countries), such measurements and their reporting have been sporadic. The monitoring has however been thorough enough to detect potential issues such as leaks through the upstream facing of the dam. These leaks were accurately located through diver inspections in the past, and recently through the use of an underwater remotely operated vehicle. A major maintenance activity has then been the repair of the rubber water stops of the dam concrete facing to limit leakage. Rehabilitation of the water stops was accomplished in 1979 and again in 1989 and 2010.

PROCEDURES FOR DAM SAFETY MONITORING

The primary function of dam monitoring is to ensure the longevity and safety of a dam. Longevity to keep providing the benefits the dam was built for, and safety to prevent property damage and life loss in case of failure. Monitoring must enable the timely detection of any behavior that could deteriorate the dam, potentially result in it shutdown or failure, in order to implement corrective measures.

A reliable dam safety monitoring program must use staff and resources effectively, and follow systematic procedures. Such a program must involve the following basic elements:

- Direct visual inspection processes performed regularly and duly recorded; these are defined in chapter 3;

- Instrumentation-assisted monitoring to quantity and record parameters of structural behavior over time; the relevant procedures are detailed in chapter 4;
- Annual and 5-year reviews which allow a complete internal and external review of the safety, performance, and maintenance of the dam; these are defined in chapter 5; and
- Competent, committed, and properly trained staff; LRA has been successfully operating and maintaining Qaraoun Dam for now over 50 years, even through the turmoil of civil war and conflicts with neighboring countries. Moreover LRA engineers have recently been trained on modern dam monitoring techniques through the USAID-funded Litani River Basin Management Program, which included several activities and notably a 2-week seminar on dam safety with the US Bureau of Reclamation.

"Important measurable parameters of the dam's performance are tracked such that appropriate warning will be given concerning all significant potentially unsatisfactory performance by the combination of the instrumentation program and the inspection program."

One last element of proper dam safety monitoring is emergency planning. This topic is not covered here, as a separate Emergency Plan is being prepared for Qaraoun Dam.

ملخص تنفيذي

الخلفية

يعتبر سد القرعون السد الاكبر في لبنان لجهة القدرة التخزينية (٢٢٠ مليون متر مكعب) ولجهة حجم بنائه اي ارتفاعه (٦٠ مترًا). يعتبر ايضاً احد اهم الاصول الرئيسية للمصلحة الوطنية لنهر الليطاني وهو يوفر الدخل الاهم من خلال انتاج الطاقة الكهرمائية (ما مجموعه ١٩٠ ميغاوات في معامل الانتاج الثلاثة)، كما يوفر مياه الري للاراضي الزراعية. تم انشاء السد في العام ١٩٦٠، ان هذا السد يقاوم تأثير السنين بشكل جيد، لكنه بحاجة إلى مراقبة دائمة ودقيقة من اجل الحفاظ على قدرة هذا السد في الاستمرار بمهامه ما يوفر عائدًا لا يستهان به على صعيد الوطن ومن اجل ابقائه آمناً للسكان اسفل السد، ومن الجدير ذكره ان السد يقع بالقرب من فالق اليمونة، الفالق الاهم في لبنان والذي سبب زلازل كبيرة في الماضي.

إتخذت مراقبة اداء سد القرعون منذ انشائه اهمية بالغة وهي عادية لمثل هذا النوع من السدود حيث شملت التالي:

- مسح للتغيرات الحاصلة خصوصًا واجهة السد
- قياس التسرب في اسفل (القاعدة) جسم السد او التسرب خلال جسم السد
- قياس مستويات المياه في آبار المراقبة المحيطة بالسد

بالرغم من الاضطرابات في لبنان (الحرب الاهلية ١٩٧٥-١٩٩٠) والصراعات المختلفة، استمرت المصلحة الوطنية لنهر الليطاني في برنامج المراقبة المقرر وخصوصًا الكشف على التسربات الكبرى من خلال الواجهة المحاكية للمياه، وقد استخدمت المصلحة في الماضي غطاسين مختصين للكشف على التسربات اما اليوم فقد تم استخدام جهاز آلي غاطس يعمل بالتحكم عن بعد ما مكن الفريق الفني في المصلحة من اعادة تأهيل نقاط التسرب المكتشفة في الـــ Water stop والتي ادت إلى تخفيض نسب التسرب، من الجدير ذكره ان مثل هذه التصليحات تمت خلال الاعوام ١٩٧٩، ١٩٨٩ واخيرًا في العام ٢٠١٠.

إجراءات لرصد سلامة السد

تهدف برامج مراقبة السدود بشكل اساسي إلى سلامة وإطالة عمر المنشأة. إن الصيانة الدورية للسد تؤدي إلى استمرار الاستفادة منه بنفس الوتيرة التي بني من اجلها كما انها تؤدي الى الحفاظ على الممتلكات

وحياة الناس اسفل السد في حال حدوث اي فشل (انهيار) في السد. ان المراقبة الجيدة يجب ان تمكن من التقاط اي خلل في الوقت المناسب واتخاذ التدابير التصحيحية وخصوصًا اذا ما كان الخلل الحاصل قادرًا على جعل السد يتراجع في ادائه. إن اي برنامج مراقبة موثوق يجب ان يعتمد على المصادر بشكل فعال ويتبع إجراءات منهجية، حيث يشتمل هذا البرنامج على العناصر الاساسية التالية:

- يجب الاعتماد على الكشف البصري المباشر بإنتظام وتسجيلها حسب الاصول، الشرح في الفصل الثالث؛
- الاعتماد على ادوات المراقبة المساعدة في قياس الكميات وتسجيل معطيات تصرف البنى عبر الزمن، شرح الاجراءات ذات الصلة في الفصل الرابع؛
- اجراء مراجعة سنوية، ومراجعة اخرى كل خمس سنوات فبهذه الطريقة يمكن استعراض العوامل الخارجية والداخلية الكاملة لسلامة الاداء، وصيانة السد، تعريف ذلك يمكن ايجاده في الفصل الخامس؛
- يجب الاعتماد على فريق جيد التدريب، مختص وملتزم.

المصلحة الوطنية لنهر الليطاني عملت وبنجاح للحفاظ على سد القرعون لأكثر من ٥٠ عامًا بالرغم من معمعة الحرب الاهلية والصراعات المختلفة. اكثر من ذلك فإن مهندسي المصلحة الوطنية لنهر الليطاني قد تم تدريبهم على الطرق الحديثة لمراقبة السدود من خلال برنامج دعم ادارة حوض نهر الليطاني الممول من قبل الوكالة الامريكية للتنمية الدولية عبر العديد من النشاطات واهمها فترة التدريب التي استمرت لاسبوعين في الولايات المتحدة الامريكية في Bureau of Reclamation على أمان السدود.

إن اهمية المعطيات القياسية لتعقب اداء السد تكمن في اعطاء التحذير المناسب عن اي تغيرات غير مرضية وذلك بالجمع فيما بين برامج الاجهزة وبرامج المراقبة.

يلعب مخطط الحالات الطارئة العنصر الاهم في برامج مراقبة السدود، لذلك يجري الاعداد لمثل هذه الخطة بشكل منفصل عن برنامج أمان سد القرعون.

1. INTRODUCTION

1.1. PURPOSE

The present Dam Safety Monitoring Plan defines the procedures adopted and implemented by "Office National du Litani", operator of Qaraoun Dam, to monitor the health, condition and safety of the dam. This plan includes the following chapters:

- Present introduction with a rapid description of the dam;
- General methodology of the safety monitoring program;
- Surveillance procedures; and
- Instrumentation monitoring procedures.

References are also provided while appendices provide some additional information and specific forms to be used.

1.2. BACKGROUND

Qaraoun Dam is the largest dam in Lebanon, both in terms of reservoir capcity (220 Mm3) and size (60 m high). It is also a key asset of the Litani River Authority (LRA). The dam provides income through the production of electricity (a total of 190 MW in three hydroelectric power plants) and supplies irrigation water to agricultural lands. Built in 1960, the dam is aging well but requires close monitoring to keep providing benefits to the country for years to come and remain safe for downstream populations and properties. Qaraoun Dam is also located close to the Yammouneh fault, one of three major fault lines in Lebanon which has suffered from several large earthquakes in the past.

Quaraoun Dam is a concrete faced rockfill dam. Its main characteristics are:

- Length 1,100m
- Height 60m
- Volume 2 Million m^3
- Elevation of top of Spillway 858m NGL
- Highest reservoir elevation for 600 m^3 flow 860.5m NGL
- Elevation of crest of dam 861m NGL
- Slope of DS embankment 1.35H:1.0V
- Slope of US embankment from 1.2 to 1.0H:1.0V
- Thickness of reinforced concrete facing from 50cm at bottom to 30cm at top

- Reservoir capacity (at elevation 858m) 220 Million m^3
- Area of reservoir (at elevation 858m) 1,200 ha
- Nominal capacity of spillway 600m^3/s
- Drains capacity below elevation 858m 140m^3/s
- Flow through the Markabi water intake 22m^3/s

Figure 1 shows the dam in plan view while Figure 2 presents the maximum cross-section.

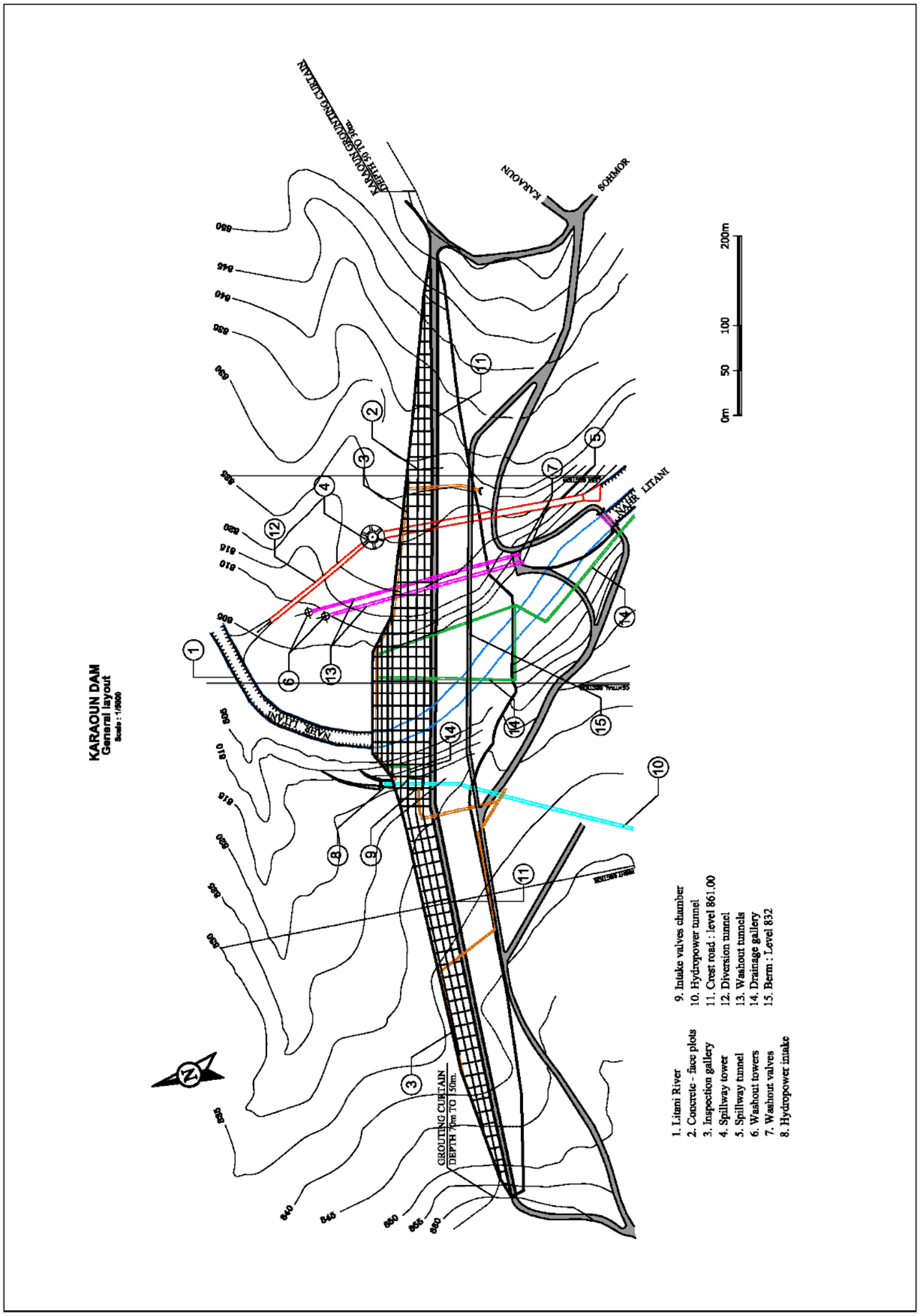
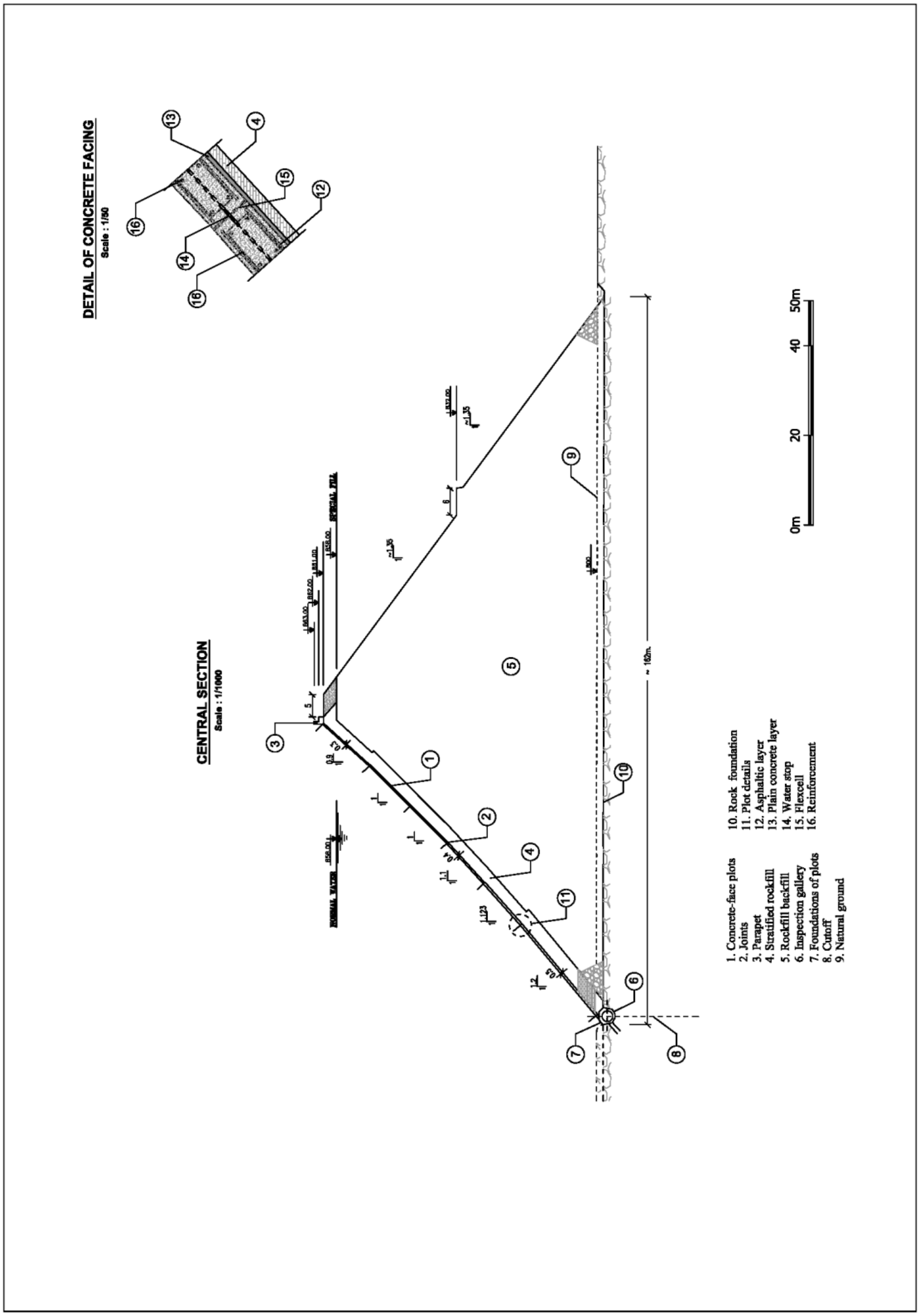


Figure 1: Qaraoun Dam, Plan View

Figure 2: Qaraoun Dam, Maximum Cross-Section



2. GENERAL METHODOLOGY

2.1. MONITORING PRINCIPLES

The primary function of dam monitoring is to ensure the longevity and safety of a dam. Longevity to keep providing the benefits the dam was built for, and safety to prevent property damage and life loss in case of failure. Monitoring must enable the timely detection of any behavior that could deteriorate the dam, potentially result in it shutdown or failure, in order to implement corrective measures.

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2.2. PAST MONITORING

Since the completion of construction of Qaraoun Dam in the early 1960s, monitoring of the performance of the dam's has included the basic elements of a sound program for this type of dam:

- Surveys of dam deformation;
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Due to uncertain times in Lebanon (Civil War 1975-1990, conflicts with neighboring countries), such measurements and their reporting have been sporadic. The monitoring has however been thorough enough to detect potential issues such as leaks through the upstream facing of the dam. These leaks were accurately located through diver inspections in the past, and recently through the use of an underwater remotely operated vehicle. A major maintenance activity has then been the repair of the rubber water stops of the dam concrete facing to limit leakage. Rehabilitation of the water stops was accomplished in 1979 and again in 1989 and 2010.

3. VISUAL SURVEILLANCE

3.1. TYPES OF VISUAL INSPECTIONS

Proper surveillance of a dam requires several types of inspections, with varying frequency and thoroughness:

- Daily visual observations;
- Specific inspections;
- Annual reviews;
- 5-year

These are detailed in the following sections.

3.2. DAILY VISUAL OBSERVATIONS

LRA staff is positioned on the dam to operate its afferent structures (sluice gates, pump stations, forced conduits, etc.) as well as neighboring water structures (Canal 900). This staff is instructed to observe the dam as they go about their daily tasks. They should pay particular attention to:

- Rock movement or fall, chiefly on the downstream slope of the dam;
- Fresh cracks on the crest road or parapet or on the upstream concrete facing;
- Land moves around the dam;
- Vegetation changes around the dam;
- Changes in the flow of nearby springs; as well as
- Suspicious public activities.

Such observations will be reported at once to the Dam Chief Engineer, and also recorded. Dam Chief Engineer will inspect the issue as soon as possible (preferably the same day), assess it criticality, and record it and/or report to LRA General Director for action (such as ordering a specific inspection).

3.3. SPECIFIC INSPECTIONS

A specific inspection is to be carried out in case of:

- Severe weather, such as rainstorm, snowstorm, high winds, flood, etc.
- Neighboring landslide or earthquake, or other major natural or manmade disruption (bombing?) that may have impacted the stability of the dam;
- Visual observations as discussed above that raise significant concerns; or
- Decision by the relevant authority (LRA General Director).

3.4. INSPECTION PRINCIPLES

The purpose of inspection is to identify deficiencies or concerns that potentially affect the safety of the dam. Thus, it is important to look at the entire surface area of the embankment. The general technique is to walk over the slopes and crest as many times as is necessary in order to see the entire surface area clearly.

At regular intervals while walking the slope and crest of a dam, the inspector should stop and look around in all directions to:

- Observe the surface from a different perspective, which sometimes reveals a deficiency that might otherwise go undetected.
- Check the alignment of the surface.

The areas where the embankment contacts the abutments (referred to as the groins) should be inspected carefully.

In addition to the above, viewing a slope from a distance may also reveal a number of anomalies such as distortions of the embankment surfaces and subtle changes in vegetation. When checking the alignment of the crest of the dam at the inflexion point, the inspector should center his eyes along each shoulder of the crest and move from side to side in order to view this line from several angles.

Some tools or techniques that are helpful in sighting are:

- *Binoculars and Telephoto Lens* – The use of binoculars or a telephoto lens can help in observing misalignments because distances are foreshortened and distortions perpendicular to the line of sight become more apparent.
- *Reference Lines* – The use of a reference line can also be of great assistance in sighting. Reference lines can be either the parapet wall or the row of lighting columns

3.5. INSPECTION TECHNIQUES

The purpose of an examination is to identify existing or potential dam safety deficiencies. During inspection, Form no.1 is to be filled out.

3.5.1. SEEPAGE

3.5.1.1. SEEPAGE: INSPECTION ACTIONS

If uncontrolled seepage is observed, then it should be monitored. To monitor seepage, the following should be recorded:

- The location of all seepage exit points.
- Seepage flow rates and clarity.

- The occurrence of recent precipitation that could account for what appears to be seepage, or that could affect the appearance and quantity of actual seepage.
- The level of the reservoir at the time of the observation.

Notes, sketches, and photographs are useful in documenting and evaluating seepage conditions.

The amount of seepage usually correlates with the level of the reservoir. Generally, as the level of the reservoir rises, the seepage flow rate increases. An increase in a seepage flow rate for a similar reservoir elevation is cause for concern.

In some cases, dye can be used to confirm that the reservoir is the source of seepage. .

If sand boils are observed:

- They should be photographed and their location documented.
- The clarity of the exiting seepage should be noted. If there are any deposition cones around the seepage exit points, this should also be recorded.
- Flow rates should be measured or estimated along with the corresponding reservoir elevation. However, the seepage flow rates may be difficult to ascertain since sand boils are often under water.

During an examination the inspector should:

- Locate each drain. –
- Measure the flow. A simple method of measuring the flow from a toe drain outfall is to catch the flow from the pipe in a container of known volume and to time how long it takes to fill the container.
- Compare the amount of flow with the amount of flow anticipated for the current reservoir level based on previous readings.

A drain that has no flow at all could simply mean that there is no seepage in the area of the dam serviced by the drain. However, an absence of flow could also indicate a problem.

If a drain has never functioned, it could mean that the drain was designed or installed incorrectly, or that it flowed at one tune but has now stopped flowing because it may have become plugged.

A plugged drain can be a serious problem because seepage may begin to exit down slope, or may contribute to internal pressure and instability. If possible, blocked drains should be cleaned so that the controlled release of seepage may be restored.

Decreasing amounts of flow from a drain for the same reservoir level may indicate that the drain is becoming blocked. Conversely, a sudden increase in drain flow may indicate that the core is becoming less watertight, possibly as the result of transverse cracking. Recording drain flow rates and reservoir levels over time will help in assessing a dam's seepage conditions.

3.5.2. CRACKING

Another potentially serious deficiency is embankment cracking. Cracks may appear in the crest or slopes of the dam. Cracking falls into the following three major categories:

- Longitudinal cracking
- Transverse cracking
- Desiccation cracking

3.5.2.1. LONGITUDINAL CRACKING: INSPECTION ACTIONS

As with transverse cracking, if longitudinal cracking is observed the inspector should:

- Photograph and record the location, depth, length, width, and offset of each crack observed.
- Closely monitor the crack for changes.
- Recommend that the cause of the cracking be determined.

3.5.2.2. TRANSVERSE CRACKING: INSPECTION ACTIONS

If transverse cracking is observed, the inspector should:

- Photograph and record the location, depth, length, width, and offset of each crack observed.
- Closely monitor the crack for changes.
- Recommend that the cause of the cracking be determined.

3.5.3. INSTABILITY

3.5.3.1. SHALLOW SLIDES: INSPECTION ACTIONS

If shallow slides are observed, the inspector should:

- Photograph and record the location of the slide.
- Measure and record the extent and displacement of the slide.
- Look for any surrounding cracks, especially uphill from the side.
- Check for seepage near the slide.
- Monitor the area to determine if the condition is becoming worse.

3.5.3.2. DEEP-SEATED SLIDES: INSPECTION ACTIONS

A deep-seated slide in either the upstream or downstream slope may be an indication of serious structural problems. In most instances, deep-seated slides will require the lowering or draining of the reservoir to prevent the possible breaching of the dam.

If a slide is suspected, the inspector should:

- Closely inspect the area for cracking or scarps which indicate that a slide is the cause.
- Recommend an investigation to determine the magnitude and cause, if a deep-seated slide is considered probable.

- Recommend possible lowering and restricting the reservoir if release of the reservoir is threatened by continued movement of the slide.

3.5.4. DEPRESSIONS

3.5.4.1. SETTLEMENT: INSPECTION ACTIONS

Although settlement, in most cases, does not represent an immediate danger to the dam, it may be early indicators of more serious problems. Therefore, the inspector should:

- Photograph and record the location, size or extent, and depth of any settlement. Have a survey performed of the crest if there is a concern about loss of freeboard.
- Probe the bottom of localized depressions to determine whether or not there is an underlying void or flowing water that would indicate that a sinkhole exists that is caused by the removal of subsurface material by internal erosion or piping.
- Inspect the depression frequently to ensure it is not continuing to settle or enlarge.

3.5.4.2. SINKHOLES: INSPECTION ACTIONS

If a sinkhole is encountered, the inspector should:

- Probe the bottom of the sinkhole to determine if a larger void exists.
- Photograph and record the location, size, and depth of the sinkhole.
- Recommend that the cause of the sinkhole be investigated immediately and the threat to the dam be determined.

3.5.5. MAINTENANCE CONCERNS

Maintenance includes the measures taken to protect and maintain the dam in a serviceable condition. While poor maintenance may not immediately threaten the safety of a dam, if maintenance is neglected, deficiencies may worsen and become dam safety issues. Deficiencies associated with inadequate maintenance include:

- Inadequate slope protection
- Surface runoff erosion
- Inappropriate vegetative growth

3.5.6. SLOPE PROTECTION

The inspector should:

- Make sure that the slope protection is adequate enough to prevent erosion.
- Look for beaching, scarping, and degrading of the slope protection. If inadequate slope protection is observed:

The findings should be recorded and the area photographed.

The extent of embankment damage (i.e., embankment material removed) should be determined. Corrective action should be recommended to repair or to replace the inadequate slope protection.

3.5.6.1. SURFACE RUNOFF EROSION: INSPECTION ACTIONS

The inspector should:

- Make sure that the upstream slope and crest protection are in good shape to prevent erosion.
- Check the downstream slope for areas that may have been subjected to surface runoff problems.
- Look for gullies, ruts, or other signs of surface runoff erosion. Ensure that upstream and downstream shoulders are checked for low spots since surface runoff can concentrate in these areas.
- Check for any livestock problems which may be contributing to erosion.

If surface runoff erosion is observed:

- The findings should be recorded and area photographed. The photos locations should be indicated on a map.
- The extent or severity of the damage determined.
- Corrective action should be taken to repair the areas damaged by surface runoff and measures taken to prevent more serious problems.

3.5.7. VEGETATION GROWTH

The inspector should:

- Look for excessive and deep-rooted vegetation on all areas of the dam.
- Make sure that there is no vegetation growing in the riprap on the upstream slope.
- Check for signs of seepage around any remaining stumps or decaying root systems on the downstream slope or toe area.

If inappropriate vegetation is observed:

- The size and extent of the vegetation should be recorded and photographed. The photos locations should be indicated on a map.
- Appropriate corrective action should be taken to eliminate inappropriate vegetation and measures taken to prevent the future growth of undesirable vegetation.

3.6. SCHEDULE FOR PERIODIC VISUAL MONITORING:

Ongoing Visual Inspection Frequency

Dam: Qaraoun Ref. Dwgs: nos. …

Project: Litani River Storage

Mohafaza : Bekaa

Dam Construction Completed: 1964

Monitoring Method	Monitoring Schedule
Ongoing visual inspection	Monthly (1) (2) (3) (4) Daily when RWE > +857m
Reading Reservoir Elevation (inside dedicated booth)	Daily

RWE = Reservoir Water Elevation

Notes and Remarks:

1. Perform ongoing visual inspections using the checklist (should be filled at the dam)
2. Report whether any precipitation has occurred in the preceding 48 hours.
3. Perform immediately after an earthquake acceleration of 0.05g or more and again 2 weeks later.
4. Continue 2 weeks after RWE has dropped below +857m.
5. For Reservoir Elevation, use Form no.7

Visual Inspection and Instrumentation data should be transmitted to: ….

If unusual situation develop, follow the procedures stated in the SOP/EAP and call the contact below to determine appropriate adjustments to monitoring schedules

Contact: ……………………………; email: …………………….; GSM no.: …………………….;

Phone no.: ………………………….; Mailing Address: …………………………………………….;

Date: ……………………………….;

4. INSTRUMENTATION MONITORING PROGRAM

At the time of the construction of Qaraoun Dam, dam safety instrumentation was limited. With assistance from the USAID-funded LRBMS program, and based on the findings of a PFMA study, additional equipment has been installed to monitor the safety of Qaraoun Dam.

4.1. EQUIPMENT LIST AND PURPOSE

Item	Description	Purpose	Number	Monitoring Frequency	Location	Reporting Form
1	Vibrating wire piezometers (VWP)	Monitoring water levels in standpipe piezometers / Monitoring pore pressures around inspection gallery / Monitoring seepage beneath dam foundation	10	Monthly (1) (2) (4) Daily when RWE > +857m	Inside Piezometers nos and at Joints nos. inside the gallery	no.2
2	Data logger with software	Real time monitoring of VWP	1	N/A	At reservoir level monitoring booth	N/A
3	Overspeed sensors	Closing of swing valves controlling penstock inlets and Markabi Power tunnel in case of seismic event	4	Instantly	At Markabi, Awali and Joun Penstock inlets and the Markabi Power Tunnel Inlet.	N/A
4	Survey Monuments (Prisms)	monitoring of displacement of three (3) key points on the Dam face	3	Yearly	At inflexion point and at each end of the Dam body	no.3
5	Automated leakage measurement	Leakage measurement inside the inspection gallery and at point 11 (Separation of the flow of the spring located inside the Dam and the leakage at that same point)	6	Monthly (1) (2) (3) Daily when RWE > +857m	At points nos. 30, 50, 10 and 4 inside the dam and at points 11 and 1	no. 4
6	Measurement of mud thickness	Measurement of fines thickness at the invert of the inspection gallery inside the dam	N/A	Monthly	At points nos. inside the gallery	no. 5
7	Measurement of Joints Openings	Monitoring Joints movements inside the gallery	3	Monthly (1) (2) (4) Daily when RWE > +857m	At Points nos. 30 and 50 inside the gallery	no.6
8	Reservoir water level sensor	Monitoring the water level in the reservoir	1	Daily	At point no.1 on the Dam Face	no.7
9	Crack Monitors	Monitoring crack evolution throughout the Dam	23	Monthly (1) (2) (4) Daily when RWE > +857m	N/A	no.8
10	Observation Wells Water Elevation	Monitoring the fluctuation of the water surface	1 (existing)	Monthly (1) (2) (4) Daily when RWE > +857m	Observation Wells nos.	no.9

RWE = Reservoir Water Elevation

Notes and Remarks:

(1) Report whether any precipitation has occurred in the preceding 48 hours.

(2) Perform immediately after an earthquake acceleration of 0.05g or more and again 2 weeks later.

(3) Only when the gallery is not flooded.

(4) Continue 2 weeks after RWE has dropped below +857m.

All instrumentation locations are indicated on the attached as built drawing.

Blank data collection sheets as well as instrumentation details and pictures are provided in the appendix of this document.

4.2. ACTION LEVELS

Action Levels have been established for instruments that are used to evaluate and monitor the development of a specific Potential Failure Mode.

The Threshold Value is a reading that indicates a significant departure from the normal range of readings and prompts an action.

Deviation of the readings relative to the Threshold level starts the process of a more detailed examination defined by the Action Levels.

Once an instrument reading exceeds the Threshold Value an action is necessary. It may be necessary to designate multiple Action Levels that are progressively serious. These should account for:

- a minor departure from the historical record;
- a major departure from the historical record;
- a departure from historical reaction to other instruments; or
- levels indicating the approach of instability or other forms of failure such as piping.

The Action Levels for each instrument are developed in the tables appended to this document.

4.3. EQUIPMENT MAINTENANCE

The maintenance program for the instrumentation consists of the following:

- An annual visual inspection, including cleaning, and calibration check for all instrumentation.
- Maintenance of abandoned instruments should be considered in the case readings need to be reinstated.
- Checking instrument performance if erratic readings are observed.
- For automatic data acquisition equipment: visually observe for moisture intrusion and overheated components, replace desiccant, test transient protection devices, and test

- Test that the notification capabilities are working properly in order to determine if an action level has been encountered.

5. PERIODIC REVIEWS OF THE DAM SAFETY MONITORING PLAN

5.1. INTERNAL / ANNUAL REVIEWS

Annual reviews, basically issue identification processes, include the ongoing assessment of the monitoring and surveillance information that is reported and the status of all identified dam safety and maintenance issues and an annual examination and review report that addresses the current status of the safety, performance, and maintenance of the dam. To support this activity, a proper maintenance of files and databases that contain all information on the dam and its performance and maintenance has to be put in place. These records are needed to support the annual reviews and the 5-year comprehensive external reviews described under the next component. The annual reviews would be submitted to management to allow decisions to be made regarding safety and maintenance issues. Specific requirements for the successful accomplishment of this component include the following:

- Qualified and trained personnel assigned to the ongoing review of the safety, performance, and maintenance of the dam and to the annual assessment and report preparation
- An annual examination, assessment, and reporting process that provides managers (decision makers) the information they need to make decisions about dam safety and maintenance issues and the continued operation of the dam
- A complete record keeping system that contains information on the dam including its design and construction and any technical studies performed during operation of the project
- A database that is kept current containing all monitoring information and presentation tools for presenting that information in an meaningful way
- Complete files containing past inspection, examination, and dam safety or maintenance review reports
- A database that contains all previously identified dam safety and maintenance issues and the current status of those issues

5.1.1. PERSONNEL QUALIFICATIONS

Personnel assigned to the surveillance and monitoring duties are designated in Appendix D of this report. It is desirable that personnel performing these duties be stationed in the LRA offices in Beirut since their communication with the decision makers is critical. The designated personnel have received specific training in dam safety at Reclamation in the summer of 2010.

5.1.2. RESOURCE REQUIREMENTS

Staff time requirements will depend on the number of unresolved dam safety and maintenance issues. As the dam safety program becomes more formalized, there will be time requirements for the establishment of record keeping and databases. It should be noted that these files and databases would not be massive or complicated. There would be a base level of staff time required throughout the year with a concentrated effort at the time of the annual report. To provide continuity and quality it would be desirable to have at least two individuals trained and experienced in performing these duties. Based on these assumptions, it is estimated that the time required would be approximately the equivalent of each designated person working 30 percent of the time. This does not include time that might be needed to address dam safety and maintenance issues.

5.2. EXTERNAL REVIEWS

A comprehensive review of the safety, performance, and maintenance of Qaraoun Dam should be performed by qualified engineers who are external to LRA. These reviews should be performed at 5-year intervals. The external reviews should provide assurance of the soundness of the program and overall credibility to the program. The review process provides a training opportunity for LRA personnel as they interact with the review consultant. Since the LRA dam safety program is limited in scope, the external consultant should bring a broader perspective to the program based on the consultants experience with other dams and qualifications. Specific requirements for the successful accomplishment of this component include the following:

The services of an independent consultant or consulting firm with extensive experience in dam safety and maintenance evaluations

A process for providing the consultant all pertinent information on the dam and its performance.

An examination process that include the LRA personnel assigned responsibilities under Components 1 and 2.

Formal written review reports from the consultant

5.2.1. PERSONNEL QUALIFICATIONS

The consultant or consulting firm hired for the independent review should demonstrate significant experience in dam safety review. The individuals performing the review should be senior level professional engineers with more than 10 years of related experience.

5.2.2. RESOURCE REQUIREMENTS

The independent review component will require expenditure equivalent to an estimated 10 staff days of the consultant's time every 5 years. There will be some time demands on the LRA staff assigned to Components 1 and 2 during the independent external review activity. The resource requirements estimated for under paragraph 1.5.2 above should adequately cover those demands.

ANNEX 1: POTENTIAL FAILURE MODE ANALYSIS (PFMA)

The main results of the PFMA report are summarized here. Further details can be found in the PFMA report.

STEP BY STEP PROCESS

- Step 1 Designation of the Potential Failure Mode Analysis participants
    - (Core Team: Dam Designer, Geotechnical Engineer, Hydraulics Engineer, and Civil Engineer).
    - Facilitator / Team Leader
- Step 2 Collection of background data on the dam for review by the Core Team
- Step 3 Site review including interviews with key owner personnel at the Project (Core Team)
- Step 4 Comprehensive review of all of the background data on the dam by the Core Team
- Step 5 Conduct of the PFMA Session
- Step 6 Consideration of Surveillance and Monitoring opportunities and/or risk reduction measures for identified potential failure modes
- Step 7 Documentation of the PFMA and Surveillance and Monitoring and/or risk reduction opportunities

The main activities of the team during the meeting sessions were to:

- Brainstorm potential failure modes and failure scenarios with the group of persons most familiar with design, analysis, performance, and operation of the dam. Record the identified potential failure modes, the reasons why each potential failure mode is favorable/less likely and adverse/more likely to occur and identify any possible actions related to each that could help reduce risk (i.e. monitoring enhancement, investigation, analysis, and/or remediation).
- Specifically identify possible surveillance and monitoring enhancements and/or risk reduction measures for each potential failure mode for consideration by the owner.
- Document the analysis, including immediately recording the major findings and understandings from the brainstorming session.

FAILURE MODES IDENTIFIED/ EVALUATED DURING PFMA

The PFMA session resulted in shedding light on some major events that might threaten the Qaraoun Dam. These are listed here below:

<u>Static Loading Condition</u>

- Dam failure resulting from deformation caused by collapse of the bearing stratum
- Dam failure resulting from pore pressures causing foundation deformations

- Dam failure resulting from excessive long term settlement
- Dam failure resulting from concrete dam face and/or joint deterioration causing excessive flow and sediment through the dam body

Flood Loading Condition

- Spillway tower failure resulting from cavitation during flood event
- Dam failure resulting from collapse of drainage gallery caused by extreme flood event
- Dam failure resulting from slope instability under extreme flood loading
- Dam failure resulting from overtopping of the crest under extreme flood

Seismic Loading Condition

- Dam failure resulting from deformations caused by seismic loading
- Spillway tower failure caused by seismic loading
- Power waterway failure caused by seismic loading
- Outlet works failure caused by seismic loading
- Dam failure resulting from drainage Gallery collapse caused by seismic loading

A detailed description of each of these potential failure modes is provided in Annex 3.

SUMMARY OF RESULTS

The lack of design, construction, and long-term monitoring data that usually forms the basis of a PFMA required certain assumptions in the PFMA process and reliance on anecdotal information and interpretation of construction photographs. However, sufficient information was obtained and the PFMA exercise that was undertaken has been very helpful in understanding the credible failure modes for the project features and the areas of highest potential risk where monitoring is most important. The PFMA results indicate the following:

- The Qaraoun Dam and appurtenant structures have functioned satisfactorily to date. Leakage through the dam face joints has occurred to varying degrees over the years but that is to be expected for a concrete facing placed on dumped rockfill. Joint repairs have been made on several occasions and the amount of leakage has never reached alarming levels. Settlement of the dam was high during and shortly after construction but survey measurements show that settlement has been stable for the last 19 years.
- The potential for large seismic events to take place in the region, the dam's proximity to the Yammouneh and Rachaiya faults, the steep slopes of the dam, and the fact that the project was reportedly designed for a pseudo-static load of 0.1g makes seismic loading the greatest risk to the dam and its appurtenant structures.

- Extensive damage to the dam and appurtenant structures is possible under severe seismic shaking. However, there is no known method of measuring and collecting data that would alert operations staff to the danger. Earthquakes are not predictable and therefore do not lend themselves to a monitoring program.
- Under static loading, the most indicative dam performance parameter is the leakage through the concrete face slab joints as indicated by seepage measurements.
- Foundation seepage is also considered an area requiring monitoring due to its potential detrimental effects on the karstic limestone foundation underlying a portion of the dam.
- Seepage measurements will typically include a combination of face leakage and foundation seepage but the trend in the total seepage will give warning of deteriorating conditions.
- The most effective monitoring instrument is considered human observation/inspection. No instrumentation can predict earthquakes and the potential adverse effects on the dam and distress under static loading will most probably develop over time (if at all); therefore, regular monitoring by the site staff is considered to be the most effective means of detecting unacceptable performance under normal loading conditions.
- Real time data collection is not considered a critical need; however, to ensure timely access to accurate data, consideration will be given to automating data collection/reporting related to monitoring dam leakage and reservoir level.

A detailed review of the potential failure modes was considered when identifying monitoring instrumentation needs. The evaluation of existing instrumentation and need for additional monitoring instruments focused on the following: leakage through the dam face, foundation pore pressures, reservoir level, dam body deformation, and protection of the power waterways.

The following table presents the main findings of PFMA:

PFMA mode	FERC Category	Proposed Instrumentation/Monitoring
Dam failure resulting from deformations caused by seismic loading	I	Visual observation following the seismic event
Dam failure from deformation caused by collapse of the bearing stratum and/or sliding	IV	Pursuing the ongoing survey monitoring activity
Foundation pore pressure build-up that "would cause it to break"	II	Installation of vibrating wire piezometers and follow up of pore water pressures & Automated leakage measurement

Dam failure resulting from excessive long-term settlement	IV	Pursuing the ongoing survey monitoring activity
Dam failure resulting from concrete dam face and/or joint deterioration causing excessive flow carrying fine soil particles through the dam body	IV	Installation of crackmeters on selected joints and monitoring their evolution & visual and quantitative observation of sediments accumulation inside the drainage gallery & automated leakage measurement
Spillway Tower Failure Due to Cavitation	IV	Periodic visual inspection of the Tower structure
Dam failure from collapse of drainage gallery at upstream (U/S) toe of dam due to flood loading	II, gallery IV, dam	Visual inspection following the flood event & installing a staff gage on the spillway tower as well as reservoir water level sensors to monitor the water level evolution in the dam reservoir to take preventive measures in due time
Stability failure of the dam under flood loading	IV	Visual inspection following the flood event & survey & installing a staff gage on the spillway tower as well as reservoir water level sensors to monitor the water level evolution in the dam reservoir to take preventive measures in due time
Overtopping dam failure due to extreme flood	I	Perform design flood routing to assess the potential for overtopping. Visual inspection following overtopping & installing a staff gage on the spillway tower as well as reservoir water level sensors to monitor the water level evolution in the dam reservoir to take preventive measures in due time
Spillway Tower Failure due to Seismic Loading	II, spillway IV, dam	Visual inspection following the seismic event
Power waterway failure resulting from seismic loading	I, waterway IV, dam	Visual inspection following the seismic event & Installation of over-speed sensors
Dam failure resulting from outlet works failure caused by seismic loading	II, outlet woks IV, dam	Visual inspection following the seismic event
Dam fails from collapse of drainage gallery at upstream (U/S) toe of dam due to seismic loading	II	Visual inspection following the seismic event

The objective of Component 4a of the Litani River Basin Management Support program is to assess risks associated with dam failure and develop monitoring tools that can provide advance indications of potential emergency events. The need for monitoring of the Qaraoun Dam is critical as it is for any large dam whose failure would have dramatic consequences.

In order to identify appropriate monitoring instruments for any dam, the first step is to identify and understand the various ways in which potential failure can take place, the triggering mechanism of each mode of failure, and the probability that such failure modes can actually develop. Instruments that have the ability to measure and monitor the trigger mechanisms are then identified and used for safety monitoring.

Such a process, known as potential failure mode analysis (PFMA), has been conducted in order to define instrumentation that is proposed to efficiently monitor the aging Qaraoun dam. During this PMFA, 13 potential failure modes were identified, analyzed and classified. Instrumentation was identified and selected to improve the monitoring of the high risk potential failure modes. The following table presents the list of monitoring instruments proposed as a result of the PFMA exercise.

Item	Description	Purpose	Unit & Qty
1	Vibrating wire piezometers (VWP), complete with cables and accessories	Monitoring water levels in standpipe piezometers / Monitoring pore pressures around inspection gallery / Monitoring water pressures in the dam foundation	10 units
2	Data logger with software	Real time monitoring of VWP	1 unit
2 Alt.	Mini data loggers for each VWP	Reduce the cables lengths	10 units
3	Survey monuments and surveying equipment	Monitoring of displacement of key points on the dam face. Monuments near the downstream edge of the crest, locations TBD in the field	10 mmts. and 1 survey unit
4	Automated leakage measurement	Leakage measurement inside the inspection gallery and at point 11 (Separation of the flow of the spring located inside the dam and the leakage at that same point)	6 units
5	Telemetry system with radio connection	Transmission of the status of the swing valve controlling the penstock inlet at Markabi Power Plant	1 set
6	Reservoir water level sensors and readout	Monitoring the water level in the reservoir	2 units
6	Staff Gage	Fix on Spillway	1 unit
7	Overspeed sensors	Closing of swing valves controlling penstock inlets and Markabi Power tunnel in case of seismic event	4 units
8	Crack Monitors	To be installed across joints or cracks of interest at locations TBD in the field. Not all need to be installed. Some could be held in reserve to be used at locations of future interest.	25 units

Alt. = Alternative

ANNEX 2. REFERENCES

QARAOUN DAM AVAILABLE DATA

- Pictures showing the dam under construction, property of Mr. Afif Soubra and Mr. Ahmad Issa, 1960
- EDF joints repair guide books, 1979
- Concrete face joints inspection campaign report, 1992
- Piezometers layout drawing, LRA
- Front view of the concrete face joints, LRA
- Concrete face panels settlement and displacement records, LRA, 1964, 1968, 1991&2010
- Piezometers readings and leakage records, LRA, 1997 to 2009
- General geological map of the Qaraoun area, Dubertret, 1952
- The Jubilee (50 years) book, LRA
- Mohamed H. Harajli et al., 1994, seismic hazard assessment of Lebanon: Zonation maps, and structural design seismic regulations, Ministry of Public Works – Lebanon, 198 pp.
- 1964 International Committee on Large Dams (ICOLD) paper
- General cross-section (schematic) of the dam, LRA
- Gamma ray diffraction of sediments taken from the lake, CNRSL
- Laboratory testing of the rock samples taken from the quarry and the mud sample collected from the inspection gallery, SANA Engineers, 2010.
- Summary of some findings related to some geotechnical and seepage aspects beneath the dam foundation
- Professor Sursock, 2009, Recent seismic study of Lebanon
- LRA Operation Department, 1965, Barrage de Karaoun (Réserve utilizable en m3 d'eau), Office National du Litani
- Geotechnical campaign carried out by USBR, 1954
- General layout drawings and schematics

- Plan Drawings

  Plan drawing(s) of the project structures showing project components and instrument locations (actively being monitored and those having been abandoned/terminated/idled). Locations of notable seepage or other structure irregularities that are visually monitored should also be shown.

- Cross-Section Drawings

  Representative cross-sections of project structures showing the dam structure/foundation configuration/zonation, instrument locations, and pertinent instrument details.

- Aerial photos to help orient the reviewer to the project structures and their relative locations with respect to each other.

The following data is not available, but would be very useful:

- Dam embankment stability analysis
- Qaraoun Dam design
- Official records of the construction of the dam including photographs
- Records of repair or re-asphalting of the dam crest.
- Records of piezometers readings prior to 1997
- Hydrological study for the basin and the spillway
- Details of construction of the dam
- Details of the dam foundation exposed at the time of construction

The following external references were used:

- GUIDANCE DOCUMENT FOR DAM SAFETY EVALUATION AND MONITORING PROGRAM FOR QARAOUN DAM, Professor John Smart
- ELEMENTS OF AN EFFECTIVE INSTRUMENTATION PROGRAM , Jay N. Stateler Bureau of Reclamation
- ELEMENTS OF EFFECTIVE DAM SAFETY PROGRAM, William L. Bouley, P.E., Bureau of Reclamation - Denver, Colorado
- EVALUATION OF FACILITY EMERGENCY PREPAREDNESS, William L. Bouley, P.E., Bureau of Reclamation - Denver, Colorado
- STANDING OPERATING PROCEDURES AND OTHER OPERATING DOCUMENTS, William L. Bouley, P.E., Bureau of Reclamation, Denver, Colorado
- EXAMINATION OF EMBANKMENT DAMS, William L. Bouley, P.E., Bureau of Reclamation - Denver, Colorado

INSTRUMENTATION MANUALS

Instrumentation List

Attached excel sheets.

ANNEX 3 INSPECTION FORMS

Form no.1

Visual Inspection

Form no.2

VW Piezometers Readings

Form no.3

Dam Body Displacements

Form no.4

Leakage Monitoring

Form no.5

Mud Thickness Monitoring

Form no.6

Joints Opening Monitoring

Form no.7

Reservoir Water Level Monitoring

Form no.8

Cracks Follow Up

Form no.9

Observation Wells Water Level Monitoring

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