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Estimation of the Environmental Flow Regime to Deter-mine the Minimum Flow for Pollution Reduction: Wadi Zomar - Palestine as a Case Study

تقدير نظام التدفق البيئي لتحديد الحد الأدنى من التدفق للحد من التلوث: وادي زومر - فلسطين كدراسة حالة

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Abstract: Possible factors that play a role in restoring a flow regime that supports a healthy environment were identified for Wadi Zomar, Palestine. The hydrograph shows that threshold discharges for bed drying are less than 0.14 m3/s, bar formation is less than 0.4 ms/s and floodplain inundation events are over 3 m3/s. The HEC-RAS model suggests a continuous discharge throughout the year that maintains the base flow in the range of 0.5 m3/s. The model suggests that the restoration process is controlled by two main factors: role of sufficient flow and flood inundation frequency.

Keywords: Flow Regime, Wadi Zomar – Palestine, Fecal Coliform, Restoration.

مستخلص: تم تحديد العوامل المحتملة التي تلعب دورًا في استعادة نظام التدفق البيئي الذي يدعم ويضمن بيئة صحية لوادي زومر الواقع الى الغرب من فلسطين. حيث اظهرت الروسم البيانية الهيدروغرافية أن الحد الأدنى للجريان اللازم للإبقاء على تدفق صحي يدعم النظام البيئي هي أقل من 0.14 متر مكعب/ ثانية، وبالرغم من تشكل تدفق سنوي للمياه بارتفاع أقل من 0.4 مللي ثانية / ثانية، إلا أن أحداث الغمر للسهول المجاور تحدث عند ارتفاع المستوى إلى أكثر من 3 متر مكعب/س. يقترح نموذج HEC-RAS ضمان تدفقا صناعيا مستمرًا طوال العام على شكل حقن للمياه المعالجة في عدة نقاط على مسار الوادي في فترات الجفاف بشكل يحافظ على التدفق الأساسي الذي تم تحديده كما سبق ذكره في نطاق 0.5 متر مكعب/س. كما ويشير النموذج إلى أن عملية استعادة النظم البيئية الصحية والسليمة للوادي من خلال هذا الحقن الصناعي للمياه في فترات الجفاف، يتم التحكم فيها من خلال عاملين رئيسيين: عامل وجود تدفق كافي للمياه الكافي طبيعيا في فصل الشتاء وصناعيا عن طريق الحقن بالإضافة الى عامل تكرار الفيضانات الموسمية بعد الاحداث المطرية الموسمية الكبيرة، الأمر الذي يؤدي للحفاظ على مستوى تدفق يدعم نظام بيئي صحي متوازن لمنطقة جريان وادي زومر.

الكلمات المفتاحية: نظام التدفق البيئي، وادي زمر – فلسطين، القولونيات البرازية، استعادة النظام البيئي.

INTRODUCTION:

Anthropogenic water pollution (causes serious health problems and an increase in economic costs arising from water treatment, remediation, and water supply relocation (Gasana, et al., 2002). In most cases, restoration of polluted water bodies is a necessity with positive ecological impacts on the landscape,

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contribu-tions to leisure, quality of life, and tourism (Bar-Or, 2000). Recovery of the environmental and social func-tions of polluted water bodies, as in the case of Zomar Stream, has taken an increasingly important place on the Palestinian public agenda.

Environmental flows regime haves been increasingly recognized as a central issue in sustainable water resource management (Kashaigili et al., 2007; OPTIMA, 2007). Low flows, coupled with degradation of water quality, have induced severe environmental degradation, rendering water unusable downstream. Environ-mental Flow Requirements (EFR) for water resource allocation necessitate that a certain amount of water be purposefully left in or released into an aquatic ecosystem to maintain a condition that will support its direct and indirect use values)

King et al., 2003). Maintenance of EFR has also become a high priority for stream basin management all over the world (Barnett et al., 2006). This approach determines how much of the original stream flow should be sustained to keep the stream ecosystem healthy. Moreover, understanding the dynamics of stream-dependent ecosystems is crucial to restoring efficiency and effectiveness (Puckridge et al., 1998; Pettit et al., 2001) and managing concentration, growth rate, and transport of microorganisms (Schaffter and Parriaux, 2002; Collins and Rutherford, 2004).

Process-based hydrological modeling tools will be used in this research based on the principles of conservation destruction, and development. They can be used to simulate these processes for species that are considered indicators of a balanced watershed (Bauffaut and Benson, 2003; Coffey et al. 2007). Bacterial indicators are usually composed of Coliform bacteria, E. coli, Klebsiella, Pseudomonas, and Enterococci (Townsend, 1992; USEPA, 2001). Relations between bacteria and pathogens in fecal contaminated surface water are complex and variable (Yates, 2007; Payment et al., 2003). The optimal situation is where the modeling tool simulates a state of balance for the whole system, including the surrounded environment. The computer modeling tool shows optimal hydrological condition with minimum flow necessary to maintain non-hazardous bacterial growth and gives decision support about the best restoration practices (Abu-Khalaft et al., 2003) .

In this study, a tool for analyzing the EFR of a case study area (Zomar Stream) was developed. The tool incorporates several methods of assessing hydrological and hydro-biological responses to flow change and identifies hydrometric factors controlling the stream and its impacts on the system's health. The tool was used to suggest optimal flow conditions for a healthy system.

STUDY AREA:

Zomar Stream, as it is known in Palestine, or Alexander, as it is known in Israel, has a total length of 44 km, 17 of which are naturally perennial (Fig. 1). The western segment of the stream reaches the Mediterranean Sea and is relatively wide, holding water year-round. The basin shows the effects of fifty years of continuous contamination, associated with the accelerated development and increase in the sewage discharges from the Palestinian cities of Nablus and Tulkarem as well as several settlements, most notably the city of Netanya. The quantity of the effluents discharged into the stream is estimated as 3 MCM/year. The study area has a semi-arid east Mediterranean climate with annual rainfall of 400-600 mm/year and high evaporation rates that reach 100 mm/year (OPTIMA, 2007). The effects of climatic variability and climate change on humans as well as aquatic resources have played a major role in the West Bank water crisis. For more than a decade, it has been recognized that strong links exist between ecological processes and hydraulic, hydrological, thermal, and sediment logical variables of the stream and that dynamic flow patterns maintained within the natural range of variation will promote integrity and sustainability of freshwater ecosystems (Carva-jal-Escobar, 2008).

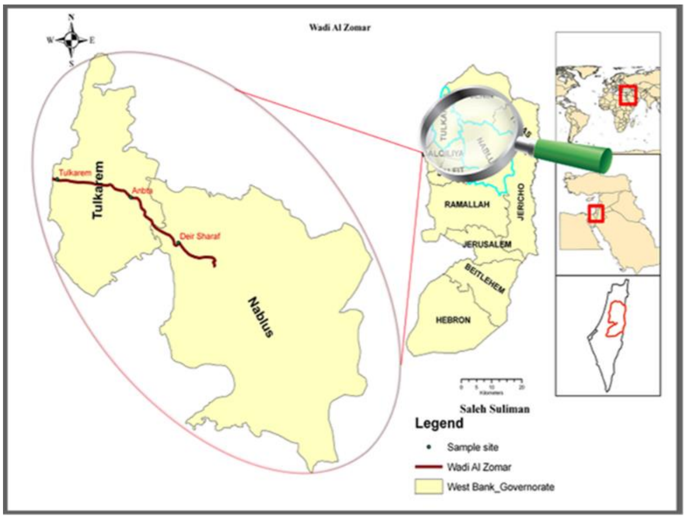

Figure 1: Location of the case study area: Zomar watershed.

MATERIAL AND METHODS

The new combined approach has four main steps:

1.Collecting fecal coliform bacteria samples and measuring parallel hydrometric conditions: Hydro-logic and hydrochemical sampling and analysis were conducted by Suliman (2010). Samples were analyzed for various indicators and enteric pathogens by membrane filter technique. Fecal coliform bacteria were used to study the biological response, mainly bacterial removal, to the flow event. Observation and sampling points were taken from the upper part of the main stream near Deir Sharaf and from an observation point near Tulkarem. Stream velocity was measured by using a propeller to calculate the amount of discharge at each section. Three sampling locations for the assessment of Zomar Stream were selected based on their characteristics and the surrounding pollution sources. Deir Sharaf was selected as the first point that receives a high load of sewage and industrial waste. This sampling point shows a significant effect of continuous waste effluent on natural restoration abilities of the stream with time and distance. The other point near Anabta where less pollution input indicated were selected. It locates further to the west of Deir Sharaf. The third sampling point was selected to the west of Tulkarem, near the Separation Wall, where the Palestinian part of the stream ends. Cross-sections at each sampling point location were created and measured values were in-serted into the surface water model.

2.Studying three hydrometric factors (i.e., flood inundation frequency along hydrologic year, bed ex-posure in dry periods, and bar formation) that control flow regime and display their effect on the whole system throughout a number of years. The integration of those three factors enhancing the presence of unhealthy conditions and increase bacterial and pathogen growth along the stream. Ideally, at least five years of flow events should be traced. However, due to a lack of historical data, these data arethe only source that can reflect the hydrological situation in the stream. The incidence of the mentioned hydrometric factors throughout the years was displayed in cross-sections and along the stream using the HEC-RAS model. HEC-RAS is a computer program that models hydraulics of water flow through natural rivers and other channels. The program is one-dimensional in that there is no direct modeling of the hydraulic effect of cross-section shape changes, bends, and other two- and three-dimensional aspects of flow (U.S. Army Corps of Engineers, 2001) .

3 .Modeling a yearly flow regime scenario based on a proposed minimum threshold flow that would overcome the negative flow regime factors mentioned above: In order to display the effect of ad-ditional base flow on flow regime factors, we followed the following steps:

a) Generate stream boundary conditions by modeling the last hydrological year 2009/2010 using a HEC-HMS hydrograph. The HEC-HM simulates the precipitation-runoff processes of drainage basins (U.S. Army Corps of Engineers, 2005.(

b) The resulting time series flow data, which depend on actual stream base flow, were compared with measured values along the stream for model calibration.

c) Depending on the calibrated model, 4 minimum discharge values were trialed as scenarios of increasing the recharge gradually above the threshold discharges for bed drying. A new hy-drograph was produced and incorporated into the HEC-RAS model for the same normal model period and flood conditions. Scenario figures and cross sections were compared.

The WMS-Watershed modeling system was used as a moderator program for the HEC-RAS/HMS programs. Surface geometry with computed slope curves and cross sections were prepared and exported to other modeling programs. Meteorological parameters such as daily rain event average volume for the period between September 1st, 2009 and August 31 st, 2010, estimated water losses, and SC-Curves were included in the model. Base flows for Zomar Stream were also set in the HEC-HMS program for computation and simulation of storm-flow hydrographs.

4 .Determining critical water levels for flushing ponds and floodplain inundation by tracing the last extreme flow event and calculating the associated discharge: From this data, spatial and temporal effects of the event on fecal coliform were identified and an optimal condition for a healthy stream with minimum pathogens was determined. The natural ability of the stream to washout pollutants in response to different hydrological conditions was also tested. Fecal Coliform count (FC) was modeled and used as a pollutant wash-out indi-cator and, consequently, as an indicator of the system's ability to rejuvenate in the face of modified flow conditions. Resulting simulation graphs give an idea of optimal conditions. Lower counts of indicator bacteria are a result of dilution by flood water; these conditions are traced spatially and temporally. For this purpose, HEC-RAS was used. In other habitat model studies, minimum flow is one of the major environmental impacts caused by low hydrological input throughout the year. These studies concentrated on the negative rela-tionship between low flow conditions and habitat availability (which is one of several criteria for the devel-opment of ecologically-oriented flow regulations). In this study, Zomar Stream is not self-sustaining and receives rain water seasonally. While

there is a continuous discharge of wastewater all year, fecal coliform bacteria are a negative indicator with its removal being a gauge for restoration toward a healthy environment.

Available hydrological and hydrobiological data were incorporated into the HEC-RAS model to display re-moval and re-growth of bacterial colonies in response to various flow conditions. FC was integrated into the flow model. The system's ability to remove fecal coliform bacteria with flood flush and to increase stream oxygen content by flushing out pollutants was displayed using HEC-RAS.

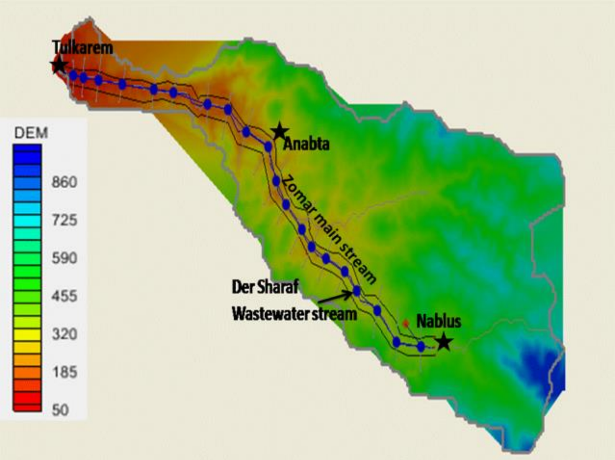

Figure 2: Digital Elevation model with delineated stream and points of cross sections, with more focus on the three sampling points.

Suleiman (2010) used the same cross-sections from sampling points 15920 near Deir Sharaf, 9792 near Anabta, and 961 west of Tulkarem near the end of the stream (Fig2). The Deir Sharaf cross section was taken as an additional wastewater flow boundary with high bacterial concentration and high BOD, Anabta was a goodself-purification point (Suleiman, 2010), and Tulkarem was the accumulation point of all contributions. Data were obtained from observation measurements as described above. Data series tables for flow in m3/s and FC counts were prepared according to periodic measurements by Suleiman (2010) (Table1). The recent extreme flow event on February 22nd, 2010 was redrawn using the HEC-HMS model program.

Table 1: The main physical, chemical and common flora for samples from sampling locations at different times during the hydrological year 2009/2010 (Suleiman, 2011)

Location	Sample Date	pH	TDS*	Temp	Cond.	COD*	BOD*	NH4-N*	PO4-P*	NO3*	FC edge	FC mid.	TC edge	TC mid.	Q	Pw	Re
Deir Sharaf	31.1.2010	7.35	154	19.6	307	176	51	41.4	1.72	0.3	12*109	2*109	7*1014	5*1012	0.22	3.06	8.4*104
Anbta	31.1.2010	7.55	158	19.2	312	94.8	37	31.2	1.4	0.6	2*1010	8*109	6*1014	4*1013	0.16	2.41	2.7*105
Tulkarem	31.1.2010	7.75	463	20.7	932	142.2	28.2	21.1	0.1	1.2	9*1010	8*109	2*1014	1*1013	0.39	2.82	5.5*105
Deir Sharaf	7.2.2010	7.53	470	19.8	970	120.4	15	11.4	1.2	0.83	12*1012	3*1010	7*1016	2*1012	0.78	3.92	8*105
Anbta	7.2.2010	7.1	612	18.6	1240	122.2	35	13	0.13	0.73	5*1010	6*109	6*1014	4*1011	0.18	2.57	2.9*105
Tulkarem	7.2.2010	7.25	636	20.1	1298	53.5	20	23.6	1.0	1.1	7*1010	3*108	2*1014	6*1010	0.36	3.48	4.1*105
Deir Sharaf	14.2.2010	7.27	545	20	1103	78.5	30	14.4	2.7	0.2	4*1012	8*1010	2*1016	4*1012	0.38	3.6	4.2*105
Anbta	14.2.2010	6.78	682	17.0	1380	99.3	35	10.7	1.9	0.5	6*1012	4*109	5*1014	8*1012	0.18	2.82	2.6*105
Tulkarem	14.2.2010	7.08	783	18.5	1534	105.9	40	19.9	5.5	0.8	2*1013	6*1010	1*1014	3*1012	0.29	3	3.8*105
Deir Sharaf	21.2.2010	7.23	458	17.3	910	385.3	180	31.1	10.4	7.7	4*1013	3*1010	7*1016	4*1014	0.1	2.4	1.7*105
Anbta	21.2.2010	6.8	430	18.3	853	385.6	165	26.6	8.14	4	8*1011	3*1010	4*1016	8*1013	0.87	2.54	2.9*105

Tulkarem	21.2.2010	7.1	560	21.1	1110	386	150	43.2	12.4	3.6	4*1012	2*1010	8*1016	2*1014	0.22	2.93	3.1*105
Deir Sharaf	2.3.2010	7.38	388	20.1	774	67.6	28	38.4	1.2	1.6	5*109	3*108	8*1014	8*106	2.6	5.5	1.6*105
Anbta	2.3.2010	7.58	257	22.7	520	4.6	2	4.6	0.8	1.3	4*105	8*104	4*107	6*106	0.76	3.62	8.4*105
Tulkarem	2.3.2010	7.22	370	21.2	750	29.9	10	20.9	0.6	0.8	2*1011	6*1010	6*1016	4*1015	0.78	3.8	8.2*105

* units are in mg/l.,FC,TC units are cfu/100ml,Q (m3/sec),Pw(m),EC(μS/cm),Sa(%0) Temp.(°C)

SIMULATION RESULTS AND DISCUSSION:

Flow event analysis:

Three current processes in Zomar Stream were considered to assess the effects of flow events on the surrounding environment:

1. The absence of sufficient quality discharge leads to low water surface extension. In this process, large thin wet areas that support the formation of bacterial and pathogen film develop near both banks of the channel (Knebel et al., 2005), Moreover, the presence of high amounts of nutrients (mainly phosphorous and nitrogen in organic and inorganic forms) enhances bacterial enrichment during summer months.

2 .Alternating bar beds are formed, especially near dry edges of banks that retain water in small depressions shortly after flood events (Fig. 3). In the absence of a sufficiently sustained stream and an increase in the wetted perimeter these formations will be filled with wastewater as soon as the dry season returns. These small bars act as bacterial pools that enhance the enrichment of bacterial and pathogen growth and lead to a deteriorated condition in the surrounding environment. During flood events these formations re-fill with fresh rainwater flushing sewage out, but only for short periods of time (i.e., until the next flood).

3. Floodplain events are triggered by inundation. Inundation of floodplains is important for the process of nutrient removal and bacterial dilution. Moreover, successive flood events in the same hydrological year will retard bacterial re-growth and lead to a healthier environment.

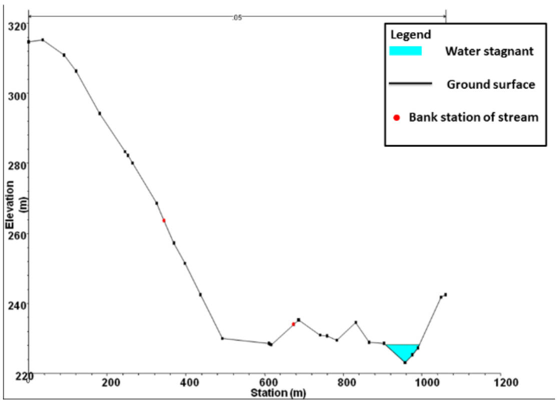

Figure 3: Cross section 15920 near Deir Sharaf, Nablus that shows the formations that re-tained some flood water for a long period.

Hydrological status during 2008 to 2010:

The daily flow events for hydrological years 2008/2009 and 2009/2010 are displayed in Figure 4. The average wetted perimeter is calculated from the model output. The Nash–Sutcliffe efficiency index (Ef) was used to assess the goodness of fit of hydrologic models.
The Ef results were varied between 0.54-0.83 .

Threshold discharges for bed drying (less than 0.14m3/s), bar formation (less than 0.4ms/s), and floodplain inundation events (over 3m3/s) are indicated as dashed lines. These thresholds are the break-points in the wetted perimeter curve. All three events are episodic and occur at least once each year (Carvajal-Escobar, 2008).

Flow must drop below the above-mentioned threshold value before large areas of bank edge are exposed, and it must rise above the threshold for bar formation and floodplain inundation to occur. Threshold discharges and magnitudes for these flow events (shown in Fig. 4) were generated using HEC-RAS for two years of flooding in Zomar Stream. Figure 3 also displays the largest flood event during the two-year period, which occurred on December 28th, 2008. Such extreme flood events occur at least once every three years. However, the flow events pass quickly and return to base flow within 5-7 days. This should emphasize the importance of reoccurring flood inundation and base flow levels, which are considered the main factors in the process of maintaining a healthy stream environment.

The data shows that an average of five bed-drying events occurs each year, and that most of these events occur in September and October at the beginning of the winter season. In the previous two hydrological years, the significant rainwater events were delayed and only occurred in December, which allowed more drying and exposure of the bed. The presence of the dry period in the first two months of winter led to unhealthy conditions for the community surrounding the stream. Moreover, many of the springs that discharge water into the stream dried, which caused all water in the stream to consist of small amounts of pure waste with huge amounts of nutrients that facilitate excessive bacterial and pathogen growth.

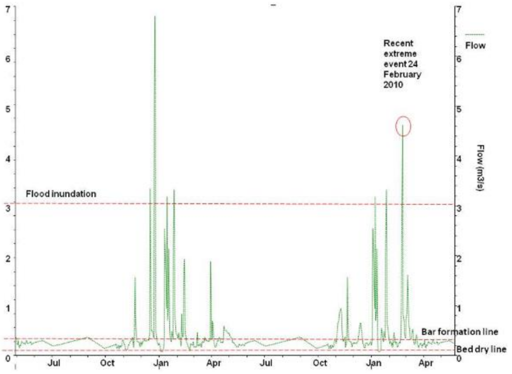

Figure 4: Two years of flooding events in the Zomar Stream (using the HEC-RAS program).

Modeling best flow scenarios:

HEC-RAS modeling results of different boundary condition scenarios demonstrate that boundary conditions were created based on actual flow conditions for 2009/2010. These results were also used in the previous section by taking into account the provision of initial conditions with suitable numbers of base flow values (Fig.5a). In order to estimate the best scenario for stream washout based on the presence of sufficient freshwater, 4 minimum discharge values were trialed as scenarios of increasing the recharge above the threshold discharges for bed drying. These 4 tested artificial increment values were added with a value of 0.25, 0.35, 0.4 and 0.5 m3/s separately as monthly constant base flow. Based on the estimated thresholds for bed exposure and bar formation. The best scenario below which deterioration of the environment is triggered was found to be 0.5 m3/s (Fig.5b). This additional water can be effluent?? from the wastewater treatment plant which is planned to be built near Deir Sharaf area.

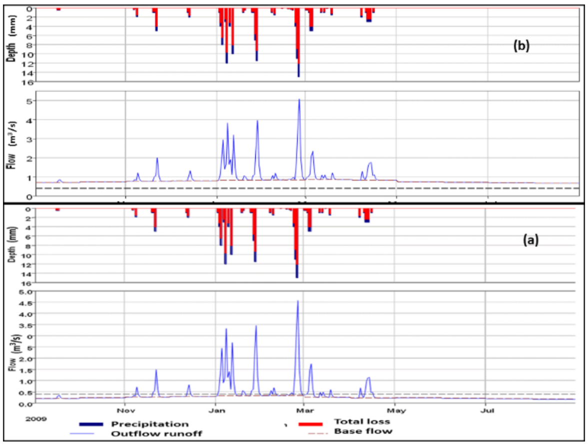

Figure 5 a&b: HEC-HMS one-year simulation normal with a monthly constant base flow (a), and additional base flow artificial of 0.5 m3/s from wastewater inlet (b).

Distribution of such treated water in proper base amounts can keep streams healthier. However, stream-wide distribution of treated water discharge is recommended. To keep surface levels constant many factors should be taken into account, such as channel width, slope, flow velocity, and channel bed formation. Evapotranspiration should be calculated carefully with additional amounts of water being added to deter loss and maintain required water levels. The two previous selected points, the cross-section in the upper stream and another one a short distance from the Deir Sharaf waste point, were used as discharge locations. Another four discharge points were assigned downstream of the reach. The additional amount of water needed to keep the minimum flow varied for the 0.8m3/s rate during summer months and the 0.65m3/s rate during winter months, the latter having lower evapotranspiration. Both normal and calculated flood boundaries are integrated into the model where flow data output from calculated and calibrated values were used in HEC-RAS.

The new hydrograph with overestimated base flow shows values between 0.5m3/s in summer and early winter as a minimum flow below which the regime deteriorates (as explained above). It also shows 0.9 m3/s in winter, which is the peak value in response to storm events, which was increased simultaneously (Fig. 5b). The new added water will retain a sufficient amount of water that can fill the stream and overcome the stagnant formations near edges even in summer time (Fig. 6).

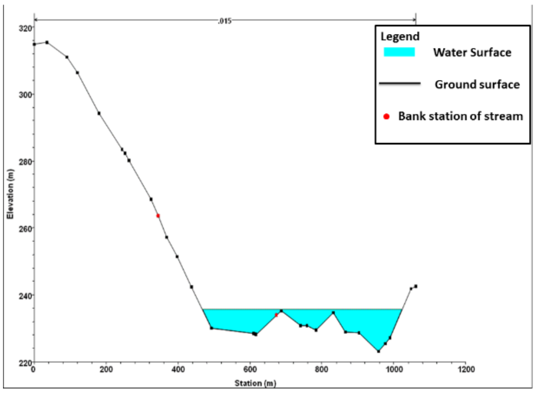

Figure 6. Cross-section 15920 near Deir Sharaf, showing a continuous filling of the stream even in summer

Modeling bacterial removal with storm water:

The flow model was run for the same period as the bacterial growth measurements. Curves were compared to view hydrological effects on bacterial activity under different spatial conditions (Figs. 7 and 8). The outputs are displayed spatially and temporally. All FC counts were reduced drastically in response to the duration, intensity, and consequently the flow rate of the storm event. In Deir Sharaf, near the wastewater source, FC bacteria decreased slowly, and then show a frequent shock a short time after the flood peak (Fig. 7a and Fig. 8c). This shock in bacterial count is a rapidly steep reduction. The bacterial count then becomes stable, which is due to time dependent variation of wastewater discharge from the nearby facilities.

The Anabta site (Fig. 7b) illustrates the time-dependent removal process where the location is far away from the pollution source near Deir Sharaf, thus allowing for a longer period of self- purification. However, bacterial growth was re-enhanced slightly by the end of the storm.

The Tulkarem site shows the same trend, but with a slightly different mechanism. A bacterial increment shock was re-enhanced shortly after the flood began, which was due to accumulation of washed bacterial colonies from the above stream points that were finally washed out with time (Fig. 8c) .

FC distribution at the beginning of the storm has a high concentration except in west Anabta, where the potential for self-purification is the highest (Fig. 8a) (Knebel et al, 2004). Figure 8b shows spatial bacterial removal during peak discharge where most of the coliform count is reduced to the minimum under the flood wash. The bacterial accumulation near Tulkarem, by the end of the stream, is also shown in Figure 8c. By the peak of the recession, most bacterial colonies are washed away except for the newly formed colonies that are transported by wastewater discharge near Deir Sharaf point (Figure 8c). The sequence and intermittency of peak flows greatly controls the incremental contamination and toxic algal bloom in stagnant ponds (i.e., longer interval between floods equals more toxicity, shorter interval equals frequent flushing and cleaning of the channel).

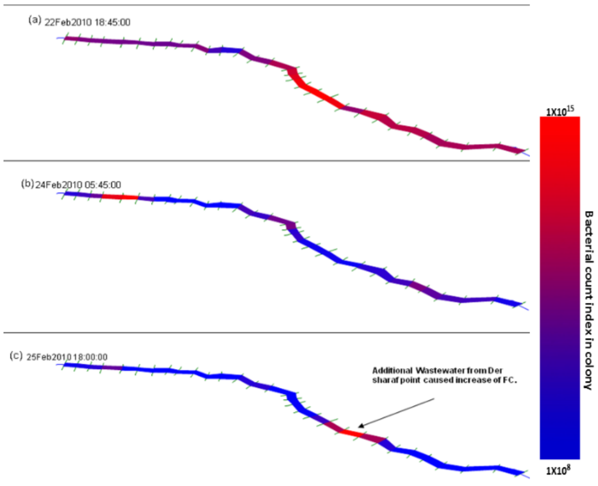

Figure 7: Temporal response of Fecal Coliform bacteria in the three cross-sections along the Zomar Stream.

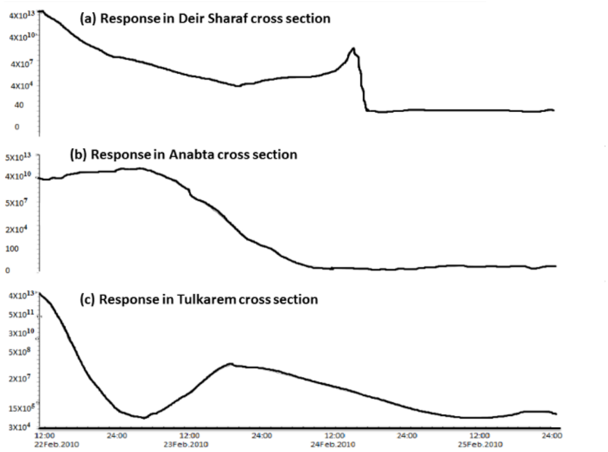

Figure 8. Temporal response of Fecal Coliform bacteria in the three cross sections along Zomar Stream.

CONCLUSIONS:

In this study factors that complicate a risky flow regime and conditions that inhibit restoration of a healthy regime that supports habitation by the surrounding population, were identified. Three flow scenarios that complicate the problem were considered: bed drying with less base flow in summer time (mostly waste flow), bar formation, and floodplain inundation, which correspond to low, medium, and high flow events, respec-tively. The HEC-RAS model suggests a continuous discharge base flow in the range of 0.5m3/s throughout the year. This flow range is a sufficient minimum flow that prevents the first two flow scenarios from occur-ring and consequently creates a hazardous, unhealthy condition with excessive bacterial and pathogen growth, as well as a high pollution load. The model suggests that the restoration process is controlled by two main factors that depend on the presence of sufficient base flow. These are the role of sufficient flow in preventing a bacterially rich environment and the role of flood inundation frequency in keeping the system balanced by increasing the number of bacteria and nutrients flushed out of the system.

The suggested additional amount of base flow can be provided from the planned wastewater treatment plant near Deir Sharaf area. Sufficiently treated wastewater can be released along the stream to maintain a con-tinuous flow that prevents accumulation of stagnant water and removes pathogens .

In order to choose the best locations and amount of discharge to keep sufficient base flow, further improvements of the model are needed. These improvements should depend on practical experiments for ar-tificial discharge. The amount of wastewater discharged into the stream must be treated sufficiently and re-discharged as part of the sufficient base flow. The improved model must identify treatment levels and discharge distribution locations that will guarantee an equal distribution for sufficient base flow throughout the stream.

RECOMMENDATIONS:

The technologies and management strategies are certainly available for solving the pollution problems of the study area. The primary obstacles to environmental progress in recent years have been economic and geopolitical. Without sufficient resources for sanitary infrastructure, pre-treatment of industrial facilities and best management practices for nonpoint runoff, progress will remain elusive. Without coordinated efforts and real cooperation between Palestinians and Israelis, neither side will succeed in restoring its streams .

For successful restoration of the Zomar stream, it will be important to engage the respective Ministries of Agriculture as partners. Establishing parks along the stream is an important stage in enlisting the public and transforming streams from a perceived hazard to an attractive recreational resource .

Pollution levels contained in the base flows will prevent the attainment of any of the potential uses in transboundary streams. Wastewater treatment has been the focus of efforts to date. Yet, additional pollution sources, from the Palestinian olive oil and stone cutting industries --Israeli industrial zones, fish ponds and fruit juice plants will sabotage water quality progress unless they are systematically identified and abated. Enforcement efforts are now underway in Israel to address these pollution sources, but compliance remains inadequate. The Palestinian regulatory capacity has been considerably weakened in recent years and sub-stantial institutional strengthening will probably be required before results will be seen in improved pollution discharge levels.

Facilitating Best Management Practices for nonpoint source controls requires a fundamentally different policy approach than does that involved in controlling point sources. It is axiomatic in public policy that as the number of actors increases (e.g.??), the difficulty of attaining compliance grows exponentially. Nonpoint source controls therefore constitute an enormous institutional and regulatory challenge.

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