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LITANI RIVER BASIN MANAGEMENT SUPPORT PROGRAM

LITANI RIVER CONSTRUCTED TREATMENT WETLAND

DESIGN REPORT

June 2012
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EXECUTIVE SUMMARY

The Litani River Basin Management System (LRBMS) program seeks to develop a constructed wetland adjacent to the Litani River. The wetland will serve multiple objectives, including treating polluted Litani River water, restoring wetlands and riparian habitat, promoting environmental awareness and education regarding water resources, and demonstrating an innovative, natural water treatment technology not yet implemented in Lebanon.

This document presents the technical basis for design of the constructed wetland, and outlines construction, startup, and operations guidance. It is intended to be used by LRBMS staff, Litani River Authority staff, and the construction contractor(s) prior to, during, and after construction to ensure that the system is properly designed, constructed, and operated. While constructed treatment wetlands are, by their nature, simple systems with substantially less construction and operating complexity than their traditional counterparts, their success is critically dependent upon certain construction and operation details.

Design

At the chosen site, the Litani River suffers from the cumulative effects of the agricultural, industrial, and domestic wastewater discharges upstream. In addition, most wastewater treatment plants in the Bekaa (even the recently constructed ones such as the Joub Janine plant just upstream of the wetland site) are currently not or only marginally operated and untreated domestic wastewater directly enters the Litani River. Concentrations of nutrients such as nitrogen and phosphorus, suspended solids, biochemical oxygen demand, and pathogens are present in elevated concentrations that impair the river.

The constructed wetland system has been designed to treat as much of the flow in the Litani River as possible given the project budget constraints. At approximately 2.5 ha in size, the wetland will receive 30 L per second of flow during the dry season and 60 L per second of flow during the rest of the year. These flows will represent between 20 to 100% of the Litani River flow during the dry season and approximately 1 to 2% of the flow in the wet season. The wetland system will remove between 30 to over 90% of the mass of pollutants entering it, depending on the individual pollutant and the time of year.

The system will consist of a basin containing alternating deep (2-3 m) and shallow (30-50 cm) zones planted with vegetation adapted for each zone. A pump basin next to the river will provide the inflow while an adjustable weir outflow structure will maintain consistent water levels and convey wetland effluent to a discharge channel that brings the effluent back to the Litani River.

Construction And Startup

Construction of the system shares much similarity to construction of similar ponds, lakes, and water storage basins. Several key differences exist, however, that must be respected:

- Site grading to exactly the design elevations is critical, especially the shallow vegetated zones which must be flat, smooth, and all graded to the same elevation. Elevation tolerances for these zones are very strict because any variability or marks left by grading equipment have the potential to cause small channelization of flows in the finished wetlands that will decrease treatment performance. Therefore these defects must be minimized to every extent practical.
- Proper coverage of the specified vegetation communities is critical for project success. Dense, uniform growth of wetland vegetation is required for optimum treatment. Successful development of shrub and tree species on sloped areas will ensure stability and prevent slumping or other erosion problems. It is important that a qualified specialist in the establishment of the specified species be involved with the construction and site startup.
- Proper installation of rock structures that protect the connection of the discharge channel with the Litani River will ensure the long-term sustainability of the site.
- Because this is a natural system, it must be specially handled to ensure that the necessary vegetation grows in quickly and strongly. Also, after construction, the wetland basin must be filled with water in a very particular fashion to prevent significant erosion damage to the system. This document provides clear, explicit guidance in the proper startup procedures.

Operations

The system has been designed to be simple and require minimal maintenance. However, certain maintenance tasks will be required for optimal performance. This document describes the general maintenance tasks required and it is up to the project sponsors and owners to provide the necessary staff and equipment to keep the system running. Expected maintenance duties will include:

- pump station maintenance
- hydraulic structure maintenance, adjustment, and cleaning
- vegetation health monitoring
- berm and other embankment inspection and repair as necessary, particularly after significant storm events.

ملخص تنفيذي

يسعى برنامج دعم ادارة حوض الليطاني إلى اقامة منطقة رطبة (Wetland) بالقرب من مجرى النهر، حيث تتعدد الاهداف من إنشاء مثل هذه المناطق والموائل النهرية، لجهة معالجة نوعية المياه بشكل طبيعي وإلى تعزيز الوعي لدى الشرائح الاجتماعية فيما يتعلق بالموارد المائية، ومن الجدير ذكره ان تكنولوجيا معالجة المياه هذه لم تنفذ في لبنان قبل ذلك.

ان هذا التقرير يعرض الاساس التقني لتصميم الاراضي الرطبة، حيث يحدد كيفية البناء والتصميم وطريقة الادارة، والتوجيهات العملية لموظفي كل من المصلحة الوطنية لنهر الليطاني والLRBMS، كما وتشمل هذه التعليمات طريقة الادارة لمتعهد البناء قبل وأثناء وبعد البناء لضمان أن النظام تم تصميمه بشكل صحيح ويعمل بالطريقة التي صمم من اجلها. ويعتمد نجاح هذا المشروع على سهولة ادارته والذي تساهم بشكل اساسي في استمرارية هذا المشروع.

التصميم

يعاني نهر الليطاني من الآثار التراكمية لتصريف المياه المنزلية والنشاط الزراعي والصناعي، اضف إلى ذلك العمل الضعيف والهامشي لمحطات الصرف الصحي، لا بل لقلتها نسبةً إلى الحاجة، ما يؤدي إلى دخول المياه غير المعالجة إلى مياه النهر، حيث تتعاظم تراكيز النيتروجين والفوسفور والمواد الصلبة العالقة والاهم الخلل الحاصل في نسب الاكسجين الحيوي الممتص والملوثات العضوية الاخرى والتي تنال بشكل كبير من مياه النهر.

إن تصميم ال(Wetland) كنظام الأراضي الرطبة التي تشيد من اجل علاج جزء من مياه نهر الليطاني وذلك بسبب الميزانية المحدودة للمشروع. لذلك غطط الاراضي الرطبة المذكورة حوالي ٢,٥ هكتار فقط ، اما كمية المياه التي سيتم علاجها فهي ٣٠ ليتر في الثانية صيفاً و٦٠ ليتر في الثانية من تدفق النهر خلال الفترة المتبقية من العام. وسوف تمثل هذه التدفقات بين ٢٠ إلى ١٠٠٪ من تدفق نهر الليطاني خلال موسم الجفاف، وحوالي ١-٢٪ من التدفق في موسم الأمطار. سيقوم النظام هذا بإزالة ما بين ٣٠ إلى أكثر من ٩٠٪ من الملوثات التي تدخل إليها، اعتمادا على الملوثات الفردية والوقت من السنة.

سيتكون النظام من حوض يحتوي بالتناوب منطقة عميقة (٢-٣ م) و واخرى ضحلة اي (٣٠-٥٠ سم) وهذه المناطق سوف تزرع بالنباتات المناسبة والتي يمكن ان تتكف مع كل منطقة. وسيبنى حوض لضخ المياه بجوار النهر لتوفير التدفق المناسب في حين ان المياه الناتجة او المعالجة سيتم نقلها عبر قناة التصريف إلى نهر الليطاني.

البناء وبدء التشغيل

إن بناء هذا النظام هو شبيه إلى حد كبير ببناء احواض مماثلة او بناء البحيرات واحواض تخزين المياه. توجد العديد من الاختلافات الرئيسية، ومع ذلك، لا بد من احترامها:

- انه من الضروري جداً اعطاء الاهمية القصوى لتصميم الاختلاف في الارتفاعات وسط المناطق المزروعة الضحلة والتي يجب ان تكون مسطحة، على نحو بسيط ومتدرج إلى نفس الارتفاع. ان اهمية التدرج في المناطق الضحلة ترتبط بشكل كبير بقدرتها على العلاج لذا يجب ان يكون تنفيذها او تنفيذ تصميمها صارماً دون اي اخطاء.
- التغطية المناسبة للنباتات المحددة هو أمر حاسم لنجاح المشروع. فالمطلوب الكثافة، والنمو الموحد للغطاء النباتي للwetland وذلك من اجل العلاج الأمثل. إن التطوير الناجح للتشجير وأنواع الأشجار في المناطق المائلة هو ضمان لاستقرار ومنع حدوث مشاكل التآكل والهبوط في المنحنايات وغيرها. كما وانه من المهم جداً أن يعمل أخصائي مؤهل في إنشاء هذا النواع من المناطق الرطبة وان يشارك في بناء وبدء تشغيل الموقع.
- ان التركيب الصحيح للصخور التي ستحمي قناة التصريف مع نهر الليطاني من شأنه ضمان استدامة الموقع لوقت طويل.
- لأن هذا النظام هو نظام طبيعي، يجب التعامل معه بشكل خاص وذلك لضمان نمو النباتات اللازمة بسرعة وقوة. وبعد البناء، يجب ملء الاحواض بالماء بطريقة خاصة جدا لمنع حصول اي ضرر مثل التآكل الكبير للنظام. تقدم هذه الوثيقة الواضحة، توجيهات صريحة في إجراءات بدء التشغيل السليم.

العمليات

لقد تم تصميم هذا النظام ليكون بسيط ويتطلب الحد الأدنى من الصيانة. ومع ذلك، سوف تكون هناك حاجة لبعض مهام الصيانة وذلك لتحقيق الأداء الأمثل. تصف هذه الوثيقة مهام الصيانة العامة المطلوبة، والأمر هنا متروك للجهة المانحة للمشروع وأصحابه من اجل توفير الموظفين والمعدات اللازمة للحفاظ على نظام تشغيل. واجبات الصيانة المتوقعة كما يلي:

- صيانة محطة الضخ
- صيانة المنشأة الهيدروليكية، التعديل والتنظيف
- رصد صحة النباتات
- مراقبة السواتر الترابية وغيرها عند الضرورة وخصوصاً اثناء الفترات العاصفة.

1. INTRODUCTION

This document describes the basis of the design, general construction requirements, and expected operations and maintenance activities for a constructed wetland system along the Litani River near Joub Jannine in the Bekaa Valley, Lebanon. To the extent practical, the system has been designed to require as little maintenance as possible. The system will receive water pumped directly from the Litani River, remove a variety of pollutants in a treatment wetland system, and discharge the treated water back to the Litani River Basin through a constructed floodplain wetland and channel that will provide additional aquatic habitat.

1.1. SUMMARY OF FEASIBILITY STUDY

A feasibility report (LRMBS 2012a) assessed the potential for constructed wetlands to improve water quality in the Litani River Basin. The Litani River Basin is essential for agriculture, urban development, and industry in Lebanon and suffers from widespread water pollution due to lack of discharge regulation and enforcement, few operable wastewater treatment facilities, and environmentally damaging agricultural practices. The major sources of water pollution in the basin are wastewater releases from domestic, industrial and agricultural sources as well as solid wastes and leachates.

Treatment wetlands are systems that harness physical, chemical, and microbial processes found in natural wetland environments to remove pollutants from wastewater. The systems have been in use for over 60 years and have seen widespread advancement in the past two decades as a viable option for controlling water pollution with little to no conventional energy input and the potential for greatly reduced operations and maintenance demands relative to traditional technologies. These aspects combined with their wide applicability to different implementation scales and pollutant types make them well-suited for the Litani River Basin. Additionally, treatment wetlands offer significant potential for environmental education, passive recreation, and restoration of wildlife habitat that other more conventional systems lack.

NewFields conducted reconnaissance in the Litani River Basin and identified four potential treatment wetland sites. These were evaluated for their logistical, technical, and engineering feasibility. Based on their comparative strengths and weaknesses, a preferred site was chosen that offers the best potential for satisfying the goals of this pilot treatment wetland project under the LRBMS.

1.2. SITE SELECTION JUSTIFICATION

The LRA-owned parcel along the Litani River near Joub Jannine bridge was selected for development of the constructed treatment wetland system. The site offers plenty of available land adjacent to the Litani River, public ownership, and proximity to a currently untreated wastewater outfall. A treatment wetland sited here will provide improved water quality downstream to Qaraoun Lake and Canal 900. The site is adjacent to the LRA Khirbet Kanafar water management center, and 10 km away from Lebanon's only remaining natural wetland (Aammiq), offering significant potential for environmental education, wetland habitat restoration, and other ancillary benefits.

The site maximizes the available budget for a LRBMS-sponsored pilot treatment wetlands system as well as the water quality benefit to the Litani River Basin. The available size of land will allow the system to treat most or all of the flow in the Litani River during the summer when water quality is poorest. The site also offers significant potential for ancillary benefits that the other evaluated sites did not.

For further description of the site selection process, please refer to the Feasibility Study (LRBMS 2012 a).

2. SITE OVERVIEW

2.1. WATER QUALITY

NewFields has developed a geographic information system (GIS) that contains all available water quality sample data from the Bekaa Valley collected between 1999 and 2011 obtained from LRBMS (2012b). A summary of median values of pollutants of interest for samples collected in the Litani River near the Joub Jannine bridge crossing is presented in Figure 3.1. With the exception of BOD (slightly higher during the wet season) and nitrate (similar median concentrations in both seasons) most pollutants of concern are present in substantially higher concentrations in the dry season versus the wet season. This indicates that that the Litani River near Joub Jannine likely receives domestic sewage and agricultural drainage containing nutrients and pathogens during the dry season and similar are pollutants diluted by storm events during the wet season.

It is important to note that most samples that make up this data set date from prior to the completion of the wastewater treatment plant located downstream of the Joub Jannine bridge and may or may not have been collected downstream of its outfall. Therefore, this data set may or may not accurately represent current water quality conditions in the Litani River at the site of the wetland pump station. For the purposes of treatment performance expectations (described in Section 4.2.4), we obtained published literature values for typical domestic wastewater (USEPA 2002) and have assumed that the contribution from the Joub Jannine wastewater treatment plant is approximately 25% in the dry season and 2.5% in the wet season. The resulting estimated current water quality at the constructed wetland site is shown in Figure 3.2 and represents a significantly poorer water quality than the available data suggests (LRBMS 2012b).

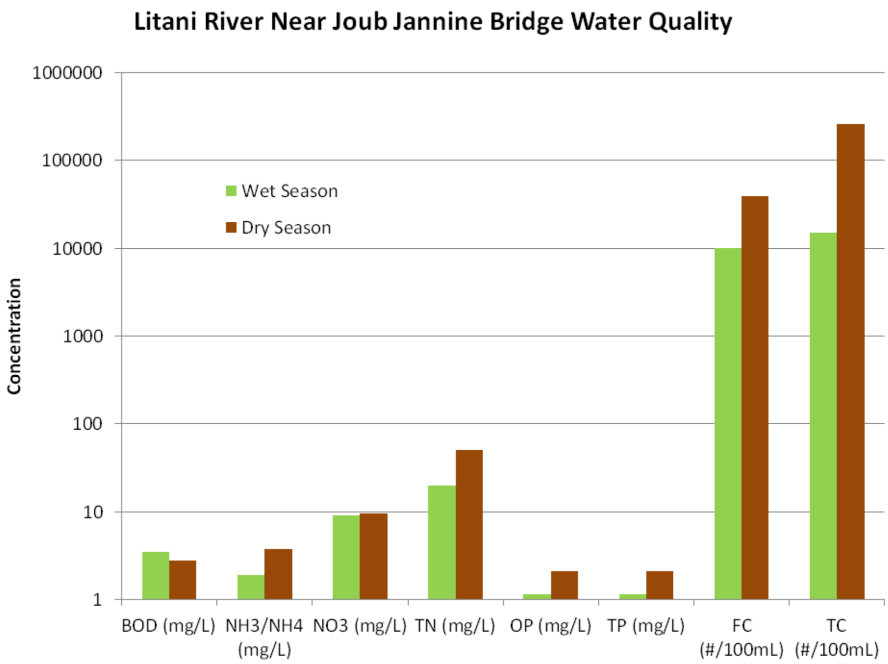

Figure 2.1: Summary of Water Quality Litani River Near Joub Jannine Bridge

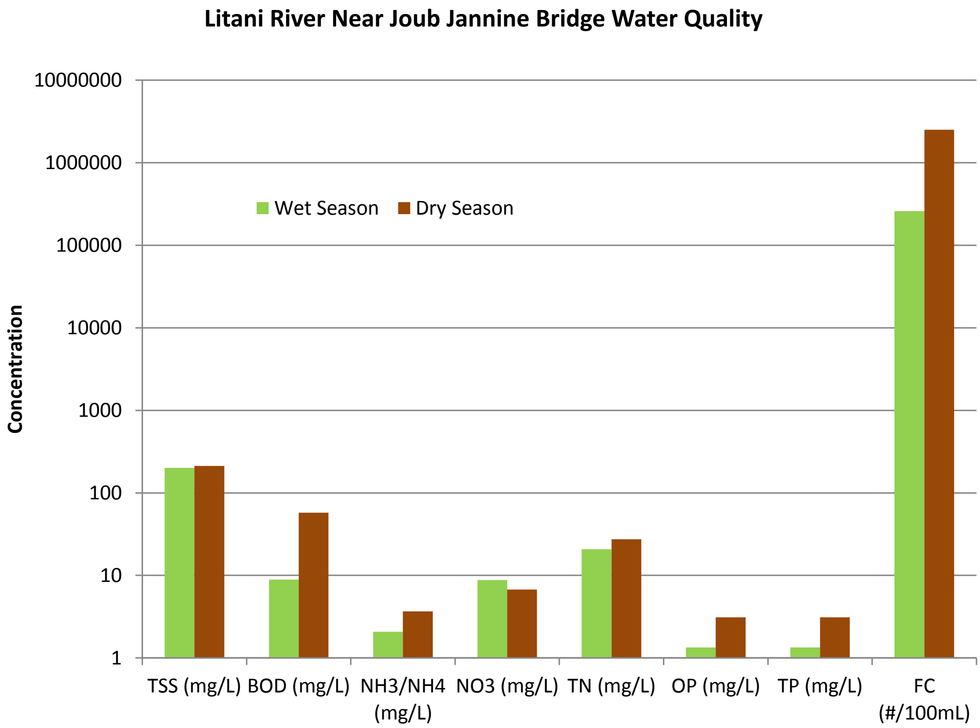

Figure 2.2: Summary of Estimated Water Quality Litani River at Site

Note logarithmic scales; TSS = total suspended solids, BOD = Biochemical Oxygen Demand, NH3/NH4 = Ammonia, NO3 = nitrate, TN = Total Nitrogen, OP = orthophosphate, TP = Total Phosphorus, FC = fecal coliforms

2.2. HYDROLOGY

The most reliable stream gaging station in the Litani River Basin is located on the Litani River at the Joub Jannine bridge, which is located immediately upstream of the LRA property. Figure 3.3 shows the average observed flow rate between the water years 1999 to 2009 distributed by month. The stream flow pattern typifies the Mediterranean climate; very high flows are observed January through April (peaking with an average flow in February of 24.1 m^3 /s) with very low flow between July and October (with the lowest average flow in August of 0.2 m^3/s).

On average, the Litani River provides ample flow year-round to support the constructed wetland system. However, in some years the Joub Jannine bridge stream gage reports zero flow in July through September. It is unclear whether this truly represents a dry riverbed or a very low flow below the measurable threshold at the gage. Anecdotal evidence suggests that flow in the river never stops and the stream gage does not capture the effects of the recently completed sewer collection system and wastewater treatment plant immediately upstream.

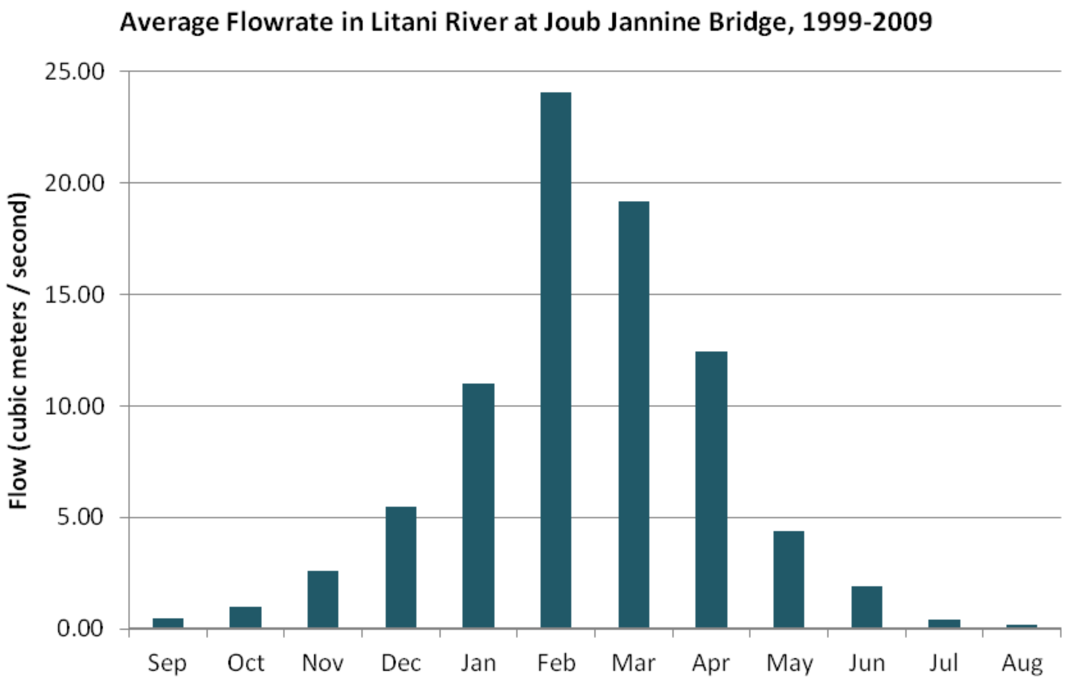

Figure 2.3: Average Flow in the Litani River at Joub Jannine

2.3. TOPOGRAPHY

A site topographic survey was completed in March of 2012 and a digital elevation model based on the survey is shown in Figure 3.4. The area within the project boundary is generally flat, with elevations ranging from 859.5 to 862 m. Several drainage ditches run through the parcel towards the river that are as deep as 858.5 m.

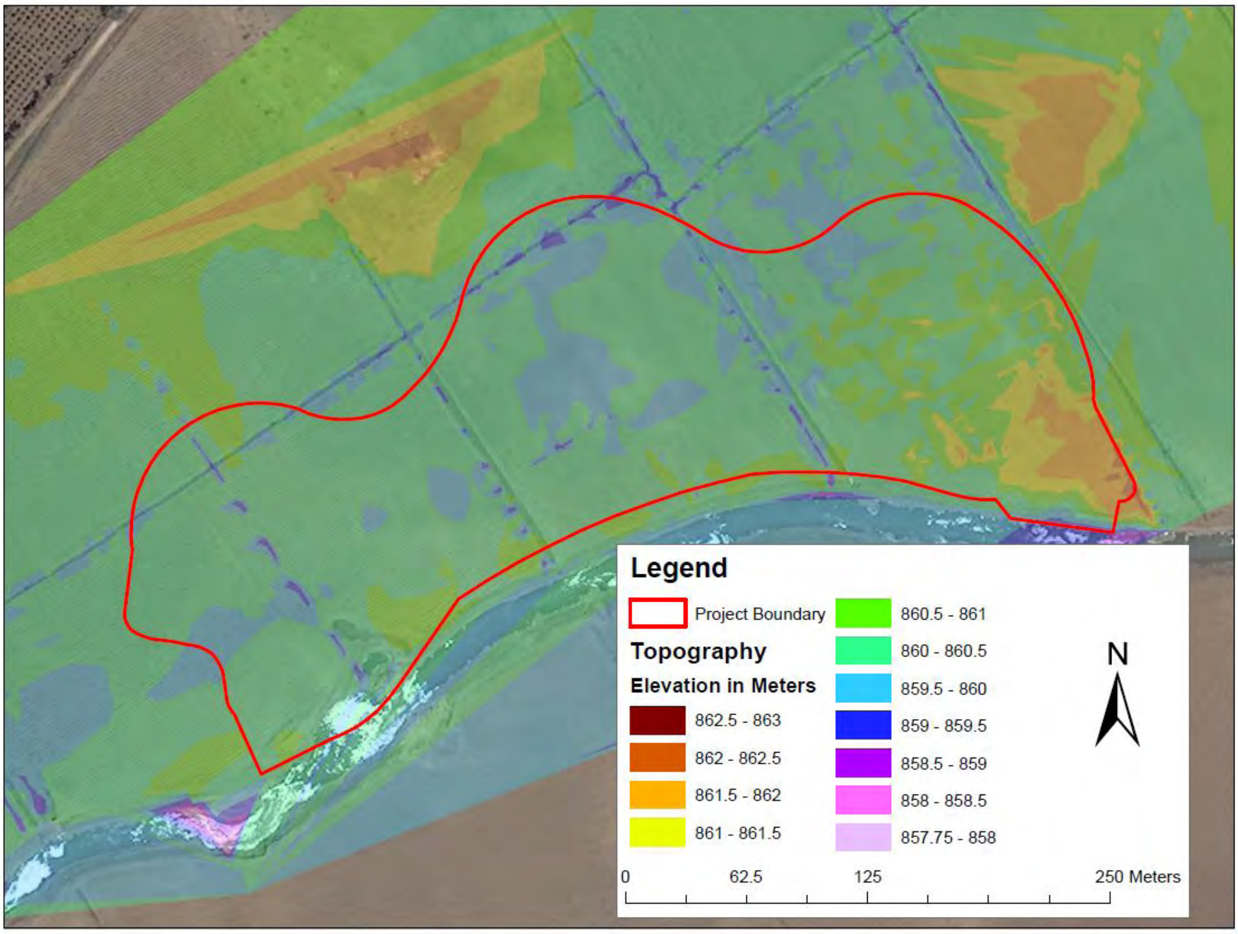

Figure 2.4: Digital Elevation Model of Wetlands Site

3. TREATMENT WETLAND PROCESS: BASIS AND FEATURES

The constructed wetland system comprises three main elements – the main constructed wetland itself, a pump station to provide inflow to the wetland from the Litani River, and the discharge channel to convey treated wetland effluent back to the Litani River and provide additional habitat features. This section describes the basis for design of the general features of each of these components. Figure 4.1 shows the general layout of the system.

3.1. PUMP STATION

3.1.1. SIZING

The type of pump recommended is the mobile and self priming pump (Horizontal Shaft). Using mobile suction pumps is preferred over the wet well/dry well pumping station, because the latter means a deep reinforced concrete well structure (below the lowest river water level) and a pipe to connect to the river. This would be both costly and intrusive in the riverbed.

For safety of operation and bearing in mind that the proposed flows are 30/60 liters per second (i.e. 30 l/s in Summer and 60 l/s in Winter) therefore 2 variable pumps (each max capacity 60 l/s) shall be required.

3.1.2. CONNECTION TO LITANI RIVER

The intake will be quite minimal (to avoid creating an erosion weakness in the riverbank), with a simple pipe going into the river and being held there by a concrete block.

3.2. CONSTRUCTED WETLAND

3.2.1. SIZING

Due to budget constraints for implementation of the constructed wetland system, sizing of the wetland was determined by the largest system that could be constructed with available funds (approximately US$300,000). Given anticipated local costs for earthmoving and procurement of the necessary water movement and control structures at the time of engineering design, we determined that a wetland of approximately 2.5 ha could be constructed for the available budget.

3.2.2. LOCATION, LAYOUT, AND FEATURES

To facilitate inflow and outflow connection to the Litani River, the wetland has been sited directly adjacent to the river, southeast of the LRA agricultural extension center in Khirbet Kanafar (Figures 4.1 and 4.2). The constructed wetland system will consist of an alternating sequence of deep (2 m) and shallow (30-50 cm) zones. The deep zones serve to promote mixing and uniform flow, while the shallow zones promote growth of emergent wetland vegetation that provides a biologically and chemically diverse environment where much of the pollutant removal will occur. An approximately 70/30% ratio of shallow areas to deep areas has been included in the design which will maximize each zone's effectiveness as a part of the overall system. The entire wetland will be surrounded by an approximately 2 m high berm to contain the water and provide perimeter access via a roadway on top. To minimize earthmoving costs, an approximate balance between excavations for the deepest areas and backfill for the berm was achieved.

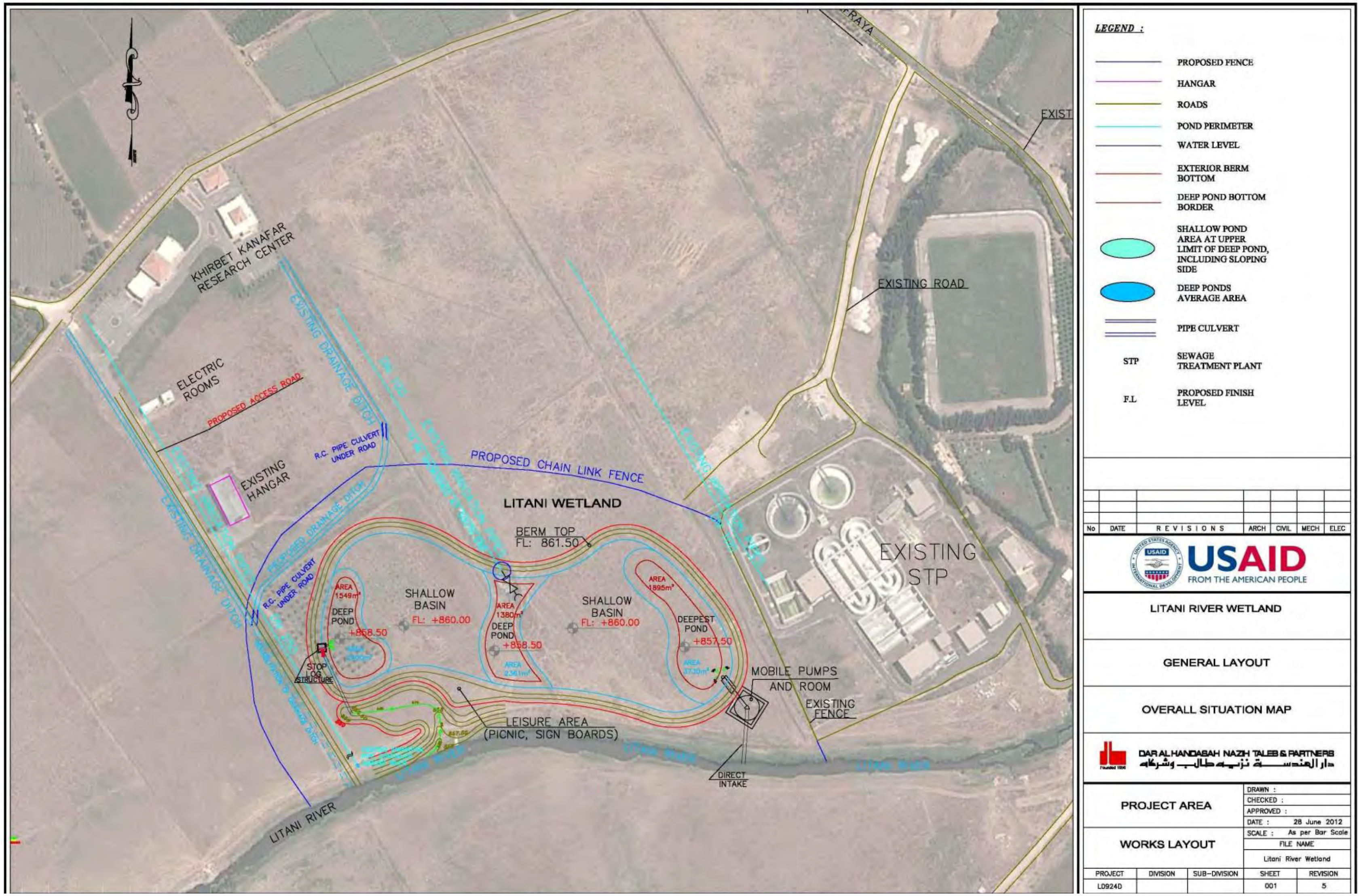

Figure 3.1: Site overview

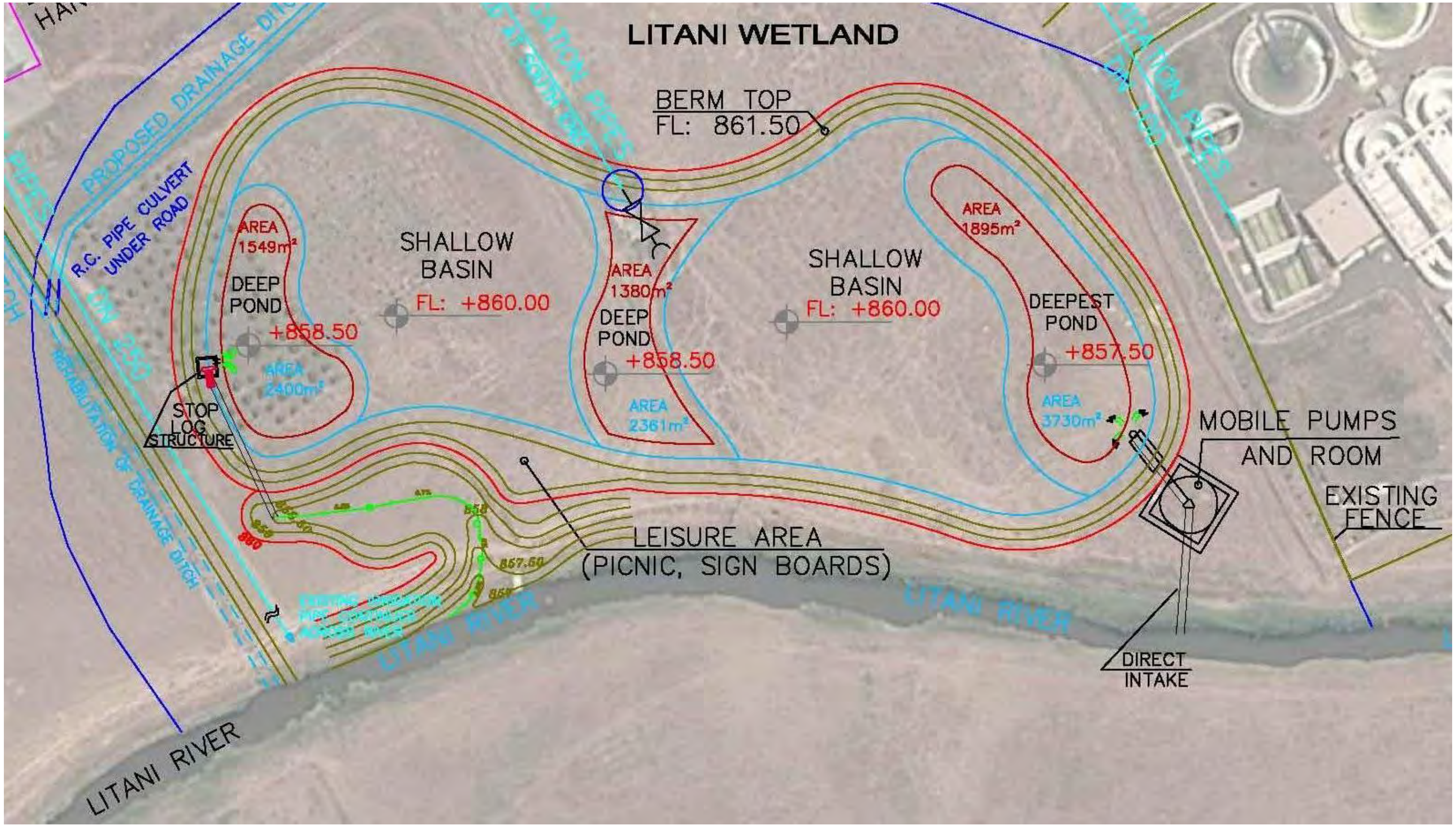

Figure 3.2: Wetland detail

3.3. EXISTING ON-SITE DRAINAGE CANALS

A series of drainage canals exist on the current site that convey storm water from the North Side the Litani River Basin down to the river itself (several are visible in figure 4.1). These canals typically terminate in a pipe placed through the stream bank that discharges directly into the river. When the treatment wetland is constructed, the surrounding berm will cut off three of these canals. These canals will be reconfigured to divert to the nearest similar canal not cut off by the wetland and those canals will be enlarged if necessary to convey the additional runoff. At the downstream (western) portion of the site, these canals can be diverted to flow into the wetland discharge channel to facilitate connection to the Litani River.

3.4. DISCHARGE CHANNEL

Flow will exit the wetland over an adjustable weir composed of stop logs, and then flow through a pipe installed in the berm and discharge at the upper end of an excavated channel that will route flow back to the Litani River.

3.4.1. SIZING

The discharge channel has been sized to accommodate a normal flow of between 20-60 L per second based on expected outflows from the constructed wetland system. This corresponds to a channel width of approximately three to five meters with the exception of the widened, flattened central area (Figure 4.2).

The portion of the Litani River stream bank where the discharge channel connects will be fully stabilized with rock capable of withstanding the predicted velocities in the river during at least the 1 in 10 year flow event. While a detailed hydrologic analysis has not been performed for the Litani River Basin, we know that a 182 m^3 per second flow event occurred at Joub Jannine in February of 2003. This flood represents one of the two highest recorded peak flows in the Litani River on record (1968 being the other). Given that this flow of 182 m^3 per second likely represents at least a 1 in 25 year flow event, it has been used as the basis for design criteria (maximum velocities, etc.).

3.4.2. LAYOUT AND FEATURES

The discharge channel accepts the wetland outflow from a pipe exiting the berm and conveys it in an arc-shaped channel including streambed features, a nearly-flat central wetland area with very shallow side slopes, and rock-lined slopes to control erosion. This feature is intended to mimic an oxbow or former river meander bend cut off and abandoned from normal flow.

During normal operation, this channel will serve to convey only the outflow from the wetland, which will vary between approximately 20 and 60 L per second depending on time of year. During very high winter flows and especially during large storm events, flow from the Litani River will back up into this feature and cause temporary flooding. This is meant to imitate historical floodplain inundation that would have occurred in oxbows and other depressed areas adjacent to the river before human modification. The nearly-flat central area serves to promote spreading of the wetland outflow and creation of additional wetland vegetation communities. To facilitate this, the upstream end of a rock "wedge" (Figure 4.2) intended to prevent erosion in the steepest portion of the discharge channel will be constructed of large, smooth stones arranged to function like a low (30-50 cm) dam.

The channel will connect to the Litani River at approximately a 2 m height above the bottom of the river. This will ensure that dry season flows in the Litani River do not back up into the discharge channel. However, using the river hydraulic model developed by LRBMS (2011) at flows above approximately 10 m^3 per second (which occur on average between January and April) the depth of flow will be approximately 2 m and the river will begin to back up into the discharge channel (Figure 4.2).

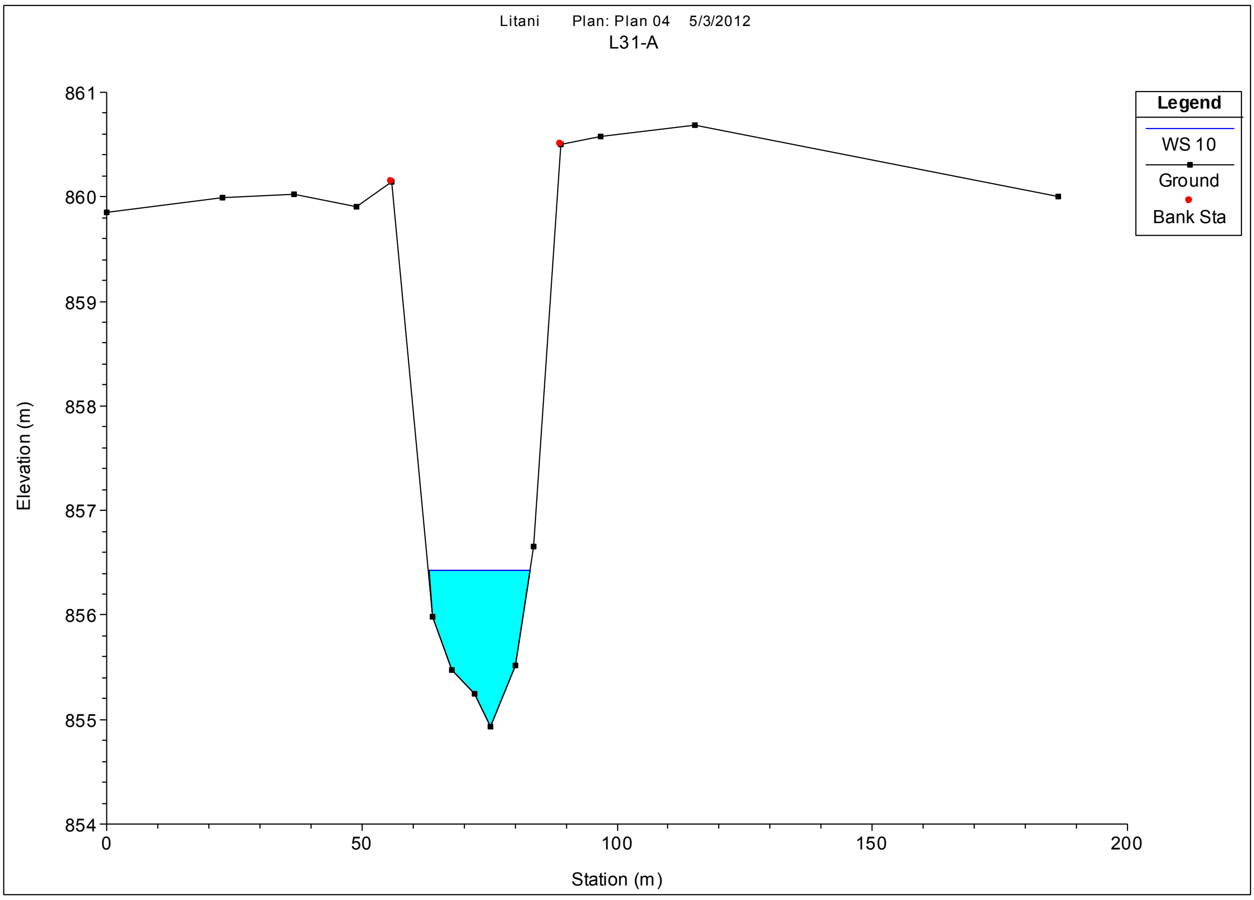

Figure 3.3: Results of hydraulic modeling in the Litani River at discharge channel outlet location

4. POTENTIAL PERFORMANCE OF WETLAND

4.1. WATER BALANCE

Design of this constructed wetland system requires an understanding of expected water losses due to infiltration and evaporation and water gains due to precipitation so that an appropriate design inflow rate can be determined that will ensure a constant outflow and no risk of flooding.

Various precipitation and reference evapotranspiration (ET0) records for the Bekaa Valley were available from LRBMS (2012c). Infiltration testing has been conducted at the chosen site, and the soils have a relatively low infiltration rate characteristic of clay-loam soils.

Table 4.1 summarizes the water balance for the proposed wetland at two operating flow rates (30 and 60 L per second during summer and winter, respectively).

Month	Precipitation (m/mo)	Evapo-transpiration (m/mo)	Infiltration (m/mo)	Inflow (m3/d)	Outflow (m3/d)
January	0.132	0.039	0.28	5184	5035
February	0.154	0.045	0.26	5184	5057
March	0.078	0.079	0.28	5184	4962
April	0.020	0.110	0.27	5184	4890
May	0.012	0.150	0.28	2592	2262
June	0.002	0.183	0.27	2592	2224
July	0.000	0.204	0.28	2592	2211
August	0.002	0.191	0.28	2592	2222
September	0.003	0.150	0.27	2592	2252
October	0.062	0.102	0.28	2592	2339
November	0.040	0.060	0.27	2592	2354
December	0.115	0.042	0.28	5184	5019
Average	*0.05*	*0.11*	*0.28*	*3672*	*3402*

Table 4.1: Water balance for wetland

4.2. TREATMENT PERFORMANCE EXPECTATIONS

Because detailed, long-term water quality data is not available in Litani River near the constructed wetland site, only approximations based on assumed water quality can be made. Using the inflow water quality procedure described above in Section 3.1, we estimate the following treatment performance on both a concentration and mass basis. Because of significant water losses due to evapotranspiration, especially during the summer months, the concentration-based calculations do not fully represent the true pollutant removal capability of the wetland and therefore the mass-based removal rates provide the best means of demonstrating the effect the constructed on system will have on water quality in the Litani River. Table 4.2 summarizes seasonally expected performance expectations.

Dry Season	BOD5	TSS	NH_4-N	$NO_{2/3}$-N	TN	TP	FC**
Inflow Concentration (mg/L)	60	200	4	7	28	3	2,500,000
Inflow Mass Rate (kg/ha/d)	64	213	4	7	30	3	NA
Outflow Concentration (mg/L)	32	37	2	4	8	2	26,000
Outflow Mass Rate (kg/ha/d)	22	25	1	2	5	2	NA
Concentration Removal	47%	81%	44%	46%	72%	23%	99%
Mass Removal	66%	88%	65%	66%	82%	52%	NA
Wet Season	**BOD5**	**TSS**	**NH_4-N**	**$NO_{2/3}$-N**	**TN**	**TP**	**FC****
Inflow Concentration (mg/L)	9	200	2	9	20	1	280,000
Inflow Mass Rate (kg/ha/d)	20	427	5	19	43	3	NA
Outflow Concentration (mg/L)	7	20	2	8	15	1	29,000
Outflow Mass Rate (kg/ha/d)	13	37	3	14	27	2	NA
Concentration Removal	24%	90%	19%	10%	26%	14%	90%
Mass Removal	35%	91%	31%	23%	36%	26%	NA

***Fecal coliform (FC) concentrations report in #/100mL. Mass-basis calculations are not possible for FC.*

Table 4.2: Treatment performance expectations by season

In the dry season, the constructed wetland will treat on average 20% of the Litani River flow (up to the entire flow during dry years). In the wet season, the constructed wetland will treat only a small percentage of the Litani River flow at Joub Jannine.

4.3. COMPARISON TO LEBANESE STANDARDS

The purpose of the wetland is to simply improve, as a demonstration/pilot activity, the water quality of the Litani River. There are no known guidelines for wetland design and performance in Lebanon, so comparison is only possible to Lebanese standards for wastewater treatment and release. These are based on two decisions issued by the Ministry of Environment

- Decision 52/1 on July 29, 1996 (Measures for the Mitigation of water, soil, noise and air pollution); and
- Decision 8/1 on January 30, 2001 (wastewater treatment plants: liquid waste and air pollution standards)

The expected performance of the wetland compares favorably to the environmental limit values for surface water:

Dry Season	BOD5	TSS	NH_4-N	$NO_{2/3}$-N	TN	TP	FC**

Outflow Concentration (mg/L)	32	37	2	4	8	2	26,000
Wet Season	**BOD5**	**TSS**	**NH_4-N**	**$NO_{2/3}$-N**	**TN**	**TP**	**FC****
Outflow Concentration (mg/L)	7	20	2	8	15	1	29,000
Environmental Limit Values (mg/L)	25	60	10	90	30	10	2,000

`Table 4.3: Comparison to Lebanese standards

5. VEGETATION AND HABITAT FEATURES

While this constructed wetland system has been designed primarily with water quality improvement in mind, a secondary benefit is the opportunity for creation of freshwater wetland, floodplain, and riparian aquatic habitats that have been lost to development in the Litani River Basin. The foundation of these habitats is the choice of vegetation communities that will be supported by the local hydrology, help stabilize critical slopes and stream banks, and provide potential nesting and foraging habitat for birds, amphibians, and other wildlife species. Species native to Lebanon have been selected whenever possible.

5.1. CONSTRUCTED WETLAND

The constructed wetland requires a dense coverage of emergent vegetation in its shallow zones with species adapted to constant flooding. *Phragmites australis,* or common reed, is native to Lebanon and a robust emergent marsh plant species that provides habitat for a variety of bird species. Because it is commonly found near the chosen site (for example, at the Aammiq wetlands) and is readily propagated by planting its rhizomes (root structures), *Phragmites australis* provides an ideal primary species for the wetland.

In the deep, open water areas of the constructed wetland, both floating and submerged plants will serve to enhance biodiversity and can enhance the treatment effectiveness for certain pollutants. *Nymphaea alba*, or water lily will be planted in the wetlands for this purpose.

While not required for use in treatment, the outside slope of the wetland berm should be seeded with a mixture of native flowering plants to enhance slope stability and improve aesthetics of the site.

5.2. DISCHARGE CHANNEL

The discharge channel serves two main purposes – it provides a conduit for outflow from the constructed wetland back to the Litani River, and it provides a diverse array of riparian and floodplain habitats using treated water as a source. The discharge channel features initial and terminal narrow stream channels whose banks will be seeded with the same mix of plant species as the outside of the wetland berms discussed above. The central, flat and wide portion of the discharge channel mimics a floodplain wetland area and will be vegetated with *Phragmites australis*. At the end of the central wetland area, a sloped rocky "wedge" area that returns the discharge channel back to its original narrow width will be vegetated with *Salix alba, Salix libanotica,* or *Salix varifolia*, which will help serve to stabilize the slope.

The Litani River streambanks surrounding the discharge channel connection must be stabilized. *Salix alba, Salix libanotica,* or *Salix varifolia* will be planted in these areas. The same is true at the pump station connection to the Litani River.

5.3. LITANI RIVER BANKS

Use of the site for sheep grazing has resulted in a complete loss of any riparian vegetation. Because future sheep grazing will be excluded from the constructed wetland site by means of a fence, riparian vegetation will once again be able to establish itself along the north west bank of the river. *Salix alba, Salix libanotica,* or *Salix varifolia* planted both at the up and downstream ends of the site (pump station and discharge channel) will over time propagate themselves and hopefully establish a new continuous corridor of riparian vegetation adjacent to the wetland site. Such a corridor will provide many important benefits for the Litani River such as habitat for wildlife, shading of the river and associated reduction in water temperature, and prevention of erosion during major storm or flooding events.

6. CONSTRUCTION AND STARTUP

6.1. EARTHMOVING AND GRADING

The earthmoving and grading work required for this constructed wetlands does not significantly differ from any similar pond or lagoon construction project. However, certain aspects of how the grading work is performed can have a significant impact on the final treatment efficiency of the wetland and therefore it is of critical importance that certain specifications are rigorously followed.

6.1.1. CONSTRUCTED WETLAND

Optimal treatment efficiency in the treatment wetland is directly tied to the uniformity of flow through the system. As water flows across the shallow vegetated zones, it experiences frictional resistance from plant stems and variability in the ground surface. As the depths of flow are very low (between 30 and 50 cm) small variations in topography or plant growth can cause preferential flow paths to develop that move water more rapidly in some areas. The net effect of this is so-called "short-circuiting" which serves to move water and pollutants more rapidly through the wetland than is desirable and decreases overall system performance. Therefore, the following specifications ***must*** be followed:

- The shallow vegetated zones must be graded perfectly flat and all three should be graded to the same elevation.
- The surface of the shallow vegetated zones must be graded to the tightest vertical tolerances possible. A vertical tolerance lower than +/-5cm is required; +/- 2cm should be adopted if possible.
- Scoring or other marks left by machinery should be smoothed out to the greatest degree possible. Machinery driven across the surface of the shallow vegetated zones ***must*** do so in a pathway ***perpendicular*** to the direction of flow so as to ensure that vehicle tracks do not run parallel to flow across the shallow vegetated zones.

Figure 6.2 depicts several critical grading problems in a newly constructed wetland. The photograph shows a shallow vegetated zone. While much of the graded surface of the zone is not visible because it is under several centimeters of water, one patch is obviously 10 cm or more above the water. This was far outside of the specified elevation tolerance. Additionally, the grading machinery has left deep track marks in the soil, some of which extend a significant distance parallel to the flow of water.

Figure 6.1: Uneven grading and machinery marks left during grading of a constructed treatment wetland.

6.1.2. DISCHARGE CHANNEL

The discharge channel serves to convey outflow from the constructed treatment wetland back to the Litani River. Because it does not serve a treatment function, the strict grading tolerances and procedures described above for the constructed treatment wetland do not apply. However, for it to function as intended certain aspects must be properly constructed.

Much of the discharge channel is simply an earthen trapezoidal channel. Grading should be performed so as to leave the bottom of the channel gently sloped laterally towards the center so as to form a gentle "V" that conveys the flow down the center of the channel. The central, widened wetland area should be graded laterally flat (longitudinally it has a gentle slope). At the downstream end of the central wetland area, a "wedge" of rounded stones serves to narrow the flow back to a channel and resist erosion as the slope is steepest in this area. In addition, at the downstream end of the wedge feature, a dam of rock should be installed underneath the finished grade down to approximately the elevation of the bottom of the Litani River nearby. This is a preemptive measure against potential erosion of the channel feature downstream of this point. Should so-called "headcutting" erosion occur at the discharge channels connection with the Litani River it will eventually reach this buried rock structure and be stopped as it migrates up the discharge channel.

6.2. PLANTS AND PLANTING SPECIFICATIONS

Vegetation is a very important part of this natural system. Plant species have been selected that are adapted to the local climate and other physical conditions, that will provide the necessary water pollution treatment functions, and that will provide a diversity of aquatic and riparian habitat. It is important to note that some selected species are of critical importance for the proper functioning of the system, while others will not affect the overall success of the project if they either do not fully establish or are outcompeted over time by other similar species that perform a similar habitat function. These differences will be noted below in the specific descriptions of vegetation species and locations.

It is recommended that the contractor selected for construction of this system retain a qualified landscape specialist familiar with all of the specified plant species. While species have been selected that are adapted to the site conditions and readily propagate with little specific intervention, construction of natural systems such as this often requires adaptive decision-making during construction to ensure successful growth and development of vegetation features. Often, climate and other key physical conditions at the site cannot be predicted in advance of construction by designers and project success depends on the presence of a qualified individual to select appropriate vegetation establishment techniques and perform troubleshooting as necessary.

6.2.1. *PHRAGMITES AUSTRALIS*

Phragmites australis, or common reed, is a common emergent macrophyte in the Eurasian continent. It grows well in shallow water or saturated soils. It propagates by seed dispersal and lateral growth of rhizomes (its root structures). A uniform, dense coverage of *Phragmites australis* is crucial to the effectiveness of treatment in the constructed wetland.

Because this species is locally common in the Bekaa Valley, the likely least expensive method for planting *Phragmites australis* is excavation and stockpiling of the approximately top 30 cm of soils from local ditches and other water bodies where *Phragmites* australis already grows. This rhizome-containing soil should be mixed uniformly with the top layer of soils in the shallow vegetated zones during grading. *Phragmites australis* can also be readily propagated by seed which can be collected from existing local stands of the plant.

6.2.2. *SALIX SPECIES*

Salix alba, Salix libanotica, or *Salix varifolia* are common in the nearby Aammiq wetlands. The exact variety (presumed to be one of the three listed) of *Salix* present in the Aammiq wetlands is not currently known; however, it will be harvested for use in the constructed wetland. *Salix* species are common along river banks and other aquatic habitats because they favor moist soils and can tolerate short periods of inundation. They are fast growing and develop strong roots that are useful for stabilizing slopes. For this reason, *Salix alba, Salix libanotica,* or *Salix varifolia* will be used throughout the project site but particularly on the newly created slopes connecting the discharge channel the Litani River and the excavated channel connecting the pump basin to the Litani River.

Salix species are readily propagated with cuttings. Cuttings should be installed at approximate densities of one per square meter in specified areas.

6.2.3. *NYMPHAEA ALBA*

Nymphaea alba, or water lily, is a floating plant native to Europe and the Middle East. While it may serve a limited treatment benefit (by adding oxygen to the water column through photosynthesis) its primary purpose in this project is for habitat diversity and aesthetics. It can be obtained from local nurseries and planted in the deep open water areas once the wetland is filled.

6.2.4. OTHER SPECIES

Other species, particularly transitional species (adapted to the sloped region between wet areas and dry, upland areas) will be established on many of the slopes on the berm and in the discharge channel. These will be best established through use of hydroseeding which is the spray application of a slurry of water, seeds, and other binding ingredients.

6.3. INITIAL FILLING OF THE WETLAND

NOTE: It is of critical importance that the wetland be initially filled with water via the general procedure described below. Initial filling of the wetland (or any refilling of the wetland after it has been drained) must be performed using this procedure or serious erosion problems may occur that could cause significant damage to the wetland.

A temporary, portable small pump system will be used to initially fill the wetland. All four open water deep zones must be individually and completely filled with water to the height of the shallow vegetated zones before any water is input to the wetland via the inflow structure. Water may be pumped directly from the Litani River with the hose and placed at the bottom of each deep zone via another hose. With a portable pump, this can be accomplished for each of the four open water deep zones from the perimeter berm where it lies directly between the Litani River and the constructed treatment wetland system. Depending on the flow rate of the pump and velocity of water exiting the pump outflow hose, a simple stabilization mechanism may be required to prevent localized erosion at the end of the hose in the soils at the bottom of each deep zone.

Failure to fill each deep zone before inflow is sent to the wetland via the permanent inflow pump station will cause significant erosion on the transitional side slopes between each shallow vegetated area and the next downstream deep zone.

6.4. STARTUP REQUIREMENTS

The constructed wetland system startup period will be used to establish a baseline operating condition which can be modified as necessary to optimize system performance.

The wetland startup period is expected to take up to 6 months following initiation of continuous inflows. Over this period, flows should be gradually increased until the target, full flow rate is achieved. Startup of a constructed wetland system is normally gradual because of the need to fully establish plant cover before discharging full flows or raising water levels. Inflow to the wetland should be continuous during this initial period, and the water levels should be maintained at approximately 15 centimeters or lower in the shallow vegetated zones. Target water depth should be maintained by adjusting the stop logs in the outlet structure to achieve the desired depths in the shallow zones as indicated by depth gauges at the inlet and outlet structures.

Because vegetation cover in shallow zones is critical for wetland performance in general, additional plant growth monitoring of all wetland cells is recommended during the project startup phase. The design ratio of vegetated cover: open water for the wetland is intended to be 70:30%. It is necessary to achieve this goal by establishing dense stands of vegetation in the marsh zones. Methods for monitoring plant cover and growth are described in the operations and maintenance guidance section of this document.

6.5. OPPORTUNITIES FOR FUTURE EXPANSION

One goal of this project is the demonstration of successful wetland-based treatment systems to provide multiple benefits to the Litani River Basin, including restoration of habitat, environmental education, and water quality improvement. Should expansion of the initial wetlands be desired in the future, additional land is readily available at the chosen site. Expansion has been considered during this design process in the following ways:

- The pump basin has been over-sized to accommodate expansion with additional pumps to provide additional inflow.
- The closest location for construction of additional treatment wetlands is directly across the Litani River from the initial wetland. Inflow generated from additional pump installation can be readily piped across the river and additional wetlands constructed adjacent to the other bank. Expansion northwards of the initial wetland is currently limited due to existing buildings.
- Alternatively, if the buildings immediately north of the initial wetlands can be relocated or removed, a second wetland cell could be constructed immediately to the north (sharing a berm side with the initial wetland) with its outflow also fed into the existing discharge

channel, which has the capacity to convey significantly more flow than the initial wetland will discharge.

7. OPERATIONS AND MAINTENANCE GUIDANCE

7.1. OPERATOR RESPONSIBILITIES

The treatment wetland system has been designed with simplicity in mind. However, a water treatment system cannot continuously operate with no maintenance of any kind. Some simple routine maintenance activities will be required, and more technical maintenance may be required after significant flood events in the Litani River or other natural and unpredictable events.

Management personnel should have a good working knowledge of pumps, motors, and electrical and electronic equipment. Operators should also be able to interpret and record system operating and monitoring data.

Successful operation depends on qualified personnel and adequate supplies to enable a prompt, thorough response to system maintenance requirements and to correct system problems. Although this guidance is based on previous experience and consideration of the goals and objectives determined by the project designers, it is important to realize that all operational activities at the chosen site must be flexible and based on common sense. It is likely that unforeseen issues will arise.

This section describes the expected typical operations and maintenance activities and provides guidance for typical troubleshooting activities common to these types of constructed wetland systems.

7.2. SITE ACCESS

The treatment wetlands site is located south of the LRA agricultural extension center, accessible by an access road that leads to a perimeter roadway on top of the wetland berm. From this access road and berm, operators can reach all portions of the site, including the pump station, inlet structure, and outlet structure.

7.3. SAFETY

Minimal safety equipment is required for the work in the wetlands since it is a natural system. However, it is important to express caution when working within this natural environment for potential hazards associated with the natural surroundings such as snakes, insect bites, and extreme hot and cold temperatures. Safety equipment as it pertains to the wetlands may include:

- Hip waders when performing work/maintenance within the wetland cell marsh or deep zones.
- Hardhat/safety vests during periods of construction
- Safety Glasses
- Sunscreen/ and or additional sun protection equipment
- Insect/bug repellent spray

In addition, work in and around the wetlands, especially if water contact is required, should be performed with care and attention to hygiene. All equipment and body parts that come in contact with water should be thoroughly washed after exposure. It must be remembered that the Litani River often contains untreated domestic wastewater which will enter the wetland ponds and may contain disease-causing organisms. Proper sanitary precautions, such as the use of gloves and personal cleanliness, are important.

Maintenance staff should not wade into the cells without someone on shore to assist in case of emergency. Boots or hip waders should be worn when entering the wetlands -- marsh areas will typically contain 30 to 50 centimeters of water while open water areas may be as deep as two meters.

7.4. TREATMENT PROCESSES

The wetland system has been primarily designed to remove total suspended solids (TSS), BOD, nutrients, and heavy metals. TSS removal occurs via several processes. Vegetative shading of the water disrupts algal growth and reproduction. Physical trapping, settling, and filtering of algal solids occurs as water flows across the vegetated shallow zones. BOD is consumed by the wetland through production of oxygen by wetland plants and by oxygenation of water due to wind mixing in the deep open water zones. Nutrients are taken up by plants and algae, transformed by the wetland nitrogen cycle, and removed by microbial processes. Heavy metals form precipitates and other complexes in the root zone of the shallow areas and settle into the deep zones. In both places, they are rendered unavailable to wildlife or further movement downstream.

The most critical factor in ensuring that these processes occur is the maintenance of consistent water surface elevations and uniform flow through the wetland. The intended design water surface elevation will be maintained by setting the stoplogs at the outflow structure to the proper height (achieving a depth between 30 and 50 cm in the shallow vegetated zones). Consistent flow through the wetland will be ensured by maintenance of the pump station.

7.5. PUMP STATION

1- General: Installation shall comply with pump manufacturer's written installation instructions.

2- Pump Installation shall be performed in the location indicated on the General Layout Drawing. Access and Space within the Housing Pumps and Electric Control Panel Room shall be provided for periodic maintenance, including removal of motors, impellers, couplings, and accessories.

3- Piping shall be supported so that weight of piping would not be supported by pumps.

4- Pumps shall be base mounted on concrete Slab bases. Pump base plate shall be supported on rectangular metal blocks and shims, or on metal wedges having small taper, at points near foundation bolts shall provide a gap of (19 to 38 mm) between pump base and foundation for grouting.

5- All tests shall be run in accordance with the latest standards of the Hydraulic Institute.

6- Operation and Maintenance manuals (including suitable lubrication and Grease application) shall be prepared upon completion of Installation, and shall include the following activities:

   a. Check suction line connections for tightness to avoid drawing air into pumps.
   b. Perform field acceptance tests for each pump unit
   c. Startup Services: Provide services of factory authorized service representative to provide startup service and to demonstrate and train Owner's maintenance personnel as specified below.
      i. Test and adjust controls and safeties.
      ii. Train Owner's maintenance personnel on procedures and schedules related to startup and shutdown, troubleshooting, servicing, and preventive maintenance.
      iii. Review data in the "Operating and Maintenance Manual"
   d. Final Checks Before Startup:
      i. Lubricate oil lubricated bearings.
      ii. Remove grease lubricated bearing covers and flush bearings with kerosene and thoroughly clean. Fill with new lubricant according to manufacturer's recommendations.
      iii. Disconnect coupling and check electric motor for proper rotation.
      iv. Check general mechanical operation of pump and motor.

7.6. CONSTRUCTED WETLAND

Routine O&M of the wetland will include the following:

- Water level adjustment at outlet structures

- Distribution and inlet flow meter adjustments
- Inspection and periodic cleaning of the wetland inlet and outlet structures for sedimentation and flow blockage
- Vegetation density monitoring and management
- Observation and correction of channelization caused by fluctuations in water elevation
- Periodic inspections of the berms and access roads, especially any soil erosion issues arising after heavy rainfall events

Inflow rate and water depth controls are the only process-related adjustments for the wetland and will be performed infrequently. Pump and weir inspections should be conducted daily.

7.6.1. WATER LEVEL CONTROL

Careful water level control is extremely important in treatment wetland operation. Excessive depth has been shown to stress wetland vegetation and decrease treatment wetland performance. If the wetland water levels are excessively shallow, then small channels may be created that will provide a short-circuiting flow path. Hydraulic residence times may be unacceptably shortened if depths are kept too shallow. Water levels should be kept between 30 – 50 cm in the shallow zones on a normal basis. Water level control is achieved through adjustments at the outlet spillway structure, which contains stoplogs that can be placed or removed to raise or lower the wetland water profile in 15cm increments.

The outflow and inflow structures should be checked daily and cleared of flow blockage as needed. Water levels should not be allowed to fluctuate extensively on a normal day-to-day basis.

7.6.2. FLOW CONTROL

The rate of inflow to the wetland has a direct effect on the hydraulic loading rate, pollutant loads, hydraulic residence time, wetland channel velocity, and potential head loss across the wetland length. It is important to ensure steady, uniform distribution of flows to each pond, and as described above, minimize the creation of flow channels. Structures should be inspected daily to prevent flow blockage.

7.6.3. VEGETATION MANAGEMENT

Vegetation management should be approached systematically and thoughtfully. As a rule, there is normally very little management of wetland plants undertaken at treatment wetlands because the top priority is to establish rapid growth of a dense cover and biomass. However, it is valuable to limit the invasion of potential nuisance species while the planted species are continuing to develop. In addition, management of vegetation surrounding the wetlands, such as trees and shrubs, may be necessary.

The wetland vegetation management program should seek to avoid a "gardening" perspective - specifically the excessive use of labor to remove or manage the occurrence of desirable species - and instead recognize that wetlands typically self-maintain as long as the water levels are set properly. Harvesting of wetland plants is not expected to be necessary unless it becomes apparent that the accumulation of vegetation has proceeded to the point that excessive short-circuiting is occurring. In this case, a review of field conditions should be conducted to determine those areas that could be subjected to thinning. Because this type of vegetation management is very labor intensive, vegetation thinning should take place only as a last resort.

To maintain optimum treatment efficiencies, a uniform distribution of flow must be maintained in the wetland cells. Channelized flow (short-circuiting) will reduce the efficiency of contact between water and wetland sediments in the ponds and reduce the level of wastewater treatment.

As the wetland plants grow, they may begin to obstruct wastewater flow in areas of the cells and cause short-circuiting. If areas become overgrown, they may be thinned out to maintain a uniform flow pattern through the cells. Similarly, if unwanted vegetation begins to overwhelm the desired species, then the undesirable invasive plants should be removed. Maintenance staff can wade into the cells with wading boots and remove the plants in the shallow zones by uprooting them by hand.

If floating species in the deep zones grow so thick as to restrict flow, they may be thinned by pulling or by raking the surface from the edge of the wetland cells. The collected material should be removed from the cells and disposed.

Wetland plants are generally very hardy, and once established in the system, they should proliferate. The health of the wetland vegetation should be monitored routinely, and the presence of a large number of unhealthy or dying plants should be investigated to determine the cause of the problem. A local nursery can be consulted for recommendations to treat the plants ensuring that a healthy stand of vegetation is maintained.

7.6.4. BERM MAINTENANCE

The berm is critical to project success and ongoing safety. It should be inspected weekly for any signs of erosion, seepage or other weakness. Any potential problems need to be reported to appropriate personnel immediately so that they can be remedied as early as possible. Any type of erosion or gully problem must be dealt with immediately. Berms should also be inspected for damage caused by burrowing animals. Such damage should be repaired immediately.

Berms and other embankments should be under constant watch during extreme weather events. Water levels should be allowed to return to normal levels gradually after a storm event. Water depths greater than 50cm in the wetland may be sustained for approximately one month in the wetland cells with no significant effect on the wetland plants.

7.6.5. CONTROL OF NUISANCE ANIMALS

Excessive grazing by herbivorous animals, such as geese or ducks, can slow growth or damage the vegetation in the constructed treatment wetlands if unchecked. These common animals are not expected to pose a significant risk to the wetland vegetation but local staff should be especially vigilant during the startup period of the wetland to ensure that grazing of wetland vegetation by these animals is not preventing proper initial growth. If excessive grazing effects become evident, and appear to be continuing, wildlife control measures should be investigated and applied. Simple methods can include exclusion fences ranging from monofilament line to silt screens and safety barriers installed around the shallow vegetated areas. More intensive measures can range from hazing using noisemakers or trained dogs to the use of professional trappers. The type of response to a grazing problem should be weighed against the apparent significance of its effects before determining a course of action.

7.6.6. MOSQUITOES

Shallow, still, or slow-moving water is the preferred habitat for mosquito breeding. Poor water quality can also increase mosquito breeding activity since natural predators of mosquito larvae are often unable to survive in water with high levels of ammonia and low levels of dissolved oxygen. Therefore, construction of the treatment wetland system is likely to create mosquito breeding habitat.

However, similar areas abound in the Bekaa Valley with poor water quality and slow moving water, particularly in summer when flows are reduced to mostly wastewater inputs only. Therefore, the relatively small size of these wetlands compared to the rest of the valley makes them an insignificant additional source of mosquitoes.

We recommend that a mosquito trapping program be initiated on site prior to construction and kept in place after construction. Frequently, when local citizen complaints of mosquitoes occur shortly after construction of a wetland, the wetland is an obvious scapegoat. However, without adequate data on existing mosquito populations prior to construction, no true evaluation can be made of whether or not the wetland actually increased local mosquito activity.

In North America, constructed wetlands frequently are stocked with G*ambusia affinis*, or western mosquito fish, as a preemptive mosquito prevention technique as these fish tolerate a wide range of physical conditions and are known to prey heavily upon mosquito larvae. While a closely related species *Gambusia holbrooki,* or eastern mosquito fish has been extensively introduced in Europe and parts of the Middle East (Patimar et al 2011) to combat mosquito populations, its existence and distribution in Lebanon is currently unknown. If a local source is available, the wetlands should be stocked with this fish species as a preventative measure.

7.7. DISCHARGE CHANNEL

The discharge channel has been designed as a generally self-maintaining system that will not require any ongoing operational tasks to serve its purpose of conveying treated water to the Litani River. However, because it has a direct connection to the river and therefore will intermittently flood to varying degrees depending upon flows in the Litani River, it will be subject to potential erosion, particularly in the first few years after construction while vegetation matures. Rock structures are included in the design to provide more than adequate initial resistance to erosion, but the discharge channel should be inspected after every significant flood and at a minimum after every winter rainy season is over to determine if any erosion is occurring that should be repaired.

Of particular importance is verifying the integrity of the rock structures located where the discharge channel connects to the Litani River and at the downstream end of the central flat wetland area. These are hard points that will maintain the channel elevations and ultimately the overall integrity of the discharge channel itself. If these structures are collapsing or becoming undermined, they should be repaired immediately to prevent more significant damage.

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