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Michel Soto Chalhoub, Ph.D, P.E., S.E.

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Surface Water Flow Theory Application to Public Policy Development and Adaptation for Arid and Semi-Arid Regions

Michel Soto Chalhoub¹, Ph.D, P.E., S.E.

Notre Dame University

Abstract

Regions that had acceptable levels of water resources are becoming arid due to global warming and human-caused damage. Yet, public policies in such regions remain unsuitable for local conditions. Although this is owed to broad economic, political, and engineering factors, this paper focuses on water project methodologies and local policy design towards sustainable development. Water surface flow formulas utilize simplified assumptions adequate for perennial rivers, but require upgrades to accommodate arid regions and seasonal river behavior. The paper proposes a framework that links engineering to public policy using field data collected in Mount-Lebanon, where drought periods are increasing. A dependent variable is defined as an index about community benefits based on water projects. Four independent variables are defined as (X_1) the extent to which local communities would contribute to the engineering management and maintenance of water facilities, (X_2) the ability to use project output for power supply, (X_3) the potential use for agricultural purposes, and (X_4) local community amenability and support for the privatization of water civil works. Results showed a statistically significant and positive relationship with X_1 , X_2 , and X_3 and negative correlation with X_4 . Public policies need to be designed to involve local communities.

Keywords: Public policy, surface water, sustainable development, open channel, river engineering methodology, semi-arid regions

¹Dr. Michel Soto Chalhoub is a licensed P.E. and S.E. in the State of California, and ASCE member. He teaches at Notre Dame University and is active in industry, on Code development committees and in natural resource management. He provides expertise in solid and fluid dynamics, urban and rural sustainable development, with applications to quality in engineering program management. He holds a Ph.D. in civil engineering from the University of California, Berkeley, and a Master in Public Policy from Harvard University with concentration in international development and business-government.

Introduction

Many developing countries face a mismanagement challenge in water resources, attributable to poor technical means, or to engineering project management failure (Brikké and Bredero, 2003; Davis and Brikké, 1995). But it was also found that water supply issues, especially in arid and semi-arid regions, are owed to political agendas at a local community, national, and regional level (Mollinga, 2008; NADC, 2004). Surface water challenges caused an increase in harnessing ground water instead of managing surface water and runoff (Seibert et al., 2010). Environmental and economic reasons include pollution of surface water, drought periods for surface water flow, decreasing river flow in general due to various climatic developments, and the cost-benefit associated with ground water exploration and extraction (Burke, 2002; NADC, 2004).

Ample literature addresses engineering aspects of water resources highlighting the lack of technical means in developing countries (Mathiesen, 2016). Challenges in finding local human resources have been identified as being one of the top three reasons behind low financial absorption in several water projects funded by international organizations (Hoe and Garrett, 2015). Efforts by volunteers or donor organizations expended in training local engineering counterparts during development projects may be necessary but not sufficient in terms of local human resource development. Technology and human skill transfer frameworks require a high level of local customization, making such initiatives even more challenging (Trace, 1994; Argondona and Holvik, 2009). In terms of public policy and management entrusted with engaging local communities, four dimensions have been identified and adopted by most international development agencies; leadership, mobilization, channeling, and impact. Leadership is described as the level at which guiding principles are set and policy coherence is ensured. Mobilization is used in the sense of re-orienting financial markets to adopt sustainable development goals. Channeling is regarded as the set of activities that would promote and facilitate investment in vital sectors. Impact is the set of activities that would maximize community benefits while minimizing project risks (UNCTAD, 2014; World Bank, 2012). While the social and local community dimensions are important, and while they bear ethical considerations that are critical to sustainable development, it is often treated separately from the engineering dimension. The fact that each discipline approaches sustainable development in a separate compartment has been identified as a weakness, hence the need for integration and the use of multi-disciplinary methods (NAOE, 2017; Drexhage and Murphy, 2010). As for the economic dimension, sustainable development projects are expected to show long term performance as opposed to narrowly defined short term financial benefits (Frederick, 1960; Freeman, 2010; Dempsey et al., 2011). Still, most research in the literature addressed the economic dimension as an element of social responsibility, or corporate citizenship, independently from the engineering component (Andriof and McIntosh, 2001; Battilana et al., 2012).

The three dimensions described above, albeit each one is well developed in literature in its own right, exhibit a gap in terms of converging solutions (UNSDSN, 2013; Porter and Kramer, 2011). The best though-through technical and engineering solutions would find implementation difficulties if the social and community dimension are neglected. Likewise, social work and effort in supporting local communities may not be sustainable if there is no undergirding engineering solutions that help translate theory to practice (Phills et al., 2008; Idowu and Vertigans, 2016). Further, technically sound engineering solutions, combined with local community service and participation would not be achievable without studying the economic dimension and its impact on final outcomes. In this paper, we present a framework that considers three main dimensions driving water resource management in the context of rural development in village communities: the engineering dimension, the social and community dimension, and the economic dimension. In a proposed theoretical framework, we address the interrelationship among these three dimensions

then provide a linear regression analysis that links the three dimensions based on empirical data. The model is tested on field data collected from the community around a seasonal river that originates in Mount Lebanon and has an estuary north of Amshit in Byblos County.

Analysis of Water Management Issues

While it has been common to correlate engineering and water resource management issues with developing country status, there are many common issues faced in both developing and developed countries alike (Vörösmarty et al., 2004; EEA, 2003). The perception of water as a free resource, its undervaluation, the realization that water problems are community-based, and the fragmentation in water resource management, are present in both developed and developing countries (Morris et al., 2003). These factors pose challenges in water resource engineering and management projects at a global level (WWAP, 2006).

Water as a free yet expensive commodity

There is a longstanding view that water is a free commodity that has influenced habits of water use in various parts of the world (Chartres et al., 2010). Although this view exists about less developed countries, the challenge of water undervaluation is also faced by developed countries. The view of a leaking pipe in the street causing water to flow to waste, unattended for extended periods of time, is a common scene in both developed and developing countries (VWD, 2013). At the same time, inhabitants would be purchasing containers to cater to their daily water needs. This paradoxical image has a serious undergirding from an engineering economics perspective. The free rider concept applies to this phenomenon as it entails engineering and public works that no one is entitled or interested in performing (Comes and Sandler, 1994). Why would the individual bear the cost singlehandedly to generate social benefits to a community? In Nevada, for example, not-for-profit agencies fulfill the role of water conservation (VWD, 2013). In West Midlands, UK, authorities assign the responsibility to the private owner for water conservation and reporting water wasted through leaks (SSW, 2013). In late 2013, in Detroit, Michigan, millions of gallons of water went to waste in unattended facilities (Williams, 2013). A 1921 study showed that Detroit, a city that is historically known for being at the forefront of mechanical engineering, civil systems, and water distribution networks, leaked over 2.5 million gallons per day, of which 56% were caused by broken mains and joint leaks (Fenkell, 1921). In Lebanon, three prices are periodically paid by end users for water usage. A price is paid to the government as a lump sum for a yearly subscription. Another price is paid to private parties – typically small vendors – that supply water containers delivered to various local communities. Yet another price is paid to companies that sell drinking water and supply fountains to residential and commercial facilities. Empirical data collected in Lebanon shed light on several attitudinal features including the triple-price effects (Chalhoub, 2010).

Water as a communal responsibility

Work performed by international development organizations showed that many water management responsibilities are shifting from central government to local communities (WaterAid, 2011). The motivation behind this shift is that most problems identified were related to soil erosion, water loss, and local conflicts, all of which are community-related (Cleveringa et al., 2004; Neef et al., 2004). Similar initiatives are being implemented in developed countries where reliance on state and local government for water resource management is shifted to local communities (WaterAid, 2013; SSW 2013). Some of the challenges are related to the willingness of public sectors to relinquish control, and private parties to be amenable to the idea of transferring water service provision to non-governmental parties (Neef and Heyd, 2004; Bunclark et al., 2011).

Research performed on international development programs on water resource management in developing countries concluded that local community involvement - and even local project leadership - is a key success factor (Balland and Plateau, 1996; Wade 1988). Research on communal responsibility showed the importance of community involvement in tackling and solving such problems. Local community management in water engineering issues requires the establishment of local public policies. The Global Environment Facility (GEF) that jointly implemented with the United Nations Development Programme (UNDP) local community empowerment programs in Ghana, Guatemala, Kenya, Mauritania, Sri Lanka, Uganda, and Tanzania, concluded that for such public policies to succeed, local organizational structures need to be established ranging from local village water committees to quality reporting and auditing bodies (GEF, 2012).

Water resource management as a fragmented responsibility

The absence of a focal public body that handles the water management value chain has been identified as a major weakness in water resource management (Anderson, 1983). This feature is not only specific to less developed countries, but exists in the most technologically advanced and preservation policy-sensitive nations (Lubell and Edelenbos, 2013; Levin et al. 2002). In the USA for example, water supply and flood control is managed by the US Corps of Engineers and the Bureau of Reclamation. The USA Fish & Wildlife Service is responsible for the water-dependent sporting and related species. The Environmental Protection Agency (EPA) is responsible for water quality in general, and the proliferation of chemicals (US EPA, 2005). There are, in addition, a slew of other state-level environmental agencies that work with EPA on those issues at a state and local government level (Karr, 1991; Shih et al. 2006).

For the reasons above, there is a need to establish methods of managing a closed cycle on water resources engagements that include rivers with coordination among engineering projects, social and community priorities, and economic feasibility (Hassing, 2009). River basin management became a global concern to put limits on pollution, coordinate engineering design and execution, especially when rivers cross from an upstream country to another downstream country (Rahaman and Varis, 2005). Interestingly, the issue of responsibility fragmentation becomes more complex in trans-boundary collaboration on river waters where the integration of responsibilities crosses country borders. One of the examples is the Mekong River, the twelfth longest river in the world, which crosses Laos, Cambodia, Vietnam, and Thailand (Hassing, 2009). Other examples, albeit within the same country, address small rivers where integration is recommended at the river basin level (Hassing, 2009; UNESCO, 2008).

Small Rivers in Rural Areas

The numerical model described above is applied with field data collected from communities around a watercourse that originates in Mount Lebanon and runs into the East Mediterranean north of the city of Amshit in Byblos County. The river has a catchment basin of about 22 km². It flows across over 25 villages, which makes it an environmental asset that has a direct impact on local rural communities. The river has a high season in winter but more markedly during the snow melting season in February and March. Its bed is characterized by meandering and relatively sharp variations in slope. Its bed width varies between 5 meters and 15 meters.

Physical Properties, Water Supply, and Ecosystem Support

It would be inadequate to narrow down the role of small rivers to a mere source of water (Meyer et al., 2003). Small rivers are in fact refuges for ecosystems, many of which are not well understood by their local communities. Small rivers support ecosystems through soil formation, pollination, provision of habitat, population control, and regulation of drought (Kaplan et al., 2008). They also offer cultural features to humans such as recreation, aesthetics, and many non-materialistic values.

This feature could be developed into a more thorough discussion on environmental valuation, including existence value (Chalhoub, 2012). However, this broader discussion is left outside the scope of this paper to focus primarily on the functional dimensions set forth in earlier sections. In populated areas, small rivers are vulnerable to human actions and are subjected to stress levels, depending on the geographic location and enacted environmental protection policies (Wohl, 2006). In Byblos County, Lebanon, small villages house light industries such as the manufacturing of cement masonry units, or stone veneer saws that have deep effects on small river health (Chalhoub, 2012). River health is also influenced by variations in its water temperature. Global warming is causing a net rise in average yearly temperatures in water streams (Döll and Zhang, 2010). Water temperature is also part of small river categorization. According to Conservation Gateway, small rivers are grouped into six categories based on bed slope gradient, water temperature, width, and other engineering properties as shown in table 1 (Conservation Gateway, 2010).

Table 1. Small river macrogroups according to Conservation Gateway on North America's Rivers (2010).

Slope Category	Water Temperature	Description
Low gradient	Cold	Slow moving, marshy terrain, bed dominated by silt, sand, fine gravel, average width 21 m, water of high turbidity and poorly oxygenated, at high elevations
Low gradient	Cool	Same as above, average width 20m, at moderate elevations
Low gradient	Warm	Same as above, average width 19m, at low elevations
Moderate gradient	Cold	Fast moving, rocky terrain, bed dominated by sand, gravel, and cobble, clear water and relatively well-oxygenated, average width 20 m, at high elevations
Moderate gradient	Cool	Same as above, at moderate elevations
Moderate gradient	Warm	Same as above, at moderate to low elevations

The categorization in Table 1 is accompanied by detailed manuals explaining the types of species that exist in each setting, their habitat, and the extent to which they are endangered or affected by human interventions (Conservation Gateway, 2013).

A small river has its own practical engineering peculiarities in terms of width, catchment area, slope, and roughness. In France, 78% of total river length has a width less than 15 meters. In Slovenia, 80% of total river length in the country has a width less than 5meters, and in Denmark, 75% of total river length has a bed narrower than 2.5 meters (European Commission, 2007). In the U.S. a small river features a catchment area less than 200km², while in Europe a small river features a catchment area less than 100 km². In Scotland, 80% of river length in the country has a catchment area less than 10 km²; in Slovenia 90% (European Commission, 2007; EEA 2012). There is ample evidence worldwide that small rivers form the majority of surface water circulation. Given their vulnerability, lack of visibility, and proximity to localized communities, small rivers require special precautions in terms of environmental protection and resource management (Meyer, 2003).

In Lebanon, small river data documentation is scarce and needed for future research. Secondary data is available from works from the western hemisphere, and from developing countries as planned and implemented by international development organizations. When we turn

to local challenges, we draw on such secondary data with adaptation and adoption (EEA 2012; Conservation Gateway, 2013). This is particularly critical because small river management requires a deep understanding of human activities and their effects on ecosystems (Kremen and Ostfeld, 2005).

Engineered small river structures – pros and cons

Engineered dams for small rivers were initially intended to provide solutions against drought season and power supply deficit in both developed and developing countries (Lewis, 2013). There are about 2 million dams in the US and 80,000 large dams of a height greater than 6 feet. In the US about 500 dams were built per year in the 1980s. At present, the rate is about 300. Dams were built for various reasons including power generation, agriculture support, and recreation as a windfall. For example, the damming of the Colorado River and the Columbia River was accomplished for purposes of farming (USSD, 2013). Other dams were considered as engineering grand works such as the Hoover Dam, which created Lake Mead. Glen Canyon Dam forms Lake Powell on the Colorado River, and is used for hydroelectric generation, water distribution in between years of low and high precipitation, and provision of recreational activities and boating. Therefore, most large dam functions include a significant human entertainment feature and tourism (US Dept. of the Int., 2013). However, dams alike many other human interventions, have been criticized for disrupting the natural equilibrium of ecosystems (Whittaker, 1975; Williams and Wolman, 1984).

To generate hydropower, various alternatives must be considered and selected in favor of the one that would have the lowest environmental impact (Ward and Stanford, 1995). Although dams were generally considered as hydraulic structures with positive communal outcomes, there has been extensive research showing their negative effects. There is a closed dynamic ecological cycle for rivers that is in equilibrium among erosion, sediment transport, sediment deposit, habitat, and temperature. Causing an artificial stagnation of river waters has multiple negative ecological effects (Grant et al., 2003).

When it comes to small river dams, especially the ones that are considered for developing countries, many disadvantages surge. Since the 1960s and with the environmental movement at the time, many researchers addressed the downside of constraining the dynamism of river water. Research has shown that many river flows that were brought down to standstill water no longer support the natural habitat and ecosystem that used to exist around them (Naiman et al., 1995; NRC, 1992). The dynamic nature of river water flow has its own life sustenance system (Allan and Flecker 1993; Karr et al. 1985). Since the integrity of a free-flowing water system depends on the dynamic character of that system, blocking it needs to be well studied from an environmental engineering perspective (Williams et al. 1996). Channel geomorphology and habitat require a detailed environmental impact assessment (Power et al. 1995; Resh et al. 1988). In addition to the dynamic feature effect of the natural flow, its variability through time and location was proven to be an important factor as well (Hughes and Noss 1992). The analysis the effects of thwarting natural flow showed that it is necessary to maintain flow variability to minimize human impact on it, and when restoration occurs, it must follow a protocol to reverse the effects with minimum environmental impact (Stanford et al. 1996; Holling and Meffe 1996). In developing countries, such effects get compounded due the lack of policies and corresponding environmental laws, or for lack of proper enforcement even when such laws exist.

Mathematical Modeling Considerations for Small Rivers as Open Channel Flow

Rationale for a proposed theoretical model

To make calculations possible in open channel flow, engineers use simplifying assumptions related to channel geometry and flow properties (French, 1985). However, the challenges are greater in real life situations in hilly areas where creeks have slopes with high gradients, where river bed bents are frequent, and where natural terrain is weedy and exhibits high frictional

resistance at the river bottom. Therefore steady state flow formulas do not apply in areas where it takes several days and often weeks to build up the flow rate following water seepage in dry soil. Following the dry season, the river re-establishes its bed in the rainy or snow-melting season in parallel with a cycle of weed and sediment transport (Chalhoub, 2013).

Channel cross-sectional shapes can be reasonably modeled and controlled in human-made canals. In most other cases, the shape is a result of the works of nature. Rectangular and trapezoidal sections are commonly used in open channel computations. But in the field, a variety of random channel sectional shapes are encountered. This phenomenon becomes more complicated when the shape at a given station changes through time due to erosion in one reach and fill in another reach. The slope is another variable that changes frequently in small rural rivers. This is especially complicated in the presence of boulders and other irregularities on the river bed (Yalin, 1992).

The seasonality of small rivers complicates the set of assumptions used in the computations of river flow rates. We propose that the roughness coefficient, generally denoted by n , cannot be assumed to be a constant for a given river bed material as tabulated in most open channel flow literature (Manning, 1891). The resistance coefficient is rather a function of total flow rate Q and of small river meander (Chalhoub, 2013).

Mathematical Model

We express the total flow rate as a function of river cross sectional area A , hydraulic radius R_h , river bed slope S , and roughness coefficient n , we have:

$$Q = \frac{1}{n} A R_h^p S^r \quad (1)$$

where p and r are power exponents determined through experimental and analytical techniques. Manning found that for commonly used channel sections, an estimate of $p = 2/3$ and $r = 1/2$ provided a reasonable match with scaled laboratory results (Manning, 1891). However, we shall consider p and r in their general form, and n as a function of depth y . Using the definition of the hydraulic radius, and denoting by w the river width, expression (1) can be written as:

$$n(y) = \frac{w^{p+1}}{Q} S^r y \left[\frac{y}{w+2y} \right]^p \quad (2)$$

The variation in $n(y)$ for two streams of comparable widths and conveying similar flow rates is expressed as the partial derivative in y :

$$\frac{\partial n(y)}{\partial y} = K_{w,Q} \left[\frac{y}{w+2y} \right]^p + p y \left[\frac{y}{w+2y} \right]^{p-1} \left[\frac{w}{(w+2y)^2} \right] \quad (3)$$

where $K_{w,Q}$ is a function of river width and average flow. In the expression of the gradient in n , we introduce three basic assumptions. The first one is that small river flows are shallow. The rippling effects are observed on the water free surface which is directly influenced by the geometry of the river bottom. The second assumption is that the small river has a variable bed configuration at any given control section. This is particularly pronounced for rivers that run on seasons and present a low or null flow when out of season. The third assumption is that small

rivers, by virtue of their locations, have frequent meandering. The detailed mathematical derivation is left outside the scope of this paper. We present partial results to illustrate the correction factors required for small rivers over classical theories that apply to less rugged open channel beds (Chalhoub, 2013). Defining a function $f(\partial n/\partial y)$ that includes the simplification performed on the gradient of n , we perform an integral over the depth of the river to obtain the adjusted roughness coefficient n^* :

$$n^* = \int_0^{y_{max}} f(\partial n(y)/\partial y) dy = \left[1 + \right.$$

We present part of the results that illustrate adjustment factors to n as a function of flow depth for a given river width. Field data from Byblos County was collected and used to test the formulas above. A seasonal river that has its springs at 995 meters in altitude, traverses seventeen villages before it reaches its estuary on the Mediterranean. Its width varies between 8 meters and 30 meters, depending on the reach, bed gradient, and geologic conditions. For a river width $w = 20$ meters (m), the simulation model shows that n should be adjusted by 35% for a flow depth of 0.10 m, diminishing to 10% for a flow depth of 2 m. The adjustment percentage in the range of 35% corresponds to relatively meager depths. This result is in agreement with physical field observations as rippled shallow waters flowing in the depth range of 0.1 to 0.2 m have to overcome a larger relative roughness than a flow of say 2 m in depth (figure 1). The direction of the adjustments is in agreement with pipe flow theories that define e/D where e is the irregularity on the interior surface of the pipe, or pipe roughness, and D is the clear interior pipe diameter. Similar results were reached in a simulation for a river width of 19 m with flow depth varying between 0.05 m and 3 m. Adjustments to n in this case range from a high of 37% down to a low of 9% (figure 2).

The simulation data can be cast into a simplified formula by finding an exponential trend function for a given case. For the case of $w = 20$ m and a depth varying between 0.05 m and 2 m, we can express the adjustment over n as a function of depth at a particular control section along a given river reach:

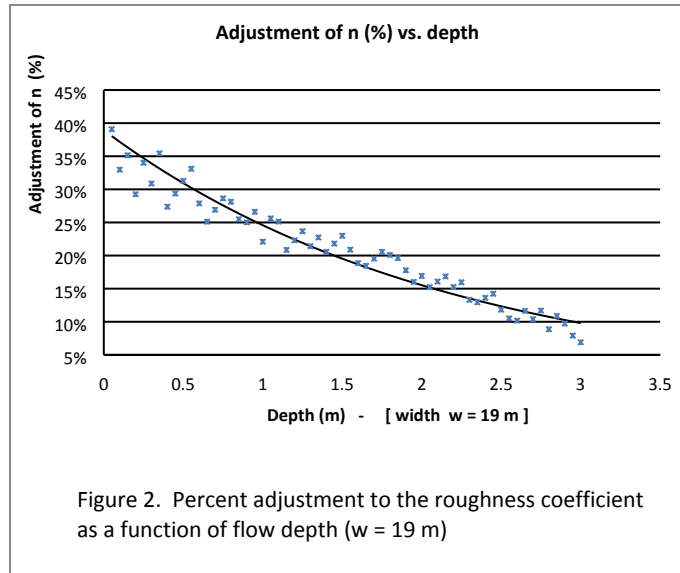


Figure 2. Percent adjustment to the roughness coefficient as a function of flow depth ($w = 19$ m)

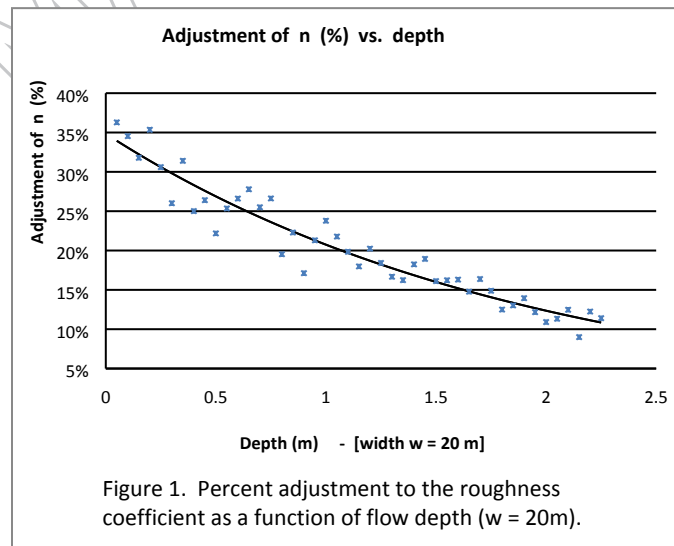


Figure 1. Percent adjustment to the roughness coefficient as a function of flow depth ($w = 20$ m).

$$\frac{\Delta n (\%)}{100} = 0.3484 e^{-0.518 d} \quad (5)$$

where $\Delta n (\%)$ is the adjustment percentage and d is the flow depth in meters. Due to field-related error margins, we consider that expression (5) may be used for neighboring values of river bed width. Similarly, we develop an exponential trend function for $w = 19$ m which is given in expression (6):

$$\frac{\Delta n (\%)}{100} = 0.3893 e^{-0.46 d} \quad (6)$$

These results also demonstrate that small rivers require a set of adjusted formulas of their own that take into consideration their meandering nature, the variability in their cross sectional shape, and their seasonality (Chalhoub, 2013). River bed coefficients that are typically tabulated in literature and used for open channel flow may underestimate the roughness of a meandering small river and therefore may cause an overly optimistic estimation of the flow carried by its stream. Such an overestimation of water flow has many implications on project planning and rural development expected outcomes.

Theoretical Framework: Engineering, Community, and Economic Dimensions Framework Development

Having discussed water resource engineering and management issues, we introduce a theoretical framework that links the engineering dimension, the social and community dimension, and the economic dimension. The theoretical framework shown in figure 3 is tested in the following sections using empirical data by performing a regression analysis. The theoretical framework includes eleven variables related to a rural development project over a small river. From the preceding analysis of water issues, no theoretical engineering solution can be implemented unless the other two dimensions – social and economic – are actively managed. We also demonstrated in the previous section that engineering solutions based on open channel flow theory may yield optimistic results leading to a mismatch between expected and actual results, whether for hydropower generation or irrigation civil projects, potentially causing water stress (WBC, 2006).

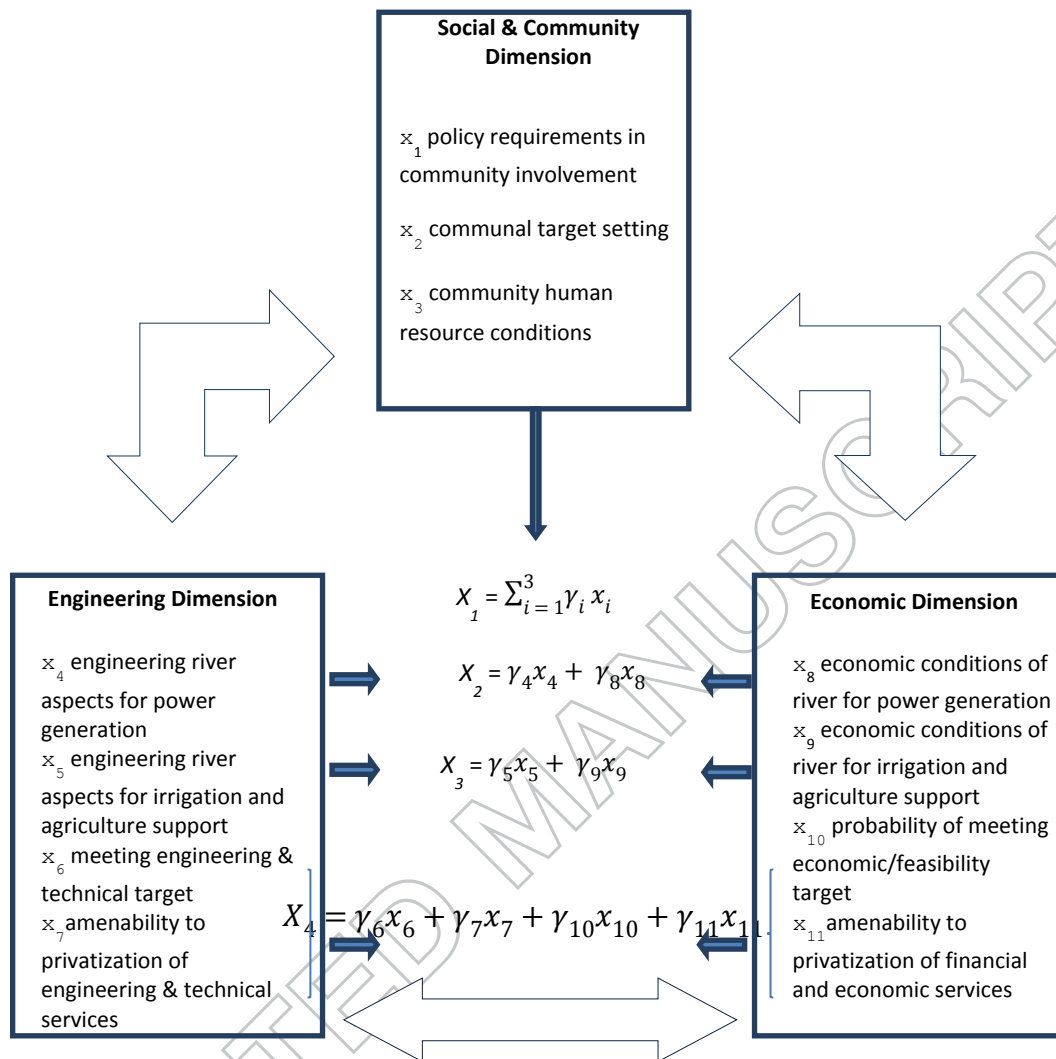


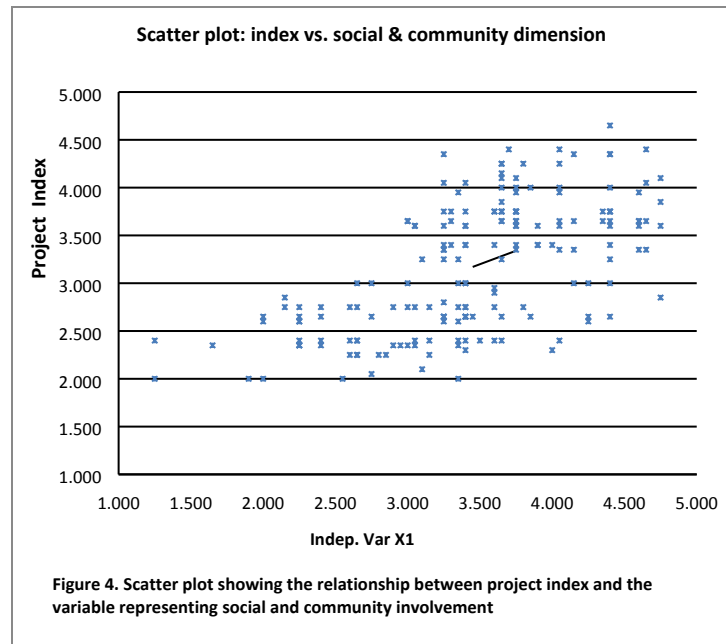
Figure 3. Theoretical framework linking the engineering dimension to the social and community dimension and the economic dimension.

The variables x_1 through x_{11} were collected on a Likert scale. These are used in a linear combination with coefficients γ_i to determine the independent variables X_1 through X_4 used in the regression equation. The rationale behind these variables is to capture, along with the engineering and technical aspects of the rural development project, the attitudinal aspects and predisposition of the community to perform according to guiding principles in water resource management.

Discussion of the Variables

In earlier sections, we discussed policy implications on the social and community dimensions and emphasized the importance of a clear public policy in creating a social network around water use and management. This variable is represented by x_1 . The second variable, x_2 , represents the importance of target setting in communities to rally the effort around clear objectives for water use. The third variable x_3 relates to the availability of human resources. The challenge faced in Mount Lebanon is its brain drain as many respondents commented during our exploratory research phase that the departure of human resource has been irreversible.

For the engineering component, variable x4 addresses the view of the community with respect to the use of a small river for power generation, while x5 addresses the use of the river for irrigation and agricultural applications. Variables x6 and x7 also address the engineering dimension whereby they represent meeting engineering targets and the amenability to let private entities manage the project, respectively. Variables x8 and x9 pertain to the economic dimension related to using the river for power generation and agriculture, respectively. The economic feasibility and the amenability to let private parties handle the economic side of the civil project are represented by x10 and x11 respectively.



With the first level variables defined above, the theoretical framework in figure 3 provides a roadmap for the relationships among those eleven variables distributed across the three main dimensions. One of the challenges faced with such frameworks is that they expect the end-user to have an understanding of engineering, managerial, and privatization concepts. That was not the case with many respondents. For example, a challenge was faced with the criteria related to amenability to privatization. Many respondents were not clearly in tune with the concepts, implications, and repercussions of privatization. Further, there may have been a predisposition due to the local Lebanese culture of being biased in favor of taking the helm of public service management in private hands.

Numerical Application of the Theoretical Framework

Empirical Model

The theoretical framework was tested empirically based on a regression analysis. We define the dependent variable Y as an index that represents the ability of local communities to handle water resource civil engineering projects. The independent variable is then evaluated using the statistical significance method in relation to the independent variables defined in the following sections.

We define the first independent variable and denote it by X1 to represent the extent to which the local community would contribute to the operation and maintenance of the facility. The representation of X1 in the regression equation uses data related to x1, x2, and x3, combined from their respective Likert scale into a weighted average where the weights are denoted by γ_i where i is the number of the variable under consideration.

Numerous examples exist about water resource project failures directly attributed to the lack of community involvement (UNDP, 2006). Research has even suggested environmental activism as a feature that is becoming a necessity in many developing countries (Gross et al., 2001). Activism relies on the fact that projects fail if there is not one pro-actively pursuing their project targets (WHO, 2008).

The second independent variable is defined as X2, which represents the community readiness and ability to harness project output towards power generation. Variables x4 and x8 are used in a weighted average to define X2. In Lebanon, the lack of power supply from the central

government is nowadays substituted by local generators. These local generators require fuel burning and cause air pollution, hazard, and cost above what is paid to the electric utility company. Some of the municipalities gave an incentive for residents to stop using private generators and to rely on a single power station led by their municipality. The marginal benefit is therefore the aggregate unused energy by individual households.

The third independent variable X3 represents the potential use for agricultural purposes. This item requires further study because of the nature of agriculture common in the geographic areas where we conducted research. The villages in Byblos County that are in the middle strip between 450 and 700 meters of altitude are populated with trees that do not require persistent irrigation such as olives, almonds, and some fruit trees (Chalhoub, 2013). Most of the region does not rely on human-made irrigation for older olive or almond trees. Irrigation in the empirical model was therefore linked to plantations that require periodic irrigation. Commercial operations such as the ones that use greenhouses were left for future research to focus on community development in its most basic sense as it relates to households and the livelihood of families.

The fourth independent variable X4 focused on the extent to which the local community sees privatization of water projects as a viable solution. This particular variable could be the object of extensive future research under separate scope. Privatization, in general, and for water resource management in particular, is still a subject of debate among engineers, public works officials, and policy analysts (Posel, 2012). It has been applied to major civil engineering projects in water resources through agreements between mega construction companies, local governments, and funding parties such as global banks (McIntosh and Yniguez, 2000; Shiva, 2000). Privatization policies especially in civil engineering water supply projects were at the same time praised and criticized. Critics of the privatization of public works in civil engineering argue that water belongs to public goods just like air, security, and safety. While those who support its privatization argue that a private party generating profit would be working under an incentive to continually provide and improve services and get feedback from the citizen as a customer (Hayes, 2003). In the context of small river engineering management, it is not customary to privatize services but it could be explored given its localized effect.

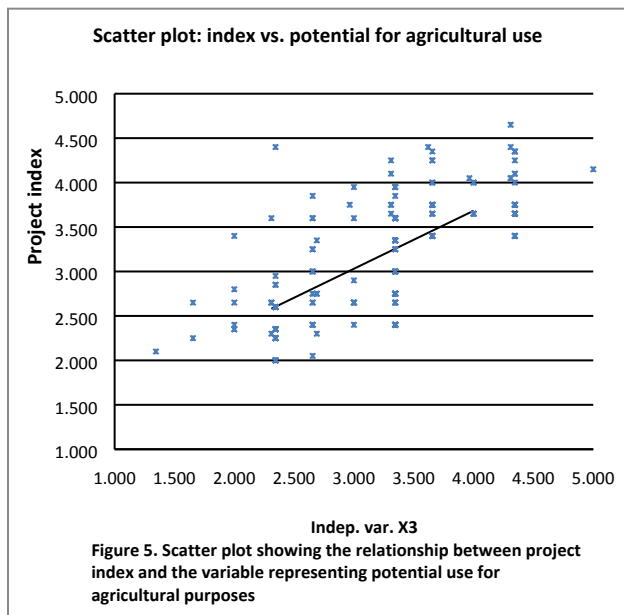
The dependent variable denoted by Y can be expressed as a function of the four independent variables:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + o(X) \quad (7)$$

where β_0 is the intercept and β_i ($i = 1, \dots, 4$) are the regression coefficients, plus an error term. Regression computations result in regression coefficients and their corresponding standard errors. These computed values help determine the statistical significance of each independent variable in defining the dependent variable, and whether correlation is positive or negative.

Discussion of results

We point at some features of the scatter diagrams showing the relationship between Y and two of the independent variables. The data plot of (Y, X1) exhibits some clustering at the high end of the Likert



scale, showing that the relationship between Y and X1 is predominantly in the 4-5 range which is primarily favorable to community involvement. The scatter between Y and X3 is sparse and exhibits a spread in the responses related to the use of small rivers for irrigation and agricultural purposes. The overall results from the multivariate regression analysis can be summarized in expression (8):

$$Y = 0.2175 X_1 + 0.3734 X_2 + 0.4685 X_3 - 0.1025 X_4 \quad (8)$$

se1 =	se2 =	se3 =	se4 =
0.0393	0.0355	0.0346	0.0275
$\gamma_1 = 0.35$	$\gamma_4 = 0.65$	$\gamma_5 = 0.655$	$\gamma_6 = 0.35$
$\gamma_2 = 0.25$	$\gamma_8 = 0.35$	$\gamma_9 = 0.345$	$\gamma_7 = 0.15$
$\gamma_3 = 0.40$			$\gamma_{10} = 0.35$
			$\gamma_{11} = 0.15$

Equation (8) has an r^2 value of 0.9. Results from the multivariate regression analysis show a positive and significant correlation between the project index and the independent variable X1 representing community involvement in river-related civil engineering projects. The relationship is statistically significant at $\alpha = 5\%$ significance level, and as the standard error value se1 for the coefficient β_1 is $0.0393 < 0.05$. This is in agreement with most ex-post studies performed on the importance of local community involvement and management in sustainable rural development as discussed in earlier sections. There is a positive and statistically significant relationship with the potential use of the river for power generation and for agricultural use as their regression coefficients are $\beta_2 = 0.3734$ and $\beta_3 = 0.3685$, respectively, and their standard error values are se2 0.0355 and se3 0.0346, respectively, and both smaller than $\alpha = 0.05$. This result is also consistent with past studies with the exception that, as stated in earlier sections, the communities under study did not exhibit awareness about the potential negative effects of human intervention such as erecting small dams or creating parallel catchment basins as documented in other regions of the world. In those regions, small river civil projects have come full circle from planning, to execution, to dismantling dams. Nevertheless, we still consider the results for X2 and X3 indicative of potential solutions that could be sensitive to environmental concerns, and still more suitable than letting the water flow back to the sea without any exploitation.

The correlation with the independent variable X4 representing amenability of local communities to the privatization of civil works on small rivers was found statistically significant but negatively correlated with project index. This can be seen from the standard coefficient error of $0.0275 < 0.05$ with a coefficient of -0.1025. This point requires further investigation in future research where we recommend that education and awareness-building in the form of town meetings and workshops be provided about privatization, its benefits, and its drawbacks. It is our belief that an educational program about the use of small rivers preceding a more detailed sequel to the present research would certainly shed light on engineering technology options, and result in a target audience that is more in tune with these options.

Conclusions

With the importance of water resources in all aspects of sustenance and development, and with disconcerting effects from direct human interventions and global climate change, attention is turning to the harnessing of headwater and upstream rivers branches in addition to traditional

facilities on the main river arteries. This trend is most felt in rural development by virtue of the location of creeks and small rivers, and their intertwined path within local communities. Human interventions through dams on small rivers have productive effects but may be counterbalanced by a larger negative environmental impact. Challenges exist because water is undervalued, communities are still not in tune with the criticality of their roles in getting involved and leading small river projects, and responsibilities are fragmented in terms of water resource management.

Another set of challenges exists from an engineering perspective because most theories developed and used to-date use simplifying assumptions that are better suitable for large rivers than for small ones. Since there are fundamental differences between a large and a small river in terms of bed geometry, reach curvature, and bed bottom composition, fundamental adjustments need to be applied to traditional open channel formulas. A discussion of open channel theory shows that the application of commonly acknowledged formulas may lead to an underestimation of roughness and meandering of a small river and may lead to overly optimistic results. Further, these engineering findings require a link to broader, more practical outlook at the relationship among the engineering dimension, the social and community dimension, and the economic dimension. From an engineering economics perspective, challenges exist because water is undervalued and often wasted. A dilemma exists in considering water as a public good just like air and security, versus putting it in private hands where managerial incentives are better delineated.

A proposed framework links the three dimensions above. It is tested with a numerical model based on regression analysis. Small river project success index is found to be significantly and positively related to the extent to which small communities are willing to get involved in civil works and subsequent engineering management, to the potential of using the river for hydroelectric power, and to the potential of using the project for irrigation. The index is negatively correlated with the extent to which local communities are amenable to the privatization of such projects.

In the course of this research, a lack of awareness was observed among respondents about the pros and cons of privatizing civil engineering works. Another finding was related to the exodus of human resources from rural areas, which was described as irreversible. Both of these points were left for future research.

References

- Allan, J. D., and Flecker, A. S. (1993), "Biodiversity Conservation in Running Waters," *BioScience*, vol. 43, pp. 32-43.
- Anderson, T. L. (1983). *Water Crisis: Ending the Policy Drought*. Baltimore: The Johns Hopkins University Press.
- Andriof, J., and McIntosh, M., Eds. (2001). *Perspectives on Corporate Citizenship*. Sheffield, UK: Greenleaf Publishing.
- Argondona, A., and Holvik, H. W., (2009), "Corporate Social Responsibility: One Size does not Fit All," *Journal of Business Ethics*, Vol. 89, pp. 221-234.
- Balland, J. M., and Plateau, J. P. (1996). *Halting Degradation of Natural Resources: Is there a Role for Rural Communities?* FAO and Clarendon Press, Oxford.
- Battilana, J., Lee, M., Walker, J., and Dorsey, C., (2012), "In Search of the Hybrid Ideal," *Stanford Social Innovation Review*, Summer, pp. 51-55.
- Brikké, F. and M. Bredero (2003), *Linking Technology Choice with Operation and Maintenance in the Context of Community Water Supply and Sanitation, A Reference Document for Planners and Project Staff*, World Health Organization and IRC Water and Sanitation Centre, Geneva, Switzerland.
- Bunclark, L., Carter, R., Casey, V., Day, S. J., and Guthrie, D. (2011). *Managing Water Locally: An Essential Dimension of Community Water Development*. Pub. Institution of Civil Engineers, OXFAM GB, WaterAid, ISBN 978-1-78077-011-6, November 2011.
- Burke, J., J., (2002), "Groundwater for Irrigation: Productivity Gains and the Need to Manage Hydro-Environmental Risk," in *Intensive Use of Groundwater Challenges and Opportunities*, eds. Llamas, R., and Custodio, E., Balkema, Abingdon, UK.
- Chalhoub, M. S., (2010), "Environmental Management, Valuation and its Challenges," working paper, 2010.
- Chalhoub, M. S., (2013), "Small River Hydraulics: Engineering and Environmental Issues," working paper, 2013.
- Chartres, C., Giordano, M., and Varma, S. (2010), "Water: A Free Public Good or a Market Commodity?" *Global Water Forum, Economics*, Sep. 20, 2010.
- Cleveringa, R., Zamalloa, T., and De Villemarceau, A. N. (2004). *Restoring Land Use through Local Water Governance and Technology in High Andes Communities: Management of Natural Resources in Southern Highlands Project, Peru*. International Fund for Agricultural Development, Rome, Italy.
- Conservation Gateway (2010). *North America Small River: Small River Macrogroups*. <http://www.conservationgateway.org/ConservationByGeography/NorthAmerica/UnitedStates/edc/reportsdata/hg/fw/Pages/SmallRivers.aspx>

Cornes R., and Sandler, T. (1996), *The Theory of Externalities, Public Goods and Club Goods*. Cambridge University Press, Cambridge.

Davis, J. and F. Brikké (1995), *Making your water supply work: Operation and Maintenance of small water supply systems*, IRC International Water and Sanitation Centre, The Hague, The Netherlands.

Dempsey, N., Bramley, G., Power, S., and Brown, C., (2011), "The Social Dimension of Sustainable Development: Defining Urban Social Sustainability," *Journal of Sustainable Development*, Vol. 19, pp. 289-300.

Döll, P., and Zhang, J. (2010), "Impact of Climate Change on Freshwater Ecosystems: A Global-Scale Analysis of Ecologically Relevant River Flow Alterations," *Hydrology and Earth System Sciences*, vol. 14, pp. 783-799.

Drexhage, J., and Murphy, D., (2010), "Sustainable Development from Brundtland to Rio 2012," background paper for the high level panel on global sustainability, United Nations, New York.

European Commission (2007). *LIFE and Europe's Rivers: Protecting and Improving our Water Resources*. Environment Directorate General, Office for Official Publications of the European Communities, Luxembourg.

European Environment Agency (2003), *Europe's Water: An Indicator-Based Assessment*. EEA 2003.

European Environment Agency (2012). *EEA Catchments and Rivers Network System*. Technical Report No. 7/2012, Copenhagen.

Fenkell, G. H., (1921), "The Waste of Water in Detroit," *Journal of the American Water Works Association*, vol. 8, No. 6, pp. 583-602.

Frederick, W. C., (1960), "The Growing Concern over Business Responsibility," *California Management Review*, Vol. 2, pp. 54-61.

Freeman, R. E., (2010). *Strategic Management: A Stakeholder Approach*. Cambridge University Press. ISBN 978-0-52115-174-0.

French, R. H. (1985). *Open-Channel Hydraulics*. McGraw-Hill Book Company. New York, pp. 201-247.

Global Environment Facility (2012). *Community Water Initiative*. GEF Small Grants Programme, United Nations Development Programme.

Grant, G. E., Schmidt, J. C., and Lewis, S. L. (2003), "A Geological Framework for Interpreting Downstream Effects of Dams on Rivers," *Water Science and Application*, 7, American Geophysical Union.

Gross, B., Van Wijk, C., and Mukherjee, N., (2001). *Linking Sustainability with Demand, Gender and poverty: A Study in Community-managed Water Supply Projects in 15 Countries*. Water and Sanitation Program, The World Bank, Washington, DC.

Hassing, J., Ipsen, N., Clausen, T. J., Larsen, H., and Lindgaard-Jorgensen, P. (2009). Integrated Water Resources Management in Action. The United Nations World Water Assessment Programme, Dialogue Paper, March 2009.

Hayes, D., J. (2003), "Privatization and Control of U.S. Water Supplies," *Natural Resources & Environment*, vol. 18, No. 2, pp. 19-24.

Hoe, W., and Garrett, J., (2015). *Releasing the Flow: addressing barriers to financial absorption in the water, sanitation and hygiene sector in Africa*. WaterAid Research Report, 2015.

Holling, C. S., and Meffe, G. K. (1996), "Command and Control and the Pathology of Natural Resource Management," *Conservation Biology*, vol. 10, pp. 328-337.

Hughes, R. M., and Noss, R. F. (1992), "Biological Diversity and Biological Integrity: Current Concerns for Lakes and Streams," *Fisheries*, vol. 17, pp. 11-19.

Idowu, S. O., and Vertigans, S., (2016), Eds. *Stages of Corporate Social Responsibility: From Ideas to Impacts*. Springer. ISBN 978-3-31943-536-7.

Kaplan, L. A., Bott, T. L., Jackson, J. A., Newbold, J. D., and Sweeney, B. W. (2008). *Protecting Headwaters: The Scientific Basis for Safeguarding Stream and River Ecosystems*. Stroud Water Research Center, 2008.

Karr, J. R., Toth, L. A., and Dudley, D. R. (1985), "Fish Communities of Midwestern Rivers: A History of Degradation," *BioScience*, vol. 35, pp. 90-95.

Kremen, C., and Ostfeld S. R., (2005), "A Call to Ecologists: Measuring, Analyzing, and Managing Ecosystem Services," *Front Ecol Environ*, vol. 3, No. 10, pp. 540-548.

Levin, R. B., Epstein, P. R., Ford, T., Harrington, W., Olson, E., and Reichard, E. G. (2002), "U.S. Drinking Water Challenges in the Twenty-First Century," *Environmental Health Perspectives*, vol. 100.1, pp. 43-52, February 2002.

Lewis, C. (2013), "Small Dams Key for Drought-Free Maharashtra," *The Times of India*, June 9, 2013.

Lubell, M., and Edelenbos, J. (2013), "Integrated Water Resources Management: A Comparative Laboratory for Water Governance," *International Journal of Water Governance*, vol. 1, No. 3-4.

Manning, R. (1891), "On the Flow of Water in Open Channels and Pipes," *Transactions of the Institution of Civil Engineers in Ireland*, vol. 20, p. 177.

Mathiesen, K. (2016), "Lack of Engineers Delaying Vital Water Projects in Developing Countries," *The Guardian*, International Edition, Global Development Professionals Network – Water in Development, <https://www.theguardian.com/global-development-professionals-network/2016/jan/15/lack-of-engineers-delaying-vital-water-projects-in-developing-countries>, U.K, January 2016.

McIntosh, A. C., and Yniguez, C. E. (2000). *Privatization of Water Supplied in Ten Asian Cities: A Study for the Asian Development Bank*. Manila: ADB 2000.

Meyer, J. L. et al. (2003), "Where Rivers are Born: The Scientific Imperative for Defending Small Streams and Wetlands," American Rivers and The Sierra Club Publication, Eds. Jensen, M. N., and Sutton, D., September, 2003.

Mollinga, P. P. (2008). Water policy – Water Politics; Social Engineering and Strategic Action in Water Sector Reform. In Scheumann, W., Neubert, S., and Kipping, M. (Eds.), Water Politics and Development Cooperation. Local Power Plays and Global Governance, pp. 1-29. Berlin and Heidelberg: Springer Verlag.

Morris, B. L., Lawrence, A. R. L., Chilton, P. J. C., Adams, B., Calow, R. C., and Klinck, B. A. (2003). Groundwater and its Susceptibility to Degradation: A Global Assessment of the Problem and Options for Management. Early Warning and Assessment Report Series, RS 03-3. United Nations Environment Programme, Nairobi, Kenya.

Naiman, R. J., Magnuson, J. J., McKnight, D. M., and Stanford, J. A. (1995). The Freshwater Imperative: A Research Agenda. Washington DC: Island Press.

NAOE – National Academy of Engineering, (2017). Overcoming Challenges to Infusing Ethics into the Development of Engineers. NAOE, Center for Engineering, Ethics and Society, Ed. Carl Anderson, National Academies Press, ISBN – 978-0-30946-215-0.

National Research Council (1992). Restoration of Aquatic Systems: Science Technology and Public Policy. Washington DC: National Academy Press.

Neef, A., Bollen, A., Sangkapitux, C., Chamsai, L., and Elstner, P. (2004), "Can Local Communities Manage Water Resources Sustainability? Evidence from the Northern Thai Highlands," 13th International Soil Conservation Organisation Conference, Brisbane, July 2004.

Neef, A., and Heyd, H. (2004). Participation of Local People in Water Management: Evidence from the Mae Sa Watershed, Northern Thailand. Environment and Production Technology Discussion paper No. 128. International Food Policy Research Institute, Washington, DC.

Norwegian Agency for Development Cooperation, "Sustainability Best Practices Guidelines for Rural Water Services, Department of Water Affairs and Forestry," No. 7.1, (2004).

Phills, J. A., Deiglmeier, K., and Miller, D. T., (2008), "Rediscovering Social Innovation," Stanford Social Innovation Review, Fall, pp. 35-43.

Porter, M.E., and Kramer, M. R., (2011), "Creating Shared Value," Harvard Business Review, January-February 2011, pp. 1-17.

Posel, S. (2012). The Groundwater Footprint: The Privatization of the World's Water Resources. Global Research; Centre for Research on Globalization, August 13, 2012.

Power, M. E., Sun, A., Parker, M., Dietrich, W. E., and Wootton, J. T. (1995), "Hydraulic Food-Chain Models: An Approach to the Study of Food Web Dynamics in Large Rivers," BioScience, vol. 45, pp. 159-167.

Rahaman, M. M., and Varis, O. (2005), "Integrated Water Resource Management: Evolution, Prospects, and Future Challenges," Sustainability: Science, Practice, & Policy, vol. 1, No. 1.

Resh, V. H., Brown, A. V., Covich, A. P., Gurtz, M. E., Li, H. W., Minshall, G. W., Reice, S. R., Sheldon, A. L., Wallace, J. B., Wissmar, R. (1988), "The Role of Disturbance in Stream Ecology," *Journal of the North American Benthological Society*, vol. 7, pp. 433-455.

Seibert, S., Burke, J., Faures, J. M., Frenken, K., Hoogeveen, J., Döll, P., and Portmann, F. T. (2010), "Groundwater Use for Irrigation – A Global Inventory," *Hydrology and Earth System Sciences*, vol. 14, pp. 1863-1880.

Shih, J. S., Harrington, W., Pizer, A. W., Gillingham, K. (2006), "Economies of Scale in Community Water Systems," *American Water Works Association Journal*, September 2006.

Shiva, V. (2000), "The World Bank's Role in India's Water Crisis," *Fourth P7 Summit, Brussels*, June 7-10, 2000.

South Staffs Water (2013). *Water Leakage and your Responsibility: Information and Guidance*. Green Lane, Walsall, West Midlands County, v. 5.3, December 2013, UK.

Stanford, J. A., Ward, J. V., Liss, W. J., Frissell, C. A., Williams, R. N., Lichatowich, J. A., Coutant, C. C. (1996), "A General Protocol for the Restoration of Regulated Rivers," *Regulated Rivers: Research & Management*, vol. 12, pp. 391-414.

Trace, S. R., (1994), "The Role of the Engineer in Developing Countries," *Proceedings of the Institution of Civil Engineers – Municipal Engineer*, ISSN 0965-0903, Vol. 103, No. 2, June 1994, pp. 105-108.

UNESCO – United Nations Educational, Scientific and Cultural Organization, (2008). *Integrated Water Resource Management Guidelines at River Basin Level, Part I, Principles*.

UNCTAD – United Nations Conference on Trade and Development (2014). *Best Practice Guidance for Policymakers and Stock Exchanges on Sustainability Reporting Initiatives*. New York and Geneva: United Nations.

UNDP - United Nations Development Programme (2006). *Human Development Report 2006, Beyond Scarcity: Power, poverty, and the Global Water Crisis*.

UNSDSN – United Nations Sustainable Development Solutions Network (2013). *An action Agenda for Sustainable Development*. Washington D.C.

United States Department of the Interior (2013). *Dams in the USA*. Bureau of Reclamation.

United States Environmental Protection Agency (2005). *Factoids: Drinking Water and Groundwater Statistics for 2005*.

United States Society on Dams (2013). *Dam, Hydropower, and Reservoir Statistics*. Denver, CO, 2013.

Valley Water District (2013). *Report Water Waste*. Las Vegas Valley Water District Organization. http://www.lvwwd.com/apps/ic/water_waste/water_waste.cfml.

Vörösmarty et al. (2004), "Humans Transforming the Global Water System." *Eos, Transactions American Geophysical Union*, 85:48, November 2004.

Wade, R., (1988), "The Management of Irrigation Systems: How to Evoke Trust and Avoid Prisoners' Dilemma," *World Development*, vol. 16, No. 4, pp. 489-500.

Ward, J. V., and Stanford, J. A. (1995), "Ecological Connectivity in Alluvial River Ecosystems and its Disruption by Flow Regulation," *Regulated Rivers: Research and Management*, vol. 11, pp. 105-119.

WaterAid (2013). *Local Communities Key to Managing Global Water Threats*. WaterAid America, NY.

WaterAid (2011). *Water Resource Management: Integrated Planning and Management at Community Level*. Sep. 2011. Nepal.

Whittaker, R. H. (1975). *Communities and Ecosystems*. 2nd edition Macmillan, New York.

Williams, C. (2013), "Detroit's Abandoned Buildings Flood with City Water from Broken Pipes," *Huff Post*, Dec. 11, 2013.

Williams, R. N., Calvin, L. D., Coutant, C. C., Erho, M. W., Lichatowich, J. A., Liss, W. J., McConnaha, W. E., Mundy, P. R., Stanford, J. A., and Whitney, R. R. (1996). *Return to the River: Restoration of Salmonid Fishes in the Columbia River Ecosystem*. Portland (OR): Northwest Power Planning Council.

Williams, G. P. and Wolman, M. G. (1984). *Downstream Effects of Dams on Alluvial Rivers*. US Geological Survey, Pap. 1286.

Wohl, E. (2006), "Human Impacts to Mountain Streams," *Geomorphology*, vol. 79, pp. 217-248.

World Bank, (2012). *Inclusive Green Growth: The Pathway to Sustainable Development*. Washington D.C.: World Bank.

World Business Council for Sustainable Development (2006). *Facts and Trends: Water*. ISBN 2-940240-70-1, Switzerland.

World Health Organization (2008). *Safer Water, Better Health: Costs, Benefits, and Sustainability of Interventions to Protect and Promote Health*.

World Water Assessment Programme (2006). *Water – A Shared Responsibility*. The United Nations World Water Development, Report No. 2, 2006.

Yalin, M. S. (1992). *River Mechanics*. Pergamon, Oxford.

Public Interest Statement

Water is a vital resource and yet it is often missing or scarce in many developing countries, even ones that have abundant rain like Lebanon. The issue does not reside in lack of engineering expertise, but is rather more related to lack of public policies, lack of programs that involve local communities, and weakness in public management. The paper presents an argument for the harnessing of surface water provided proper policy frameworks are established and implemented with water project methodologies aligned with sustainable development principles.

Modifications are also suggested to water flow formulas to accommodate arid regions and small seasonal river behavior. A framework linking engineering to public policy is proposed and tested using field data collected in Mount-Lebanon. It is found that local communities would benefit more from water projects if they could participate under clearly designed policies in power generation and irrigation for agricultural purposes among other applications.

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Author Bio

Dr. Michel Soto Chalhoub conducts research and field work in civil engineering, management consulting, and environmental protection emphasizing the alignment of development projects with sustainability principles. He designed and executed numerous projects on fluid structure interaction including docking cells in Alaska, theme parks in Orlando, testing facilities in Cape Canaveral, treatment plants in Los Angeles, ocean outfalls in San Diego, and Artificial Reefs in the East Mediterranean. His current research focuses on water resource management, quality, and impact on local communities with interest in small seasonal rivers. Michel holds a B.Sc. in Civil Engineering from l' Ecole Supérieure des Ingenieurs, a M.Sc. and Ph.D. from the University of California, Berkeley, and a Master in Public Policy from Harvard University. He is a licensed Professional Engineer (P.E.) and Structural Engineer (S.E.) in the State of California, has published extensively in academic journals and served on several Code development committees.

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