Water Resources Carrying Capacity: The Case of the Freeport Area of Bataan

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古代文明が大河の流域に生まれたように、現代の大都市圏も水資源の安定的供給なくして成立しない。本稿ではフィリピンで開発区域の拡張が予定されるバターン自由貿易港について、水資源の将来的な持続可能性を検証した。

Abstract

In light of the growing universal sustainability agenda, it can be argued that policies, plans and programs must have a thorough consideration of the environment and the environmental constraints that affect or influence their direction. This general principle however may be further challenged in the context of areas designed to promote intense economic activity, such as freeports and economic zones.

The Freeport Area of Bataan (FAB), one of several investment promotion agencies in the Philippines, is one such case. There are now more than 140 registered enterprises employing in excess of 38,000 laborers, figures that have tripled that of the 2010 statistics prior to its conversion as a freeport, attracting more than P130 Billion worth of foreign and domestic investments in the last 7 years and remains to be an ideal location to both locators and workers.

The main objective of this study is to determine the implications of the water resources carrying capacity of the FAB toward its planned expansion for the next 10 years and to provide appropriate recommendations based on this environmental constraint. The results of this study can then contribute to its development to ensure sustainability of its resources, particularly water, in its goal toward becoming a center of trade in Asia. By extension, it can also help inform policies to manage and support human capital and industries or locators. Moreover, it also hopes to enrich the scant body of research on water carrying capacity in the Philippines and promote its application in development and sustainable investment planning and governance.

Keywords water carrying capacity, sustainable development

1.1 Introduction

A historical look at urbanization points to a central element common and requisite to the establishment of cities: a large body of water, oftentimes, a river. In fact, Mesopotamia, recognized as the site of the earliest civilization, literally means “between rivers”. From then on, many more ancient and modern cities have emerged originating around or near bodies of water.

It is equally important then to recognize that water is a finite and limited resource. This characteristic makes it a common factor limiting development potential, as well as carrying capacity. It has been said that “the carrying capacity of limited-water areas is extremely low for all forms of life, including man” (Durham 1991). Carrying capacity in turn easily dovetails with the relatively younger concept of sustainable development, giving rise to enhanced definitions such as “the number of individuals who can be supported in a given area within natural resource limits, without degrading the natural, social, cultural, and economic environment for present and future generations” (Qin, et.al, 2016). As Wang et al (2014) aver, “carrying capacity is an essential component of sustainable development theory, which relates eco-environmental integrity to socio-economic development in situations with limited resource and increased environmental pollutions".

In light of the growingly universal sustainability agenda, it can be argued that policies, plans and programs must have a thorough consideration of the environment — not only for the potential environmental consequences, but just as importantly, for the environmental constraints that affect or influence their direction. This general principle however may be further challenged in the context of areas established or designed precisely to promote intense economic activity, such as freeports and economic zones. The Freeport Area of Bataan (FAB), one of several investment promotion agencies in the country, is one such case.

The FAB was created through the passage of Republic Act 9728 in 2009 and spans an area of approximately 1,700 hectares in the Municipality of Mariveles covering two barangays and an industrial zone. Prior to the conversion of the export processing zone into a Freeport, there were 12,777 workers employed by 38 locators. As of this writing, there are now more than 140 registered enterprises employing in excess of 38,000 laborers, figures that have tripled that of the 2010 statistics, prior to its conversion as a freeport, attracting more than P130 Billion worth of foreign and domestic investments in the last 7 years and remains to be an ideal location to both locators and workers. To capitalize on the growing success of the Freeport, the FAB management is considering expanding the industrial area to accommodate more locators. This would entail filling up the current phase of the existing industrial zone and carving out 2 new phases from privately owned properties but are still well within the FAB domain.

Given this direction, it is important to have an understanding of the FAB as part of an ecological system instead of a self-sustaining organism, which it may appear to be owing to the special powers and exemptions accorded by law. Especially with the expressed vision "to be the Freeport of Choice in the country by 2020, becoming a center of trade, innovation and sustainable development in Asia promoting work-life balance and global competitiveness" juxtaposed with core values of sustainability, innovation, and partnership, it will be interesting to see how it becomes defined by, and likewise manages, its given resource capacities such as water. While economic development provides social and financial benefits to the stakeholders of the FAB, there is a need to balance this with the area's maximum water resource carrying capacity to ensure that current and future generations will be able to enjoy prosperity without compromising water supply.

1.2 Statement of the Problem

What are the economic, social, and ecological implications of the water resources carrying capacity of the FAB to its expansion plans?

1.2.1 Research Questions

To further supplement the principal question of this study, the following shall likewise be addressed:

(1) What is the projected water demand in the next 10 years taking into account the type of locators based on water use intensity?

(2) What is the projected water supply taking into account the effects of climate change?

(3) What is the water resources carrying capacity of FAB by 2027 considering the various water demand and supply scenarios?

(4) What strategic policy recommendations can the FAB employ to ensure sustainability of water resource use?

1.2.2 Research Objectives

The main objective of this study is to determine the implications of the water resources carrying capacity of the FAB toward its planned expansion.

The sub-objectives are:

(1) To determine the projected water demand in the next 10 years taking into account the type of locators based on water use intensity;

(2) To determine the projected water supply by 2027 taking into account the effects of climate change;

(3) To compute for the water resources carrying capacity of FAB by 2027 considering the various water

demand and supply scenarios; and,

(4) To provide recommendations to the FAB management for residential and industrial expansion plans of the FAB based on its water resources carrying capacity.

1.3 Significance of the Study

The double bind of sustainable development lies in the argument that the path to further economic development or material growth also clearly necessitates the exploitation of natural resources. Nonetheless, sustainability continues to be a resounding buzzword and, by and by, concrete efforts are being introduced by various sectors in their respective spheres of influence. This study therefore aims to advance this agenda by underscoring the supply and demand factors in the biophysical support system to influence development and investment planning processes.

Economic developments, at times, progress to an imbalance in the supply and demand for the biophysical support system and worsen to environmental degradation. In almost all cases, such scenario can reverse the positive impacts of economic development and may even lead to losses in lives and properties. Thus, there is a need to strike a balance between supply and demand of scarce resources and understand the environment's limiting factors, including water.

Among other resources, water is particularly important to monitor and include in decision-making due to its significance in settlements development and high vulnerability to climate change. Water shortage, defined as the lack of access to adequate quantities of water for human and environmental uses (White, 2012), has become a global phenomenon. The Food and Agriculture Organization or the FAO (2012) noted that "unconstrained water use has grown at global level to a rate more than twice the rate of population increase in the 20th century, to the point where reliable water services can no longer be delivered in many regions." The FAO added that demographic pressures, the rate of economic development, urbanization and pollution are all putting unprecedented pressure on this resource. Rathnayaka et al (2016) posit that "scarcity of traditional water sources, such as surface and groundwater, coupled with low water use efficiency are increasingly threatening the security of urban, agricultural, and environmental water needs." Obot (1984) stated that "water shortage makes it impossible to implement regional development. Growth — including investments such as large-scale factories, irrigation schemes, and so on cannot be started in the area."

The Philippines is not exempt from such crisis. Webster & Le-Huu (2003, as cited in Rola et al, 2015) also noted that the per capita water availability in the country has been declining over the years due to increasing water demand and decreasing supply. An Asian Development Bank (2013) study reported that "growing population especially in the urban areas together with water pollution, wasteful and inefficient use, continued denudation of forest cover (particularly in watersheds), and saltwater intrusion caused by excessive withdrawal of groundwater (particularly in the metropolitan area of Cebu, Davao City, and certain areas of Metro Manila), are the major challenges facing the country's water resources."

The results of this study can then contribute to the development of the FAB to ensure sustainability of its resources, particularly water, in its goal toward becoming a center of trade in Asia. By extension, it can also help inform policies to manage and support human capital and industries or locators. Moreover, it also hopes to enrich the scant body of research on water carrying capacity in the Philippines and promote its application in development and sustainable investment planning and governance.

1.4 Scope and Limitation

The study covers only the existing water-impounding facility (i.e., dam), the FAB watershed, locator water consumption, and the barangays under the direct jurisdiction of the Authority of the Freeport Area of Bataan (AFAB). Territorially, the FAB covers five (5) barangays in the municipality of Mariveles, however, only two (2) of these are being supplied water since these are the original residential sites reserved for the zone workers. Through the years, these areas were subsequently organized into political units but had likewise grown in the number of informal settlements within and even outside the two (2) designated barangays. Other portions of Mariveles and the remainder of the province of Bataan were not included in the forecasting scenarios due to data and time constraints. It should also be considered that the water-impounding facility was established around the franchise territory of the FAB, and is therefore outside the general authority of the Local Water Utilities Administration. Hence, resource sharing such as the exportation of water resources outside the FAB is not viewed as an urgently viable concern since this move is subject to multiple legal and territorial impediments.

While the researchers recognize that water quality factors can affect water resource carrying capacity, especially when considering more specific uses, the variable was not included in the study. Water supply is based primarily on the precipitation and water ecological requirement; whereas demand is based on industrial and residential water consumption and taking into account the level of prosperity in the FAB. Population was projected based on the eight (8) planned housing developments of AFAB, which can approximately accommodate 1,728 residents, as it seeks to limit settlements within FAB due to space limitations. These assumptions and consequent limitations will be elaborated on in the discussion on the study's conceptual framework.

Given the lack of current data, only information collected as of 2015 were deemed sufficient and complete. As such, 2015 calculations will be used as the baseline for this study.

2.0 Review of Related Literature

Durham (1991) identified water as a factor that limits carrying capacity. He stressed that "the carrying capacity of limited-water areas is extremely low for all forms of life, including man." Recognizing the important role of water in socio-economic development, water resources carrying capacity (WRCC) has attracted considerable attention.

"WRCC is based on the carrying capacity theory and the exploration of response mechanism between human activities and water resources." It "rationally evaluates the socio-economic scale threshold that can be sustained by the local water resources." (Qin, et al., 2016). This concept has been carried over in several studies proposing various methodologies to calculate it.

Dou et al (2015) defined in their paper water resources carrying capacity (WRCC) as the "maximum sustainable socioeconomic scale that can be supported by available water resources and maintenance of good environmental conditions." The paper presented a "distributed quantitative model for WRCC, based on the principles of optimization, and considering hydro - economic interaction, water supply, water quality, and socio - economic development constraints." Dou et al (2015) elaborated the socio - economic scale as the "overall size of a regional socio - economic system in a certain period and represented by a "series of socio - economic indices including total population, urbanization ratio, industrial structure, and grain yield." Good environmental conditions, on the other hand, was elaborated as a "suitable living environment for human beings and the ecological system, in particular good water quality and healthy aquatic environment (Dou et al., 2015).

The authors further emphasized that research on WRCC should be based on two premises. First is that, the WRCC must be able to "sustain the normal operation of a regional socio - economic system" which basically entails the calculation of the quantity of water resources needed to sustain these social service functions. Second premise is that, the WRCC shall provide for the "maximum socioeconomic scale that water resources can sustain after meeting the needs of the ecosystem" (Dou et al., 2015).

Qin et al (2016) proposed the concept water resources design carrying capacity (WRDCC) as a way to calculate WCCC projection. The authors defined this concept as "the carrying capacity of water resources for human activity under a design condition, i.e., a design water resources and design socio-economic development stage." In this concept, the word "design" is taken as similar to "design flood" where flood is under a designed standard of water conservancy and hydropower engineering. Meanwhile, Peng & Xu (2012) used the Environmental Water Carrying Capacity (EWCC) to measure the carrying capacity of a 151.59 square kilometer Industrial Park in Zhuhai City with a population of 350,000. In this study, the EWCC evaluation model, which was established according to simulations of socio-economic activity, can forecast the value of assessment indicators to represent their impact degree. An entropy indicator assessment was then proposed to analyze the changes in environmental water carrying capacity and to obtain key indicators. While there are many other studies related to WCC, these examples suggest that the concept is related to the interaction of man and nature. As Peng & Xu (2012) pointed out, "it is a complex, large-scale system, involving numerous factors (including but not limited to population, resource availability, the environment, ecology, society, economics, and technology).

An earlier study of Ming in 2011, which presented the Water Resource Carrying Capacity of Chongqing Metropolitan in China, provided a computational model for the regional WRCC:

$$P = \frac{W_R + W_{Ex} - W_E + P_{RA}A_R/P_I - R_{AI}A_I}{R_{DU} \times r + R_{DA} \times (1 - r) + U_P/P_I}$$

Where,

P = WRCC

W_R = regional internal total water resources quantity

W_{EX} = regional external water flow

W_E = ecological water requirement, which "means the minimal water demand for supporting the integrality and virtuous circle of ecological system in the region, which can be divided into the ecological water requirement inside river channels and the ecological water requirement outside river."

P_{RA} = unit area agricultural average output value

$A_{R.}$ = area of agricultural production

P_I = average industrial output of value per unit water

R_{AI} = agricultural water consumption standard of effective irrigation area

A_I = agricultural effective irrigation area

R_{DU} = urban domestic water consumption standard

R_{DA} = rural domestic water consumption standard

U_P = per capita industrial and agricultural output value, which for easier calculation, can be replaced by per – capita GDP

r = urbanization rate

He emphasized that if the regional available amount of water resources, urbanization rate, and other related technical and economic indicator can be predicted in a region, the WRCC can be calculated.

While there had been a number of studies related to water supply and demand in the Philippines, a review in the literature will reveal that there is a lack of, if not absence of studies related to WRCC in the country. This presents a research opportunity to researchers to contribute to the field of water management and governance.

3.0 Research Design

3.1 Conceptual Framework

The Water Resources Carrying Capacity (WRCC) refers to the "number of individuals who can be supported in a given area within natural resources limits, without degrading the natural, social, cultural, and economic environment for present and future generations" (Qin, et al., 2016). Dou et al (2015), similarly, defines WRCC as the maximum sustainable socio – economic scale based on available water resources and maintenance of good, defined environmental conditions.

Drawing considerably from Dou et al (2011) and in consideration with available resources pertaining to the study area, below diagram summarizes the variables or factors determining the WRCC which basically are clustered into three (3) modules including:

- Socio – Economic Module;
- Ecological Module; and
- Water Quantity Module

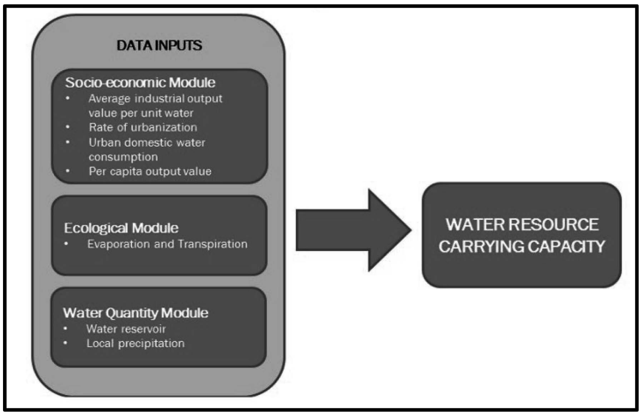

Fig. 1. Conceptual Framework

3.1.1 Socio – Economic Module

This pertains to the pressures of the socio – economic development on the water resources system of the focus area. Indices included in this module includes population including the total population and the rate of urbanization; economic including industrial output, industrial output growth; and the water consumption of residential and commercial facilities.

Industrial output — refers to the total output (in PhP) of all industries in a given location. In the case of FAB and for this study, industrial output refers to the total output of all locators inside FAB.

Urban Domestic Water Consumption — takes into account water used for residential and commercial purposes.

Average Industrial Output Value per Unit Water — is the industrial output divided by the total industrial water consumption.

Per Capita Output Value — is the industrial output divided by the total population in a given area.

Rate of Urbanization — refers to the projected average rate of change in the size of the urban population over a given period.

3.1.2 The Water Quantity Module and the Ecological Module

The Water Quantity Module pertains to the total internal water resources including the surface groundwater and local precipitation. The Ecological Module, on the other hand, pertains to the water outflow due to evaporation and transpiration in the focus area.

3.2 Analytical Framework

3.2.1 Geographic Information System (GIS)

The fundamental objective of utilizing GIS in the research is to spatially define the location and environment of the study area, as well as to construct the storage characteristics of the reservoir. Existing geographic information in various format were collected from the AFAB. Core GIS vector and raster datasets obtained include: shapefiles of watershed, AFAB, and reservoir boundary; rivers, roads, buildings, and land uses within AFAB; satellite imagery; and, the reservoir's Digital Elevation Model (DEM). Other maps acquired were generated by AFAB's previous partners—UP Engineering, The Louis Berger Group Philippines, Inc., and the Applied Planning and Infrastructure, Inc. (2012). The format of GIS files was in shapefile (.shp), drawing (.dwg), and Tagged Image File (.tif), which were interoperable within any GIS software packages.

3.2.1.1 GIS Analytical Methodology

To display and analyze the data, this research applied different spatial tools within an evaluation version of ArcGIS software (ArcGIS 10.3). The geographic information needed in the study was modeled and examined using several tools in the ArcGIS Spatial Analyst and 3D Analyst extensions. To standardize the spatial properties of GIS files from AFAB, the data were translated to the reference system commonly used in the Philippines—Projected Coordinate System World Geodetic System of 1984 Zone 51.

3.2.1.1.1 Shape Analysis and Measurement

In assessing the study area's carrying capacity, it is very important to measure the shape area, length, and other geometric properties of the features. Specifically, GIS aided in computing the parameters such as area, perimeter, and centroid while making use of the formula below ("Shape Analysis," n.d.):

(a) Area:

$$A = \frac{1}{2}\sum_{i=1}^{n}(X_{i+1} - X_i)(Y_{i+1} + Y_i)$$

(b) Perimeter:

$$L = \sum_{i=1}^{n}\sqrt{(X_{i+1} - X_i)^2(Y_{i+1} - Y_i)^2}$$

(c) Centroid (Center of Gravity):
Where in each case above, X is the base and Y is the height.

$$X_c = \frac{1}{6A}\sum_{i=1}^{n}(Y_i - Y_{i+1})(X_i^2 + X_iX_{i+1} + X_{i+1}^2)$$

$$Y_c = \frac{1}{6A}\sum_{i=1}^{n}(X_i - X_{i+1})(Y_i^2 + Y_iY_{i+1} + Y_{i+1}^2)$$

3.2.1.1.2 Digital Elevation Model (DEM) to Extract Terrain Profiles and Hydrologic Information

The potential of remote sensing to construct the topographical and hydrological characteristics of the reservoir is investigated in the study. A Digital Elevation Model (DEM) of 1-meter spatial resolution enables the research to express the physical land and bottom terrain of the reservoir. A DEM is a raster-based representation of earth's surface that composed of rectangular arrays of cells or pixels (ArcGIS 2017). Each individual pixel stores an elevation value (Manuel 2004). Hence, DEM with its simple data structure that facilitates faster calculation, is frequently utilized to analyze topography (Arun 2013). The elevation model below served as the basis for all the spatial calculation and prediction in the study using GIS.

Several GIS approaches to the DEM produced relevant hydrologic information that can be used to delineate watershed boundaries and locate streams that contribute runoff into the reservoir. An overview of the GIS processes employed is given below:

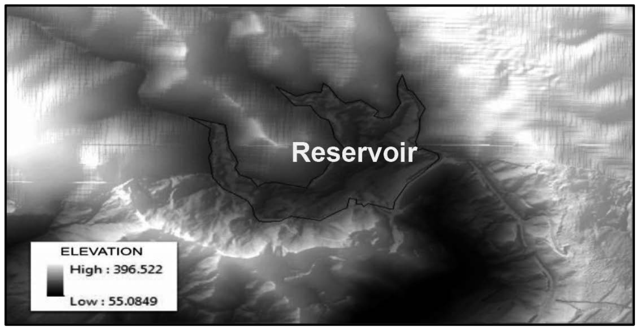

Fig. 2. DEM of the Reservoir

The first step is to recognize and address erratic changes in elevations especially the presence of "sinks" or cells that are bordered by higher elevation values which may hinder the flow of water through the slope. GIS fills in the sinks and create a depressionless DEM where runoff characteristics will be derived. By filling in the DEM, GIS will be able to define the direction of water flowing from cell to cell (flow direction) and how much water travels through a cell (flow accumulation). The flow direction and accumulation information will be inputs to delineate stream channels and watersheds from the elevation model.

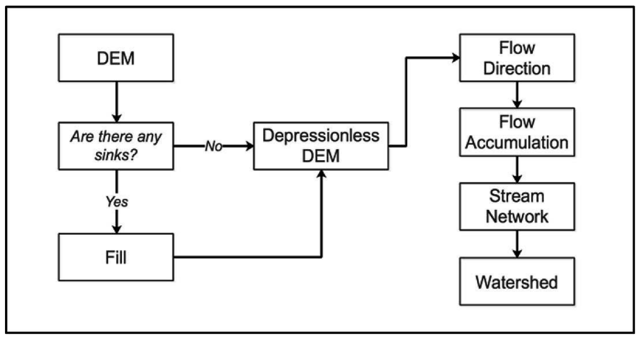

Fig. 3. Flowchart to Delineate Stream Network from DEM modified by the author

Source: http://pro.arcgis.com

3.2.1.1.3 Triangulated Irregular Network (TIN) to compute for Reservoir Volume

The study also utilized the Triangulated Irregular Network (TIN) interpolation method for extracting the parameters used for approximating the amount of water that can be stored in the reservoir. TINs are used in GIS to illustrate surface morphology of land and sea floor. Compared to the DEMs, TINs are geographic vector-based data consisting of points (nodes) and lines (edges) which are arranged to form non-overlapping irregular triangles to cover a surface ("Fundamentals of," n.d.). Each node has an x, y coordinate and a z value or surface value (McPherson et al 2009). Utilizing the triangular facets constructed by TINs, the elevation can be calculated at any location on the TIN using the geometry of the triangles (Walsh, n.d.). Figure 4 illustrates the comparison of grid surface and triangle surface. Both datasets can provide lake depth and volume, but the density of irregularly spaced network of points in TIN can calculate for the most accurate representation of a 3-dimensional structure of the reservoir basin.

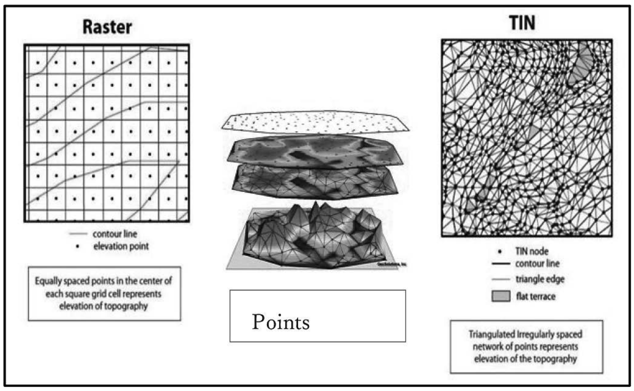

Fig. 4. Comparison of Topography Surface using Raster and TIN interpolation, modified by the author

Sources: https://serc.carleton.edu, http://www.edc.uri.edu

Variations in methods to estimate lake volume was described by Hollister and Milstead in their 2010 study. The figure below showed that among the four methods—formula for volume of a cone; formula for frustum of a cone; using depth as a function of distance; and TIN created from bathymetric survey—the latter expresses a more realistic depiction of the lake basin (Hollister and Milstead 2010). However, it should be noted that in this research, the TIN was not obtained from a bathymetric survey but from a DEM with a raster resolution of 1 meter (having a cell size dimension of 1 x 1 meter). Since the DEM is observed to have appropriate resolution to address the objective of the research, the TIN created from the DEM is considered as the most realistic representation of the actual reservoir-bed surface. Hence, the TIN will give a more precise estimate of calculating the volume of the reservoir.

There are many forms of triangulation, but ArcGIS supports the Delaunay triangulation method which "creates triangles that collectively are as close to the equilateral shapes as possible" (McPherson et al 2009). This type of triangulation "ensures that no vertex lies within the interior of any of the circumcircles of the triangles in the network" ("Fundamentals of TIN," n.d.), thus having a surface output with minimal densification of long and thin triangles. A Delaunay triangular surface is illustrated below.

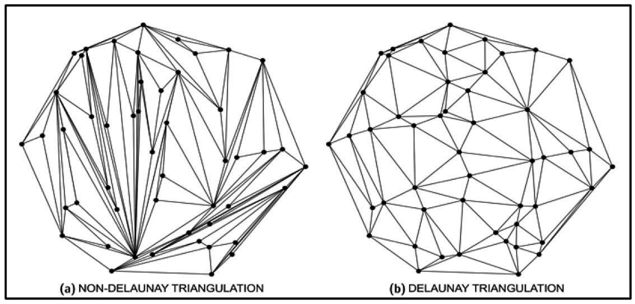

Fig. 5. Comparison of Non-Delaunay and Delaunay Triangulated Surface

Source: Kudowor and Taylor 1992

The general volume calculation of triangulated surfaces is carried out by using the following formula (Kudowor and Taylor 1992):

$$V = \frac{1}{2}\left[X_1(Y_2 - Y_3) + X_2(Y_3 - Y_1) + X_3(Y_1 - Y_2)\right]\frac{(Z_1 + Z_2 + Z_3)}{3}$$

$(X_1, Y_1), (X_2, Y_2), (X_3, Y_3)$	Planar coordinates of the triangle vertices
Z_1, Z_2, Z_3	Elevation with respect to sea level or thickness between geological horizon

In applying the Delaunay algorithm to volume calculation in GIS, the succeeding processes are required: a)

Convert the DEM information to a contour line feature class, b) Create a triangular irregular network by importing the contour map; c) Generate a closed reference plane to define the area over which to compute the volume; d) Define the height as basis for volumetric calculations; and, e) Use the 3D TIN surface and the reference plane to compute for the summation of each triangular prism volume between the reference plane and the topside of the reservoir bed.

Using the formula and notation discussed for individual triangular surface earlier, the integration of all volumes to determine the total volume is specified in the equation below:

$$V = \sum_{n}^{\infty} \frac{1}{2} \left[X_n(Y_{n+1} - Y_{n+2}) + X_{n+1}(Y_{n+2} - Y_n) + X_{n+2}(Y_n - Y_{n+1}) \right] \frac{(Z_n + Z_{n+1} + Z_{n+2})}{3}$$

3.2.2 Revised Water Resource Carrying Capacity

Ming's (2011) version of the WRCC takes into consideration other economic activities, besides industries, that require intense water use in the Chongqing Metropolitan area such as agriculture. Furthermore, Ming makes a distinction between rural water use against urban water use to take into account the effect of higher incomes on demand for water. However, given that there is no agricultural activity in the FAB and this study makes little or no distinction between rural and urban water use, a simplified version of the Ming model is hereby adapted by the study, to wit:

$$\frac{W_R - W_E}{(R_{DU})r + (U_P / P_I)}$$

Where,

W_R = Total water resources

W_E = Total water ecological requirement

R_{DU} = Urban domestic water consumption

R = rate of urbanization

U_P/P_I = Per capita output value and average industrial output per unit water

For the net water supply side of the model, total water resources cover water absorbed by the entire FAB watershed resulting from precipitation, surface runoff, infiltration, interflow, and water that goes into aquifer recharge areas. On the other hand, water ecological requirement involves evaporation and transpiration, both processes that are necessary for the sustenance of the watershed.

The water demand side (denominator) of the formula begins with total urban consumption whereby, for purposes of this study, the aggregate water consumption of FAB residents and locators will be used. Rate of urbanization is computed based on population growth while the total value of products (Net Sales) will be used to compute for (UP/PI) in conjunction with population and water consumption.

The resulting WRCC will give the researchers of this study the total number of population that the water resources can sustain based on the existing economic activity and prosperity being enjoyed in the FAB. Given that FAB management would like to further attract new locators, it should be guided accordingly since there are industries that are water-intensive while others are not. Ecological consideration must also be looked into ever since climate change has become a clear and present danger. According to the Hydrologic and Hydraulic Characterization Study of the FAB (2015), the lowest recorded water level in the dam was 133 meters above sea level (masl) in 1984 while the highest recorded level in the dam was in 2015 at 164 masl. The average dam level for the base year stood at 152.52 masl. Do note, however, that in order to maintain the structural strength and integrity of the FAB dam, water is discharged should it go beyond 157.7 masl.

Hence, on top of just computing for the WRCC for 2015 (base year), this study will project water use assuming water-intensive companies locate in the FAB versus another scenario where non-water-intensive companies locate in the Freeport. The results will then be juxtaposed with extreme cases of high precipitation (assuming dame level is at 164 masl) and low precipitation (assuming dam level is at 133-masl). The resulting sensitivity analysis should guide the researchers on what policies to recommend to the management of the FAB.

3.3 Research Design

The research follows the case study design employing primarily quantitative methods to satisfy the stated objectives. Data was collected from existing plans and studies vetted by the FAB, and in some cases, transformed or extrapolated on through GIS. It must be noted that access to and understanding of the FAB's data was facilitated through a member of the research team who is an official of the AFAB, as of this writing.

The researchers placed heavier attention on data analysis, anchored on an assessment of the quality and compatibility of various data, and the development of a workable water resource carrying capacity (WRCC) model tailor fit with the area-specific characteristics of the FAB.

3.4 Study Area

3.4.1 Geography and Land Use

The FAB is located at the southern tip of the municipality of Mariveles, province of Bataan. According to its master plan, the area is 160 km by land from Manila and about 85 km from the Subic Bay Freeport Zone. It is bound by the West Philippine Sea on its west and the Manila Bay on its eastern part, converging within the FAB's coast. A previous study on the area highlighted Mariveles' deep water bay and relative proximity to Manila as notable features that make the economic zone suitable for trade that especially involves shipping, although key infrastructure and services must complement this (Malate, 2015). The area is also part of the Zambales Mountain Range and is closest to Mt. Mariveles, considered an inactive volcano. Below is its general location map relative to Manila and other major freeport zones.

Fig. 6. General Location Map of the Freeport Area of Bataan
Source: Google Map

The FAB has an effective jurisdiction of 1,700 hectares, technically occupying portions of five out of 18 barangays of Mariveles. It may be noted that Mariveles has the highest total population among the municipalities and cities in Bataan.

The total developed area is 304.58 hectares, of which 235.46 hectares are occupied, representing a 77.31% occupancy rate. Figure 7 shows the existing land use of the FAB per its 2012 masterplan.

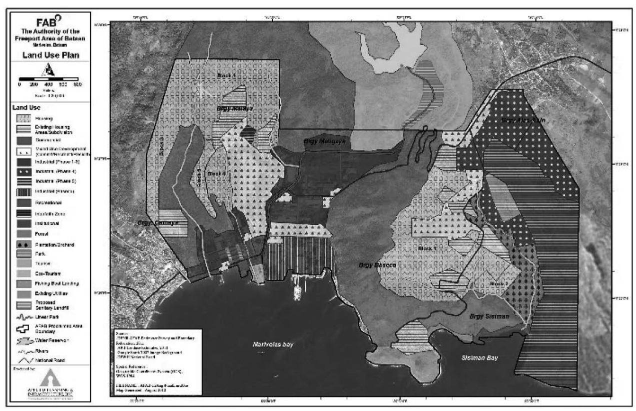

Fig. 7. Existing Land Use Map of the Freeport Area of Bataan
Source: Authority of the Freeport Area of Bataan, the Philippines

3.4.2 Masterplan

As previously noted, FAB aims to expand its operations and attract more locators. Presently, over three-fourths of its 304.58 hectares of leasable land is occupied, leaving 69.12 hectares as available land area for development.

Its land use plan is therefore premised on a scenario where there will be increased demand for industrial, residential, and commercial land. The AFAB is looking to have five (5) expansion areas for to accommodate more locators. Two of these will be for industrial use, one area will be for a township project, a fourth for a terminal, and last will be for a central business district and ferry terminal.

Table 1. Description of Leasable Land

Phase	Total Leasable Area (hectares)	Leased Area	Available Land Area
Phase I	54.41	54.19	0.22
Phase II	68.74	54.83	13.91
Phase III	28.14	28.14	0
Phase IV	58.50	43.86	14.64
Mix-use	94.79	54.44	40.35
Total	304.58 (100%)	235.46 (77.31%)	69.12 (22.69%)

3.4.3 Water Resources

The FAB core area is drained by 3 rivers and waterways including the Paniquian river which runs from the northern forested slopes, and the Aguawan river which runs through the entire length of the FAB.

Upland reservoirs are available and part of the river and drainage systems recharged by precipitation on the watershed area. The watershed of the FAB is composed of 21 sub-basins, with four contributing to the AFAB reservoir. Malate (2015) indeed observed that the natural mountainous terrain of Mariveles served the area well in that it supports water supply necessary for everyday operation. Further, the availability of clean mountain water makes it appropriate for water-intensive industries such as food processing.

Inside the FAB is an impounding facility or water reservoir constructed in the 1970s. According to the Hydrologic and Hydraulic Characterization (2015) report commissioned by the FAB, the reservoir has a capacity of 9 million [cubic meters], water sourced from three rivers, particularly the Paniquian river, and goes through a water treatment plant that is capable of processing 15,000 liters of raw liquid daily. Through nearly four decades of operation, however, the dam has been found to have accumulated more than 400,000 cubic meters of sediments, averaging 11,500 cu.m. of sediments per year

4.0 Results and Discussion

4.1 Water Quantity Module

The DEM analysis has recorded the following topographical values of the reservoir. The surface area is about 321,510 m^2 with a mean depth of 140 masl. The generated elevation map from the model revealed that the reservoir's highest elevation, is accounted to be 176 masl and lowest elevation is 118 masl. The reservoir is 4,696 meters (4.7km) long. The slope map, on the other hand, shows the range of slope within the reservoir. Steep slopes with greater than 50% are predominant specifically in areas near the dam, and surrounding the lowest surface elevation. Gentler slopes, with 0-18%, can be found on areas that are relatively flat and with higher surface elevation. Average reservoir slope is 41%. Vector-based contours, with 5-meter and 1-meter vertical intervals, were also created using the same DEM information. Contour data defining the reservoir-bed surface is required in estimating the volume capacity of the reservoir at different elevation levels. The generated contour map showed that there are relative spacing of contours at the upper end of the reservoir. The lowest contour line which is located at the center and basin floor of the reservoir is 119 meters.

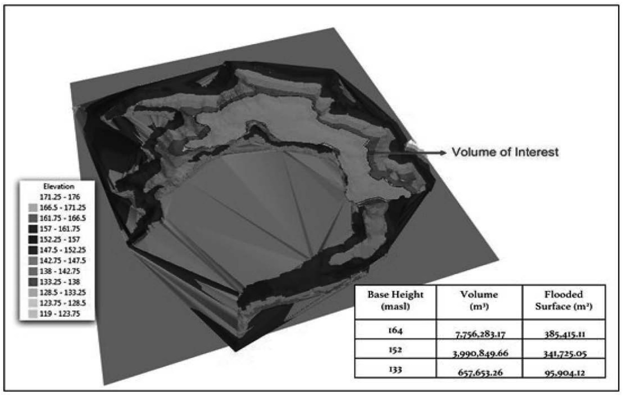

Fig. 8. Interpolated TIN surface & Estimated Volume of Reservoir

Areas of watersheds and streams are considered environmentally sensitive and should be defined since they may affect the quality and quantity of water being fed to the reservoir. Utilizing the hydrology tools of GIS, the study extracted the locations and characteristics of the contributing watershed and stream networks from the DEM file. In GIS, watershed boundary is defined by computing the flow of water across the steepest downslope direction. In the study, it was found that the watershed boundary extends down to the areas with lowest elevation (55 masl). The region and streams draining into the reservoir were also illustrated. Another interesting output from the hydrology analysis is the identification of areas with high water flow accumulation across the surface. Taking a closer look at the profile of concentrated flow, it shows the elevation (in meters) along the Y axis, and distance (in meters) along the X axis. The highest masl for that section is 160 and lowest masl is 120. As discussed in the methodology, the DEM was processed and converted into triangular facets also known as the Triangular Irregular Network, using a particular approach called the Delaunay Triangulation. The resulting TIN map above was utilized to obtain various reservoir height, water volume, and area at different scenarios or water levels.

After having estimated the watershed area as well as the different flooded areas, it is now possible to calculate the amount of water resources available. This study has considered three precipitation scenarios of high, medium, and low with the business as usual (BAU) category (medium) acting as the baseline. According to the modelling of the Hydrologic and Hydraulic Study commissioned by the AFAB in 2015, the measured rainfall for the said year was around 3.306 meters for a total water resource of 59.9 million cubic meters. By virtue of extrapolation using the recorded highest and lowest dam levels, the highest water rainfall yielded a total of 64.86 million cubic meters of water resources while the lowest recorded precipitation (at the 133 masl dam level in 1984) was estimated to be around 52.27 million cubic meters of water resources.

4.2 Ecological Module

To determine the net water supply, the amount of water lost due to evapotranspiration was estimated using a high, medium, low scenario and the resulting values were deducted from the total precipitation annual volume. The BAU category was considered as the medium scenario and was estimated using the model of the Hydrologic and Hydraulic Study (2015) that yielded an annual approximate of 0.9072 meters of water or a total of 16.45 m3. Given the same dam levels (highest and lowest recorded) as the precipitation estimate, the high and low scenarios were extrapolated, thus, giving a volume of 17.79 million m3 and 14.34 million m3, respectively.

4.3 Socio-economic Module

The population projection is needed to determine the urbanization rate. But due to space limitations within the Freeport, the AFAB has expressed its intention to limit housing developments, which consequentially will restrict population growth. In this study, 1,728 people is expected to be added until 2027 based on the planned 8 housing developments of AFAB, each having a capacity of 216 occupants. Using the formula for Compounded Annual Growth Rate, the urbanization rate of 1.56% was derived.

Urban Domestic Water Consumption considers water used for residential and commercial purposes. For the projection of residential water use, linear progression was used based on the 2012 to 2016 data. For commercial water use, a 3% growth (based on average increases from 2013 to 2016) was applied for 2017 to reflect natural increase (using linear progression will result to a decline in water use) then linear progression was done for 2018 to 2027. To compute for the urban domestic water consumption rate, the Total Urban Domestic Water Consumption, which is the sum of residential and commercial water use, was divided by total population.

Computing for the Average industrial output value per unit water will need two inputs: industrial output and industrial water consumption. For this study, industrial output value was projected using the 2015 data as baseline. The projection used the annual growth of 7% based on the projected growth of the Philippines' GDP in the medium-term. Note, however, that this study assumes that the total output of FAB will be the same regardless of the type of industry (based on water use) it attracts because there are no available data or study that correlates water use intensity and output value.

With the study's aim to reveal the effect of industry mix, based on water use intensity, on the WRCC, three (3) different scenarios on industrial water consumption were made: BAU, more water-intensive industries, and more non-water-intensive industries. BAU means growth in water for the two industry sub-sectors, water intensive and non-water intensive, will track historical performance in which the former was growing at a rate of 7% while the later at a rate of 5.75%. With this projection, composition of industrial water consumption will be at the vicinity of 80% from water-intensive industries and 20% from non-water-intensive industries until 2027. For the second scenario, which is having more water-intensive industries in the FAB, a 10% annual growth in water consumption for such industries was applied while the BAU growth for non-water-intensive was retained. The 10% growth was based on the average growth on the total industrial water consumption from 2015 and 2016 when the growth of such consumption normalized. For the third scenario, which is having more non-water-intensive industries in the FAB, a 10% annual growth in water consumption for such industries was applied while the BAU growth for water-intensive was retained.

With the industrial output and industrial water consumption computed, the Average industrial output value per unit water were derived for the 3 scenarios. To compute for the Per capita output value, industrial output value was divided by the total population.

4.4 Computation of FAB WRCC

Using the derived values of the indicators, the WRCC was then computed for the baseline year 2015 and for the various water demand and supply scenarios by 2027. In this study, there are five (5) expected scenarios: the BAU, which serves as the control of the study; the High water-intensive (more water-intensive locators) and High Precipitation; High water-intensive and Low Precipitation; Low water-intensive (more non water-intensive locators) and High Precipitation; Low water-intensive and Low Precipitation.

In the year 2015, the study revealed that the FAB was still operating at a sustainable level as its WRCC was 258,288 people — way beyond its population of 9,317. However, it can be noted that for all scenarios by 2027, there is a significant drop in the WRCC. For the worst case scenario, the High water-intensive and Low Precipitation, the WRCC drops to 92,946 or a reduction of 165,342; while for the best case scenario, the Low water-intensive and High Precipitation, the WRCC goes down to 153,825 or a decrease of 104,463. For Business as Usual, it declines to 146,686 (less 111,602); for High water-intensive and High Precipitation to 132,058 (less 125,780); and for Low Water-Intensive and Low Precipitation to 108,267 (less 150,021).

While the study shows that FAB will still be able to sustainably operate by 2027 given the 5 different scenarios, the researchers went on to explore its sustainability beyond the 10-year projection. This was done to come up with more substantial recommendations on the long-term plans of AFAB. To do so, the annual rate of decay, or the annual rate of decline, of the WRCC was computed using the 2015 and 2027 values. This assumes the continuation of the projections of all indicators in the 5 scenarios, including the urbanization rate. This means that it is also assumed that the AFAB will be

Table 2. Computation of FAB WRCC

	2015	2027				
		Business as Usual	1. High Water-Intensive and High Precipitation	2. High Water-Intensive and Low Precipitation	3. Low Water-Intensive and High Precipitation	4. Low Water-Intensive and Low Precipitation
Water Resources	61,416,712.14	63,958,053.06	72,620,989.57	52,933,963.06	72,620,989.57	52,933,963.06
Water Ecological Requirement	16,455,610.08	16,455,610.08	17,797,888.68	14,347,869.90	17,797,888.68	14,347,869.90
Urban domestic water consumption	248.12	447.51	447.51	447.51	447.51	447.51
Rate of Urbanization	1.56%	1.56%	1.56%	1.56%	1.56%	1.56%
Per Capita Output Value	1,796,524.36	3,413,098.47	3,413,098.47	3,413,098.47	3,413,098.47	3,413,098.47
Average Industrial Output per unit water	10,554.99	10,771.57	8,361.97	8,361.97	9,767.81	9,767.81
WRCC	258,288	146,686	132,058	92,946	153,825	108,267
Rate of Decay		5.49%	6.39%	9.33%	5.08%	8.06%
Sustainable until		2065	2059	2045	2072	2051

considering more housing development although at a pace that will increase population at the same rate of 1.56%.

Following the WRCC concept, the FAB is considered to be sustainable until its population already exceeds the WRCC. Applying the rate of decay, it was found out that under the worst-case scenario, the FAB will only be sustainable until 2045, and for the best-case scenario until 2072. For Business as Usual, it will be until 2065; for High water-intensive and High Precipitation until 2059; and for Low Water-Intensive and Low until 2051.

5.0 Conclusions and Recommendation

Based on the foregoing discussion, it can be concluded that the FAB will still be sustainable in its operations by 2027 in any of the 5 scenarios: Business as Usual; the High water-intensive (more water-intensive locators) and High Precipitation; High water-intensive and Low Precipitation; Low water-intensive (more non-water-intensive locators) and High Precipitation; Low water-intensive and Low Precipitation. However, its maximum sustainability will only be until 2072 at the best case scenario of Low water-intensive (more nonwater-intensive locators) and High Precipitation.

The best way to prolong the sustainability of FAB's operations, AFAB must take measures to attract more nonwater-intensive industries, such as BPOs/KPOs, banking and finance, research and development, and the like, in order to reduce pressure from the water demand side. To increase supply, it is highly recommended that the FAB initiate dredging in the water reservoir to increase its water storage capacity, instead of increasing the height of the dam wall, which will prove costly due to sophisticated engineering interventions since it will necessitate massive structural retrofitting of the existing dam wall. A study has estimated that the amount of silting and deposits have reached approximately 400,000 cubic meters which when removed, shall increase storage capacity considerably and enable FAB to capitalize on water retention during periods of high precipitation. To complement this, the FAB should also implement watershed protection activities such as reforestation, fencing, regular monitoring of water quality, and deploying forest guards. For further studies, human-related threats to water quality as well as identification of alternative water sources such as springs may also be looked into.

This study sets a precedent on incorporating water resources carrying capacity in local governance, especially in a Philippine setting. It is hoped that more government agencies, local and national, will follow in mainstreaming this concept to promote the sustainable use of our finite water resources as we pursue inclusive growth.

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