STUDY OF POTENTIAL CAPACITY FOR FLOATING SOLAR IN MALAYSIA

LIEW PEI MEI

A project report submitted in partial fulfilment of the requirements for the award of Bachelor of Engineering (Honours) Electrical and Electronic Engineering

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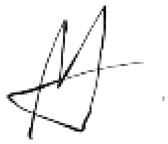
Universiti Tunku Abdul Rahman

April 2021

DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

Signature : 

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APPROVAL FOR SUBMISSION

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ABSTRACT

Lack of land space and escalating land price are the main disadvantages of large-scale ground-mounted solar farms. Deforestation is also often carried out to provide space for large-scale ground-mounted plants. Hence, a floating solar system might be a solution on top of these issues by installing solar panels on the water bodies. Since there are around 60 lakes in Selangor, they can be utilised to install floating solar plants. This project aims to study the potential capacity of floating solar in Malaysia. Selangor state is chosen as the sample location because it has the highest number of lakes. The lake images are retrieved from Google Cloud Platform through Uniform Resource Locator encoding by stating the lakes' earth coordinates, zoom level and image size. By using image processing techniques on the lake images in Python, the number of solar panels that can be installed on each lake is calculated through determining the lakes' length and width. The lake area, photovoltaic (PV) capacity, first-year electricity yield and lake utilisation rate are calculated for individual lakes. The total PV capacity installed on the Selangor lakes is then calculated, which is 1794 MW, and the total existing PV capacity in the whole Malaysia was 996 MW in 2020. Hence, installing of solar panels on lakes in Selangor allows the solar capacity to increase by 2.8 times compared to the year 2020. In short, the positive results in this project show that floating solar is another good option to be adopted for the achievement of 20 per cent of renewables in electricity generation by 2030.

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LIST OF SYMBOLS / ABBREVIATIONS

AC	alternating current, A
API	application programming interface
DC	direct current, A
FSPV	floatig solar photovoltaic
GHG	greenhouse gas
kW	kilowatt
MW	megawatt
MWh	megawatt-hour
PV	photovoltaics
RE	renewable energy
URL	uniform resource locator

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CHAPTER 1

INTRODUCTION

1.1 General Introduction

One-third of global greenhouse gas (GHG) emissions are contributed by the electricity generation from fossil fuel plants, namely coal, natural gas and petroleum oil (Kumar. J and Majid, 2020). Hence, renewable energy (RE) sources are necessary to reduce global warming emissions as they produce little or almost zero GHG emissions. Solar energy is one of the cleanest, most promising and profit-making RE sources available right now. Therefore, solar photovoltaics (PV) is selected as a clean technology in many countries to reduce the GHG emissions from the electricity generation. However, in many countries, a lack of land resources and high land prices are the obstacles for installing large-scale ground-mounted PV system. In these circumstances, a floating solar PV system is an alternative solution. Floating solar is also known as floatovoltaics, and it involves the setting up of solar panels to float on water bodies. Hence, it eliminates the usage of costly land sites for the installation of solar panels.

The first floating solar plant was installed in Aichi, Japan in 2007 and the first commercial floating solar plant of 175 kW was installed in California in 2008. China then becomes a world leader in floating solar because it is the only country with tens to hundreds of MW of floating solar plants. The floating solar PV industry is then being spread out worldwide such as England, the Netherlands and Taiwan (Nelson, 2019). In Malaysia, the first floating PV system is being developed now in Sg Labu Water Treatment Plant, which is located in Silak Tinggi Reservoir, Selangor. This project was started in 2015, and the 432 solar panels that are installed on this floating farm can generate electricity for 20 houses annually (Solarvest, 2019). Floating solar has several advantages that outweigh the ground-mounted system including enhanced energy efficiency, improved water quality by limiting algae growth, decreased shading of panels by the surroundings and reduced water evaporation from water reservoirs (Gamarra and Ronk, 2019). The true extent of the advantages to which the floating solar can achieve is still yet to be validated by larger installations in different locations.

1.2 Problem Statement

Solar energy is considered as the most promising RE source in Malaysia to sustain the increasing energy demand. However, there is a lack of land resources for large-scale ground-mounted PV system in Malaysia. Hence, deforestation has to be carried out for the installation of solar panels. It is not environmentally friendly to install solar panels by cutting down the trees. The land price is also escalating, and it is more worthy of utilizing land space for other commercial activities such as agriculture. As a result, the installation of solar panels on water bodies is better as it does not occupy valuable land space. Typically, it takes up the unused water bodies, and this location can also become a site of tourism attraction. Besides, the rooftop is also a preferable space for the installation of the PV panels. By now, several studies regarding rooftop PV capacity have been carried out. Nevertheless, so far, there is no study related to floating solar capacity in Malaysia to the author's knowledge. Hence, this project serves the purpose of determining the floating solar capacity so that Malaysia has a well-planned solution to achieve the RE target that has been set.

1.3 Aim and Objectives

This project aims to determine the floating solar potential in Malaysia. Three objectives are then set to achieve the aim stated above.

1) To determine the available area of lakes in Selangor using Google Map and Python programming.
2) To calculate the FSPV system's capacity installed on each lake based on some design criteria, such as the size of solar panels, gaps between solar panels, and the number of panels per string using Python. At this stage, the lake utilization rate is also considered to determine the PV capacity.
3) To estimate the total annual energy yield of the FSPV system in all the lakes of Selangor. During this stage, the performance ratio and the peak sun hours in Malaysia are also taken into account to calculate the first year electricity yield of the FSPV plant on Selangor's lakes.

1.4 Importance of the Study

Figure 1.1: Malaysia’s first floating solar plant in Sungai Labu (Ciel & Terre, n.d.)

Large-scale solar power plants require deforestation to create space for the solar panels even though it generates green energy for electricity consumption. Therefore, floating solar is considered a greener solution for adopting a large-scale solar plant. As such, it is important to determine the capacity of a floating solar power plant that can be installed so that the feasibility of this concept to fulfil the electricity demand can be identified. Thus, Selangor, which is a state with many left-over mining lakes as well as high electricity demand, is chosen for this study. There are only two floating solar plants in Malaysia constructed on Sungai Labu Water Treatment Plant, as shown in Figure 1.1, and a lake in Dengkil, Selangor. Solarvest recently commissioned the 13 MW floating solar plant in Dengkil on 6th October 2020. Hence, the floating solar industry in Malaysia is not mature enough, and there is also limited study or research related to the floating solar PV system in Malaysia. Although several projects of floating solar PV system are being completed and studied in other countries, the feasibility study may not apply to Malaysia due to the differences in geographical locations and weather conditions. In this project, the available lakes in Selangor, Malaysia, will be studied for the installations of floating solar PV system. The result of this study can be utilized to determine the potential of

FSPV plant in Malaysia from the economic aspect. This study is beneficial to the government or any community in deciding whether it is worth the investment of a floating solar PV system in Malaysia. Also, the results obtained from this study encourage more research or study related to floating solar system to be carried out in Malaysia to enhance and improve the existing system. At present, there is only 2% of RE penetration in the energy mix (Abdullah et al., 2019). If more floating solar plants are set up, it helps the Malaysian government achieve 20 % RE sources in the total energy generation mix by 2025 without cutting down trees for large-scale ground-based solar plants.

1.5 Scope and Limitation of the Study

The scope of this study is mainly focused on the area of lakes available in Selangor, Malaysia. Therefore, the floating solar system design is only suited in Malaysia because it is based on Malaysia's solar irradiance and weather condition. Also, the floating solar design in this project only considers the crystalline silicon PV module. Furthermore, the area of lakes obtained is an estimation calculated from the Google Map using Python. Any changes in landscape due to the natural phenomenon or human activities after the Google Image is obtained are not considered. Besides, the PV system capacity is also an estimated value obtained through the calculation using Python language. Other parameters also affect each lake's actual PV capacity, but this study aims to get the first concept on the PV capacity range that can be achieved in Selangor. Extrapolation is also used instead of individual FSPV design for each lake.

CHAPTER 2

LITERATURE REVIEW

2.1 Types of Solar PV Installations

The solar PV installations can be classified into five types, such as ground-mounted, rooftop, canal top, offshore and floating (Sahu, Yadav and Sudhakar, 2016). Each type of solar PV installation has its characteristics and landscape compatibilities.

2.1.1 Conventional Ground-Mounted Solar System

Figure 2.1: 5.5 kW ground-mounted solar system in Canada (Shift Energy Group, n.d.)

A ground-mounted solar system consists of solar panels installed on open land, as shown in Figure 2.1. The installation is usually on the suburban area or rural area in a large, utility-scale. The solar panels are located a few inches or several feet above the ground by utilizing three types of racking system, namely fixed-tilted, single-axis tracker and dual-axis tracker. Fixed-tilted racking systems hold the solar modules in a fixed orientation while the sun tracker systems can adjust the positions of PV array automatically. Hence, a single or dual-axis tracker can result in a higher energy generation of 15% to 30% than the fixed-tilted array (KMB Design Group, 2019). The racking or framing systems are attached to the ground-based mounting supports, such as pole mounts, foundation mounts and ballasted footing mounts.

2.1.2 Rooftop Solar System

Figure 2.2: Rooftop solar system in Rayong, Thailand (Symbior Solar, n.d.)

A rooftop solar system is a system that consists of one or more PV panels installed on the rooftops of residential or commercial buildings, as shown in Figure 2.2. This system contains PV modules, cables, inverters and mounting supports. There are two main categories of rooftop PV system: stand-alone system and grid-connected system. The stand-alone rooftop PV system does not connect to the electricity grid, and its capacity is ranging from milliwatts up to several kilowatts. This system has a battery that is charged during the daytime so that the inverter can invert the DC voltage from the battery bank into AC voltage to power up the AC electrical appliances. Besides, the grid-connected rooftop PV system connects to the utility grid through an inverter. This grid-connected system can be further classified into decentralized systems and centralized systems. The centralized system has PV capacity up to MW range. It can be fed directly into medium or high voltage grid while the decentralized system has a smaller power range that feeds into low-voltage grids (Ranjan et al., 2015).

2.1.3 Canal Top Solar System

Figure 2.3: Canal top solar plant in Gujerat, India (Srivastava, 2016)

A canal top solar system has solar PV panels installed on the canal top, as shown in Figure 2.3. Since Gujerat has a large irrigation canal network, the government put forward the idea of a solar PV plant on the canal top by implementing the first 1MW canal top solar power project in 2012. It is an innovative approach that gets rid of land usage and conserves water at the same time (Srivastava, 2016).

2.1.4 Offshore Solar System

Figure 2.4: Kagoshima Nanatsujima Offshore solar PV plant in Japan (Kumar, Shrivastava and Untawale, 2015)

The offshore solar system is a sustainable method introduced to generate clean energy and does not use up any land space by locating solar farms on the seawater, as shown in Figure 2.4. Offshore solar can also be integrated with offshore wind farms with solar modules floating in the sea area between the wind turbine foundations. This integration results in a more stable and continuous power supply and more than five times energy is generated per sea area (Oceans of Energy, 2019).

2.1.5 Building Integrated Photovoltaics (BIPV) System

Figure 2.5: BIPV with a total power capacity of 460 kW in Nanchang, China (Djunisic, 2019)

BIPV system, as shown in Figure 2.5, consists of integrating photovoltaic or solar cells into the building envelope such as roof and façade to produce electricity from solar energy. The main difference of this system from the others is that the building itself acts as the PV mounting structure and it also replaces the conventional building materials. Most of the BIPV systems are connected to the available utility grid but BIPV can also be constructed in terms of stand-alone systems (Strong, 2016).

2.1.6 Floating solar system

Figure 2.6: Floating solar farm in Netherlands (Mathis, 2020)

Floating solar system, as shown in Figure 2.6, is an emerging concept that is established on various types of water bodies, such as lakes, water reservoirs and irrigation ponds etc. Hence, this has become an ideal option for the countries that have insufficient land for PV installations, especially islands, namely Singapore, Japan and Korea etc.

2.1.7 Advantages and disadvantages of different PV installations

The advantages and disadvantages for different types of PV solar installations are listed in Table 2.1.

Table 2.1: Pros and cons of different PV solar installations

Types of PV solar installations	Advantages	Disadvantages
Ground-mounted	-Accommodate larger panels and has room for expansion. -Ease the maintenance, such as cleaning the dust.	-Lack of land resources in cities. -Require installation of concrete foundations for protection against strong winds and storms.

		-Cutting down trees for large-scale system
Rooftop	-Does not require land space and utilize the vacant roof -The installation is relatively faster and easier compared to the ground-mounted type. -Protect the roof and reduce the temperature inside the house by 35% or more (Simpleray, n.d.).	-The roof space might restrict solar panels. -Probability of shading losses. -Higher operating temperature and, thus, lower performance.
Canal top	-Conserve water by reducing water evaporation. -Save land space. -Higher efficiency of solar panels due to the cooling water effect.	-Limited canals are available. -More complex structures to accommodate the panels. -Hard for maintenance.
Offshore	-Conserve land space. -Increased efficiency of the module as compared to land-based. -Less shading effect.	-Corrosion of solar panels due to seawater. -High maintenance cost. -Difficult engineering works due to the harsh conditions on the sea.
BIPV	-Save building materials and labour cost. -Can be used on structures that cannot be installed with solar panels.	-Difficult and expensive to retrofit existing buildings. -Lower efficiency as thin film are usually used for BIPV modules (Abhishek Shah, 2011).

Floating	-Conserve land space. -Conserve water by reducing water evaporation. -Enhance water quality by preventing algae growth -Higher module efficiency due to the cooling effect of water.	-Corrosion of the solar PV components -A barrier for transportation and fishing activities (Dang Anh Thi, 2017).

2.2 Components of floating solar PV system

The overall layout of a floating solar system is similar to the land-based solar system. The main difference is that the PV arrays and sometimes the inverters are mounted on a floating platform, as shown in Figure 2.7. The main components in a floating solar PV system are floating system, mooring system, solar PV system, cables, and connection.

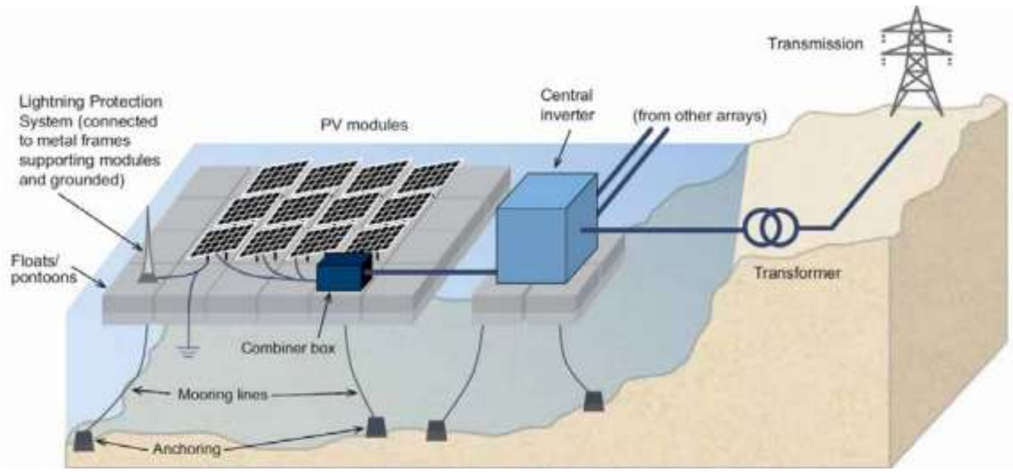

Figure 2.7: Layout of floating solar system (Gamarra and Ronk, 2019)

2.2.1 Floating system

The floating system in the FSPV system consists of floats and pontoon. A pontoon is a structure with the buoyancy that allows it to float with a heavy load. It is a platform designed to hold an appropriate number of PV modules. Meanwhile, floats are structures with effective buoyancy to its weight ratio, and it is combined repeatedly to form a giant pontoon, as shown in Figure 2.8. The floats are commonly made from high-density polyethylene, which is resistant to sunlight and corrosion, has high tensile strength, and free from maintenance.

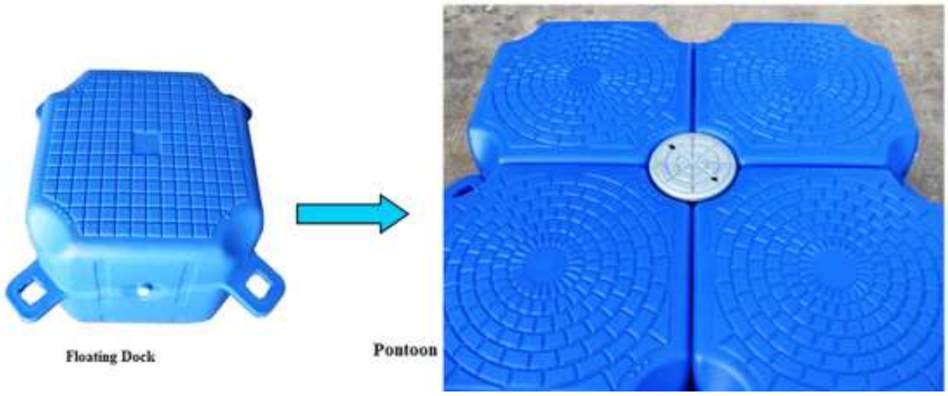

Figure 2.8: Float and pontoon structure (Sahu, Yadav and Sudhakar, 2016)

2.2.2 Mooring system

The mooring system in the FSPV system includes quays, anchor buoys, wharfs, and mooring buoys. Its primary purpose is to maintain the solar panels in the same position. The mooring system's installation is done by tieing the nylon wire rope slings to bollards on the bank and hooked at every corner, as shown in Figure 2.9. Besides, there are three types of anchoring systems: bottom anchoring, bank anchoring, and hybrid anchoring. The selection of anchoring system relies on the site configuration and condition.

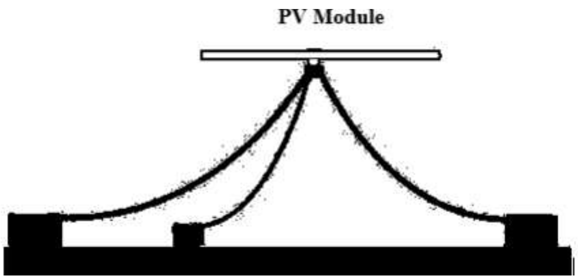

Figure 2.9: Mooring system for floating solar (Manoj Kumar, Kanchikere and Mallikarjun, 2018)

2.2.3 Solar PV system

The solar PV system consists of PV modules, inverter, and substation (Dang Anh Thi, 2017). In floating solar, the standard crystalline PV module is used until now. When more floating solar projects are implemented, it is realised that the fabricated modules have to be resistant to long-term water exposure. Almost every metal will degrade after a period; thus, the standard aluminium frames and mounts have to be replaced by polymer-made frames shown in Figure 2.10 (Sahu, Yadav and Sudhakar, 2016). A solar charge controller acts as a voltage or current regulator, similar to the land-based solar system, to prevent the batteries from overcharging. An inverter is another essential device in the solar PV system as it converts the DC energy generated from PV modules into AC energy, which is applicable for electricity usage. According to the water bodies' environment, the inverters can be located either on the land or on the floating platform. The substation is also necessary to step up or step down the voltage to the distribution level using transformers to be fed into the grid.

Figure 2.10: Polymer non-corrosive frame (Dricus, 2015)

2.2.4 Cables and connection

The cables transfer the electricity from the PV array to the land. In FSPV, the cable connection must be planned more cautiously than the ground-based solar system. The floating platform might move due to the strong wind and changes in the water level. Hence, an extra length should be provided in the form of slack for the floating platform's movement. The cables in the FSPV system can be categorised into DC cables and AC cables. For DC cables, the copper wires should be highly resistant to corrosion. However, if the cables are encased in a waterproof module junction box and are not in contact with water, regular DC cables are applicable. Also, the AC cables should be resistant to high temperatures and bad weather. There are two options for the cable routes. First, the regular DC or AC cable can be lifted by floats on the water surface. Next, the cables can be submerged through submarine cables, but this method is more expensive (TERI, 2019).

2.2.5 Installation

The installation process of FSPV is more straightforward in terms of construction because the building of mounting or supporting structures as in a ground-mounted PV system is not required. The floating platform used in FSPV is modular and prefabricated, so only the interconnection is needed to form a larger segment. The floating platforms are usually assembled on land and are pushed into the water when additional rows are added, as shown in Figure 2.11. After the assembly is completed, the whole platform is pulled to the exact location by boats. Hence, the deployment process usually takes a shorter time as a comparison to the ground-mound PV system. For instance, a China leading FSPV developer has reported that a 1 MWp FSPV system can be installed in one day by 50 people (World Bank Group, ESMAP and SERIS, 2019).

Figure 2.11: Deployment ramp (World Bank Group, ESMAP and SERIS, 2019)

2.3 Advantages of floating solar technology

The benefits of the floating solar technology are listed as following with detailed description and explanation.

2.3.1 Increased energy efficiency

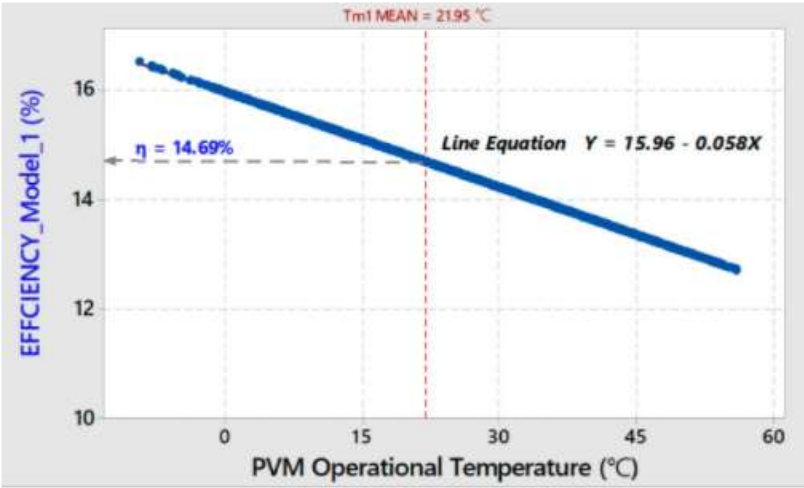

Figure 2.12 Graph of efficiency against the photovoltaic module operational temperature (Charles Lawrence et al., 2018)

The solar PV array's energy yield is highly dependent on the solar cell temperature and ambient temperature. Temperature is the primary factor that contributes to thermal power losses. From Figure 2.12, the efficiency of the PV module decreases linearly with its operational temperature. This research done by Charles Lawrence et al. (2018) shows that the floating solar system has a higher efficiency by 14.69 % based on an averaged module temperature of 21.95 °C. Another study carried out by International Energy Agency shows that the energy losses related to temperature can vary between 1.7 % at 29 °C to 11.3 % at 51 °C (Nordmann and Clavadetscher, 2003). Due to the water's cooling effect, the ambient temperature and the PV module temperature decreases. The wind speed above the water is higher than the land, resulting in cooling the module. Therefore, the thermal losses of FSPV are lower. From this aspect, the floating panels' life span is also extended compared to the ground-based solar system. Also, the usage of aluminium frames, which acts as the mounting structure of the floatovoltaics, can further increase the efficiency by transferring the cooler temperature on the water surface to the solar cell (Manoj Kumar, Kanchikere and Mallikarjun, 2018). Some earlier floating solar projects have reported an increased efficiency by more than 10 % by comparing to the land-based solar system (Choi, Lee and Kim, 2013). There is also less shading and soiling effect in the FSPV system, further increasing the energy yield.

2.3.2 Land conservation

Since the FSPV systems are located on the water bodies, it does not require any land space. This benefit is essential for some countries whereby there is a lack of land resources and limited roof space, such as Singapore and Japan. More land space can be utilised for agricultural and industrial activities, which are significant, especially in developing countries, namely India, Thailand, and Malaysia. Meanwhile, the land cost escalates due to decreased land availability, increasing the levelized tariff of electricity. Thus, FSPV also reduces an enormous burden by saving high land costs. A techno-economic feasibility study regarding a 10 MW FSPV plant shows that it has saved a land cost up to USD 352125 and reduce the levelized tariff to USD 0.026kWh, which is lesser than the land-based PV system by 39% (Goswami et al., 2019).

2.3.3 Reduced water evaporation

The installation of FSPV causes shading area on the water surface, leading to a temperature drop of the water. By implementing FSPV on the water reservoirs, it can reduce the water loss through evaporation. In the 2017 International Floating Solar Symposium, there is a speech by Professor Eicke Weber, which declares that the amount of water evaporation from the reservoirs is larger than the human water consumption. Since the water loss on the reservoirs is equivalent to a revenue loss, water evaporation reduction benefits the population by reducing lost income and saving drinking water (Riding the wave of solar energy: Why floating solar installations are a positive step for energy generation, 2018). Besides, Singapore’s National Water Agency PUB has planned to launch a 50 MW floating solar plant on the Tengeh reservoir (Renewables Now, 2019) and this floating solar will be operated by 2021.

2.3.4 Improved water quality

FSPV plants can improve water quality by inhibiting algae growth. The algae growth is mainly depending on the light intensity and water temperature. By having PV panels on the water surface, they prevent the sunlight from reaching the water surface, preventing the algae growth.

2.3.5 Complementary operation with hydropower

The FSPV plants can be integrated with the hydropower stations to enhance the power generation. The energy yield of the hydropower plant decreases during the dry seasons because the water level drops. Meanwhile, the output of the FSPV plant is intermittent due to the inconsistent solar irradiance. Hence, by combining FSPV with the existing hydropower plants, the power production variations are reduced, and the power quality is improved. This hybrid system's diurnal cycle can be optimized by having more solar power during the day and more hydropower during the night time. The skilled staff at the hydropower site and the data acquisition systems for existing hydropower plants can be utilized for the newly built FSPV system. The nearby grid connections of the hydropower plants can also link the FSPV to the grid, reducing the electrical infrastructure's investment cost (World Bank Group, ESMAP and SERIS, 2019).

2.4 Image processing techniques for calculation of irregular area

Several image processing techniques are studied and analyzed to be applied in the lake area calculation in this project.

2.4.1 Monte Carlo simulation and image segmentation

Monte Carlo methods are primarily applied in solving mathematical problems that involve several independent variables whereby plenty of memory and time is needed for calculation through conventional methods. This method mainly uses random samples of parameters to determine a complicated process; thus, it is usually applied when it is impossible to calculate an exact solution. Therefore, this Monte Carlo simulation can be utilised to approximate irregular area, such as a lake. The procedures are listed as the following:

1) The irregular area is surrounded by a specified shape, namely rectangle, triangle, or circle. Therefore, an appropriate shape is selected to confine the interested region.
2) The individual point or input is scattered within the interested area.

3) Computation is performed on each input and later verify if the input is within the irregular region or not.
4) The results of each input are combined at the end to obtain the estimation of the irregular area.

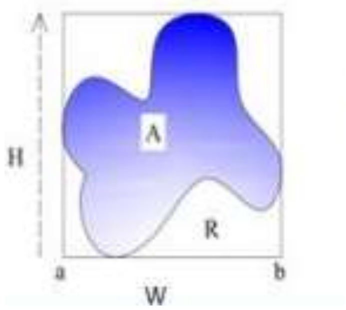

Figure 2.13: Irregular area surrounded by rectangular shape (Obaid et al., 2016)

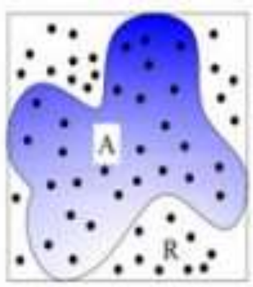

Figure 2.14: Irregular area with darts (Obaid et al., 2016)

By considering an irregular shape image, the blue lake area, A, is bounded by a white rectangle, R, as shown in Figure 2.13. By going through Monte Carlo simulation, N black darts are spread randomly in a known area of $(H \times W)$ as shown in Figure 2.14. H is known as the height of the image, while W is the width of the image. Assume K is the number of circle dots that are found within the lake. By considering one dart in each pixel, the lake area is expressed in Eq 2.1 (Obaid et al., 2016).

$$Lake\ area, A = \frac{K}{N}R \tag{2.1}$$

Scanned image analysis is needed in this method to differentiate the desired objects from the background. An algorithm using the Visual Basic program was created by Obaid et al. in 2016 to predict the scanned image area. The program takes in an image and converts into matrix form according to a given input threshold. The RGB values of each pixel are extracted to be saved into a new matrix. The RGB values in each segmented image and the percentage area covered by a specified color are computed. This method is suitable for mapping any changes in land in general but not in a particular way (Obaid et al., 2016).

2.4.2 Green's Theorem

The area of an irregular region can be calculated through Green's Theorem. By taking a triangle, as shown in Figure 2.15, the area of the triangle can be expressed as the Eq 2.2:

Let T_1 = trapezoid with vertices $(x_1, y_1), (x_2, y_2), (x_2, 0)\ and\ (x_2, 0)$,

T_2 = trapezoid with vertices $(x_2, y_2), (x_3, y_3), (x_3, 0)\ and\ (x_2, 0)$,

T_3 = trapezoid with vertices $(x_1, y_1), (x_3, y_3), (x_3, 0)\ and\ (x_1, 0)$,

$$Area = T_1 + T_2 - T_3$$

$$= \frac{1}{2}(y_1 + y_2)(x_2 - x_1) + \frac{1}{2}(y_2 + y_3)(x_3 - x_2) + \frac{1}{2}(y_3 + y_1)(x_1 - x_3)$$

$$= -\frac{1}{2}(x_2y_3 - x_3y_2 - x_1y_3 + x_3y_1 + x_1y_2 - x_2y_1)$$

$$= -\frac{1}{2}\begin{vmatrix} x_1 & y_1 & 1 \\ x_2 & y_2 & 1 \\ x_3 & y_3 & 1 \end{vmatrix} \tag{2.2}$$

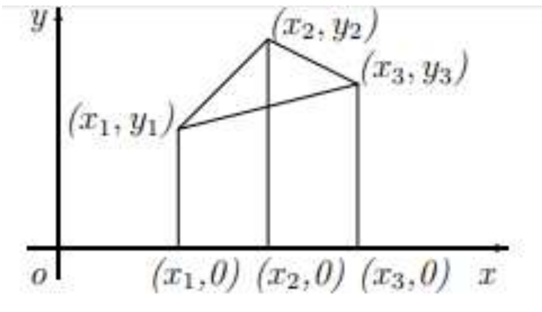

Figure 2.15: A polygon with three vertices (Davis and Raianu, 2007)

Hence, the area of a polygon with vertices of $(x_1, y_1), (x_2, y_2), \ldots, (x_n, y_n)$ in clockwise orientation can be derived as:

$$Area = \frac{1}{2}\sum_{i=1}^{n-1}(y_i + y_{i+1})\,(x_{i+1} - x_i) \tag{2.3}$$

Moreover, the area's formula stated in Eq 2.3 is a variation of the well known Shoelace formula or Surveyor's Formula in which the area can be expressed as:

$$Area = \frac{1}{2}\sum_{i=1}^{n-1}\begin{vmatrix} x_i & y_i \\ x_{i+1} & y_{i+1} \end{vmatrix} \tag{2.4}$$

Davis and Rainu (2007) created a software planimeter to show the application of Green's Theorem. The program allows the user to upload an image file and set the scale. Then, the user has to trace an enclosed region of the image by using a mouse. The program then applies the Green's Theorem to the points obtained from the traced region, and the value of the areas calculated is then shown to the user. The interpolating algorithms cannot improve the accuracy of results obtained by using this program created. Besides, the accuracy is highly dependent on the image accuracy and user's hand-eye coordination (Davis and Raianu, 2007).

2.4.3 Colour, contour,and shape detection using Open CV-Python

In 1999, Intel launched an Open Computer Vision Library (Open CV). Many upgrades have been carried out for modifications to obtain a real-time computer vision. This library is written under C and C++ programming languages but can and can be interfaced with other programming languages easily, namely MATLAB, Ruby and Python, etc.

This method requires the installation of Python software and Python modules, such as and Matplotlib. First of all, the image is read using a predefined function in Python, which is CV2.imread(). Several functions, such as imread_color, imread_unchanged, and imread_grayscale, are also applicable. The functions used to process the image consist of loading the image, detect the shapes and colours inside the loaded image. It is widely used in object detection applications, namely face recognition, accounting number of objects, and automobile spotting (Puri and Gupta, 2018). Figure 2.16 has clearly stated the steps for shape and colour detection in which shape detection employs contour detection while colour detection employs pixel detection. For identifying the lake area, colour detection is preferred as the lake’s shape differs from one another. Meanwhile, the colour of the lake on the map is more consistent.

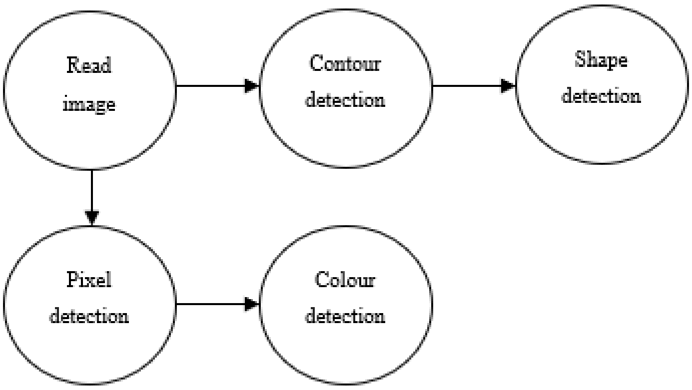

Figure 2.16: Simple flowchart of shape and colour detection (Puri and Gupta, 2018)

CHAPTER 3

METHODOLOGY AND WORK PLAN

3.1 General flow of the methodology

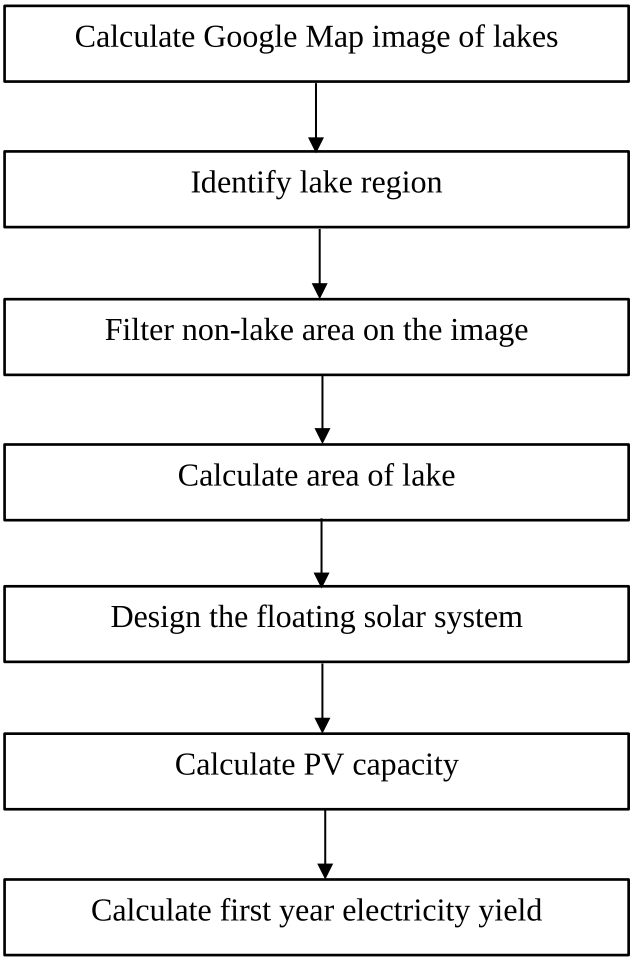

Figure 3.1: Simple flowchart of the work plan

Figure 3.1 shows a simple flow of the project's work plan. The first step is to capture all the lakes in Selangor by using Google Map API key. The zoom level, latitude, and longitude of the Google Map image are also adjusted in Python to obtain a clear view of the lake. Next, all the lakes' images are processed in Python by using pixel and colour detection. The other water bodies on the image, such as the river, are filtered out. The area of the lake is then calculated by converting the unit from pixel to metre or kilometre. The floating solar system is designed by considering several factors, such solar panels' dimension, number of panels per string and gaps between solar panels. The number of panels installed on the lake is then calculated by assuming a reasonable lake utilization rate. The annual electricity yield generated from the floating solar plant on each lake is then calculated using the related formula. Lastly, the first-year electricity yield generated from the floating solar plant on the lakes is calculated.

3.2 Capture lake image

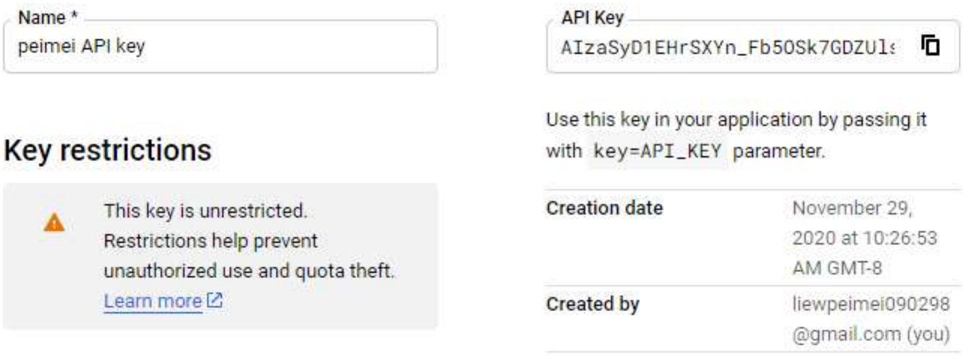

Figure 3.2: Generated API key

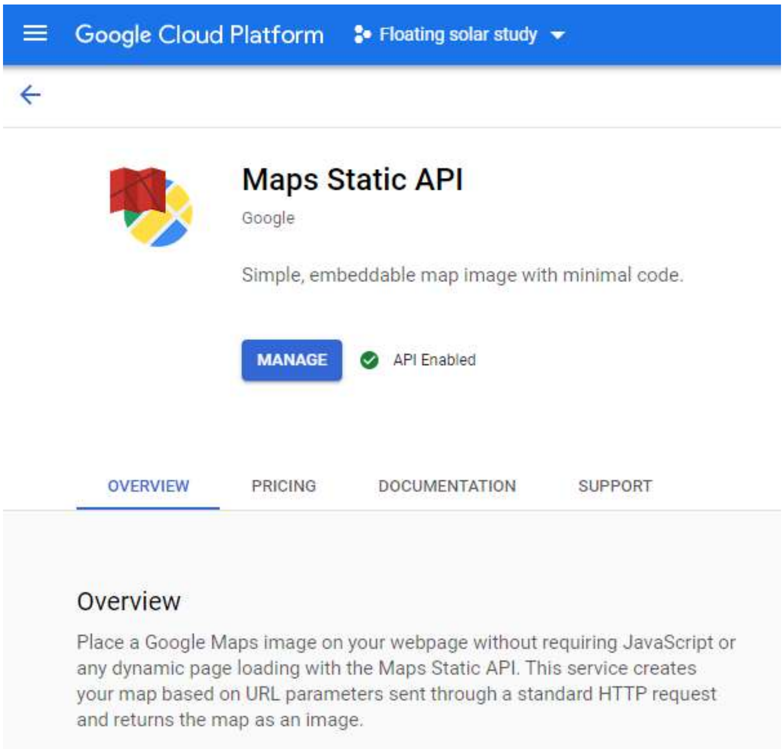

Figure 3.3: Enabled Maps Static API

First of all, a Google API key is generated in Google Cloud Console, as shown in Figure 3.2, to allow access with Google Services. The Maps Static API is then enabled in the platform, as shown in Figure 3.3, to authenticate the request of the Google Map image. For every request of the lake image, the lake's location, the size of the image and zoom level are stated clearly in the URL encoding.

3.3 Detect water region, filter non-lake area and calculate lake area

After capturing all the lake images, some image processing techniques are applied to identify the lake's landscape and calculate the lakes' area with scaling factors.

The image processing of the Google Map image can be performed by using contours in OpenCV of Python. Contours are a curve connecting all the continuous points that have the same colour or intensity. Since the lake area is in a constant blue colour, the lake area can be identified easily using this OpenCV module.

First, the dependencies and necessary modules are installed and inserted in Python IDLE, such as cv2 and NumPy. The steps are listed down as follows:

1) Read the map image by using cv2.imread() function.
2) Convert the image into a binary image in which every pixel of the image is in black or white colour. The binary image is mandatory in OpenCV because finding contours is the same as finding a white object from a black background. The desired object must be in white while the background is in black. In this project, the RGB pixel value of the lake area is (170, 218, 255). Since the imread() function by default interprets the image in BGR format, the pixel intensity value is then written as (255, 218, 170). An upper and lower range of this value is also specified to allow all the pixels that fall within this range are identified and converted into white pixels.
3) Some of the lake images might consist of other water bodies. Hence, these non-lake area is filtered out by using scikit-image module in Python. The theory behind this is to extract the largest water body, which is the lake. The small water region, like the river, is then

filtered. Besides, some lake area is made up of several regions; thus the number of regions to be extracted from the image can also be specified in the code.

4) After obtaining the desired lake region in the image, the number of white pixels is counted using the countNonZero() function. The total number of white pixels is equivalent to the lake area in unit pixels.

5) The lake area is then converted into unit metre by determining the metre per pixel. The size of one pixel in unit metre is calculated by using the Eq 3.1 below. This formula is based on the assumption that the earth's radius is 6378137 m.

$$metre\ per\ pixel = 156543.03392 \times \frac{\cos\left(\frac{latitude\ of\ lake \times \pi}{180}\right)}{2^{zoom\ level}} \quad (3.1)$$

6) The lake area in unit metre is then calculated by using the Eq 3.2 below.

$$lake\ area = number\ of\ white\ pixels \times metre\ per\ pixel \quad (3.2)$$

3.4 Calculation of PV capacity and annual electricity yield

After obtaining the area of lakes available in Selangor, the number of solar panels on the lakes is then determined. Hence, the number of rows and columns of solar panels is estimated by measuring the lakes' width and lakes' length. It is done by looping rows and columns of the pixels in the lake image. For each row, the number of white pixels is counted and converted into the unit metre to determine the lake's width, if there is any. The lake's width is then used to calculate the number of strings of solar panels that can be fit into it. After calculating the number of panels for the first row, the calculation proceeds to the consecutive rows of the entire lake region. The total number of solar panels for each row is summed up to calculate the PV capacity and annual electricity yield. Some gaps between the adjacent solar panels in the same row and the adjacent rows of solar panels are also considered. The calculation for the number of strings of solar panels in the same row is shown in Eq 3.3 and Eq 3.4 below.

$$w_{lake_i} = p \times mp \quad (3.3)$$

$$(n \times w_{panel}) + ((n+1) \times g) < w_{lake_i}, \ i = 1,2,3 \ldots \quad (3.4)$$

$$s = \frac{n}{a} \quad (3.5)$$

where

$a = number\ of\ solar\ panels\ per\ string$

$g = gap\ between\ adjacent\ solar\ panel, m$

$mp = metre\ per\ pixel, m$

$n = number\ of\ solar\ panels$

$p = number\ of\ blue\ pixels$

$s = number\ of\ strings\ of\ solar\ panels$

$w_{panel} = width\ of\ solar\ panel, m$

$w_{lake_i} = width\ of\ the\ lake\ at\ specific\ scanning\ row\ i, m$

Note: n+1 due to the gap considered at both ends of solar panels in the same row

After calculating for the first row of solar panels with respect to the lake width, the algorithm
m proceeds to the consecutive rows of the lake region. Since there is a gap between the adjacent rows of solar panels, this gap is then converted into the unit pixel to calculate the string numbers of solar panels for the next row. The distance between two consecutive rows is calculated as shown in Eq 3.6. Then, the y-coordinate of the next row is calculated by using Eq 3.7. An example is shown below.

$$d = l + g \quad (3.6)$$

$$y2 = y1 + \frac{d}{mp} \quad (3.7)$$

Assume:

$mp = metre\ per\ pixel, m$

$l = length\ of\ solar\ panel, m$

$g = gap\ between\ rows\ of\ solar\ panel, m$

$y1 = y - coordinate\ of\ the\ initial\ row\ of\ solar\ panels, pixel$

$y2 = y - coordinate\ of\ the\ next\ row\ of\ solar\ panels, pixel$

$d = pitch = total\ distance\ between\ the\ two\ adjacent\ rows, m$

When the number of strings of solar panels for each row is calculated, the result is recorded to determine the respective lake's PV capacity and annual electricity yield. According to Dr Lim Boon Han, the performance ratio of solar system in Malaysia is ranged from 80 % to 85 % and the peak sun hours in Malaysia is around 1600 hours for a year. Hence, the performance ratio is set as 80 % and the peak sun hours for a year is set as 1600 hours in this study. The PV capacity and the first-year electricity yield are calculated using Eq 3.8 and Eq 3.9.

$$PV = \frac{(s \times n) \times P}{1 \times 10^6} \tag{3.8}$$

$$E = PV \times PSH \times PR \tag{3.9}$$

where

$E = First - year\ electricity\ generation, MWh$

$PV = PV\ capacity, MW$

$s = total\ number\ of\ strings$

$n = number\ of\ solar\ panels\ per\ string$

$P = rated\ power\ per\ panel, W$

$PSH = Peak\ Sun\ Hours, hours$

$PR = Performance\ Ratio$

After that, the annual electricity yield from each floating solar PV plant on each lake in Selangor is summed up at the end to determine whether the investment in floating solar is worthy or not. Meanwhile, the lake utilisation rate is calculated to ensure it is less than 50 % to maintain a healthy ecosystem of all the lakes. Since the lake area and the number of solar panels have been determined in the previous steps, the lake utilization rate is computed using the Eq 3.10 below. The specifications of the solar panels such as the size and rated power are referred to Appendix D-1. The solar panels' width and length in this study are assumed to be 1.7 m and 1 m which are slightly higher than the value in Appendix D-1 to include the area covered by the pontoons or floats. Meanwhile, the structure of the floating system for this project is shown in Appendix D-2, Appendix D-3 and Appendix D-4 (Lee, Joo and Yoon, 2014). This system consists of Fiber-reinforced Polymer (FRP) material which results in lesser number of buoys and lower volume immersed in the water bodies (Kim, Yoon and Choi, 2017). However, the exact dimension of the floating structure is not included in this study; thus, the lake utilization rate calculated is an estimation.

$$L = \frac{N \times w \times l}{A} \times 100 \qquad (3.10)$$

where

$A = lake\ area, m$

$L = lake\ utilisation\ rate, \%$

$N = number\ of\ solar\ panels$

$w = width\ of\ solar\ panel, m$

$l = length\ of\ solar\ panel, m$

The default image retrieved from the Google Cloud Platform has the north direction pointing to the top, as shown in Figure 3.4. The algorithm calculates the PV capacity from top left to top right; thus, the solar panel is installed from north to south by default. For comparison, the lake image is rotated to calculate the PV capacity in different directions, such as from south to north, from west to east and from east to west. This is to determine whether solar panels' arrangement by different facing directions affects the PV capacity calculated.

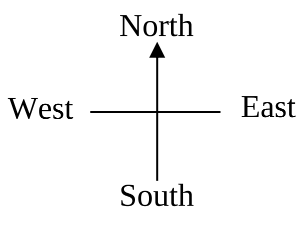

Figure 3.4: Default image direction

3.5 Verification of result

Several samples of lake images with a known size are created to go through the Python algorithm. Three different shapes of lakes, such as rectangle, t-shape and triangle, are created. All these shapes are created by stating a specified height and width. For instance, the rectangle is created by stating a width of 200 pixels and a height of 300 pixels. By controlling the input lake size, the PV capacity, annual electricity yield and lake utilization rate are also manually calculated to compare with the result from Python algorithm.

3.6 Work plan and Gantt Chart

3.6.1 Work plan

Table 3.1: Work plan with tasks and deadline

Category	Activities	Estimated completion date
Identify project scope and goals	-Identify the goals of the project. -Define the project scope and list out all the activities to achieve the goals.	28th June 2020
Research on floating solar and python coding	-Research on the basic theory and concept of floating solar. -Research on the python coding to calculate the area of lakes on google map.	21th August 2020
Preliminary testing on python coding	-Progress report writing. -Determine methods to calculate the area of lakes, estimate the PV capacity and energy yield. -Preliminary testing or investigation for calculation of lakes' area using python.	13th September 2020
Capture map images	-Save the map images of the lakes in Selangor	22th January 2021

	-Record the longitude, latitude and zoom level of the image retrieved for calculation later.	
Calculate area and number of strings	-Compute the area, number of strings of solar panels and the lake utilization rate. -Verify the result through control input and manual calculation.	26th February 2021
Calculate annual electricity yield	-Calculate and record the annual electricity generated for the lakes in Selangor.	5th March 2021
Trobleshoot and further enhancement	-Troubleshoot if there is any problem. -A further enhancement is done if necessary.	20 th March 2021
Final report and presentation	-Final report writing and preparation for presentation slides. -Complete final report submission and oral presentation of the project.	19 th April 2021

3.6.2 Gantt Chart

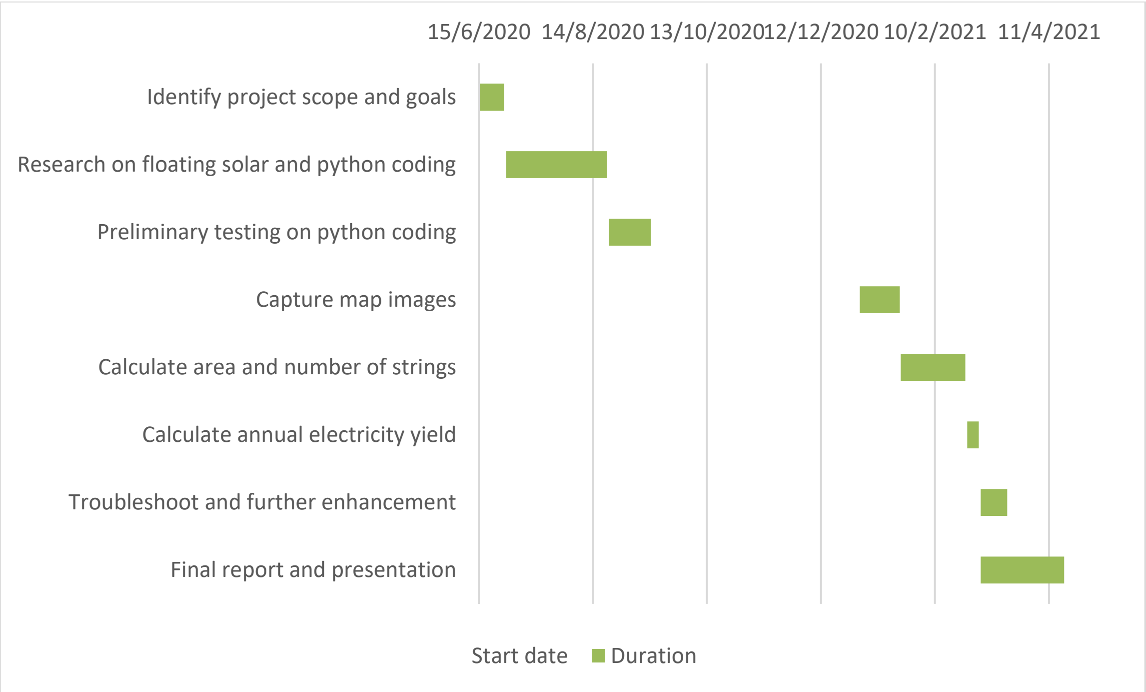

Figure 3.5: Gantt Chart of the project

Table 3.2: Duration of each project phase

Semester		Start date	End date	Duration(days)
1	Identify project scope and goals	15/6/2020	28/6/2020	13
	Research on floating solar and python coding	29/6/2020	21/8/2020	53
	Preliminary testing on python coding	22/8/2020	13/9/2020	22
2	Capture map images	1/1/2021	22/1/2021	21
	Calculate area and number of strings	23/1/2021	26/2/2021	34
	Calculate annual electricity yield	27/2/2021	5/3/2021	6
	Troubleshoot and further enhancement	6/3/2021	20/3/2021	14
	Final report and presentation	6/3/2021	19/4/2021	44

CHAPTER 4

RESULTS AND DISCUSSION

The results and discussion are divided into several sections according to the stage of project implementation. Firstly, the list of lake images is shown. The zoom level and Earth coordinate to capture the images are also illustrated. After applying image processing techniques such as contour and filtration, the processed images are displayed to compare with the original images. The lake area, PV capacity, and first-year electricity yield are also presented. The criteria of the floating solar system designed are stated, such as the solar panels' dimension and the gaps between the solar panels. Besides, all the Python codes written to obtain the results are also illustrated.

4.1 Captured lake image and identified lake region

```
# Python program to get a google map
# image of specified location using
# Google Static Maps API

# importing required modules
import requests

# Enter your api key here
api_key = "AIzaSyDlEHrSXYn_Fb5OSk7GDZUlsSDiGYxDy3o"

# url variable store url
url = "https://maps.googleapis.com/maps/api/staticmap?"

# center defines the center of the map
# equidistant from all edges of the map.
center = "3.024235,101.515225"

# zoom defines the zoom
# level of the map
zoom = 17

# get method of requests module
# return response object
r = requests.get(url + "center=" + center + "&zoom=" +str(zoom) + "&style=featur
e:all|element:labels|visibility:off&style=fillcolor:0xFFFF0033&size=500x500&key=
" +api_key)

# wb mode is stand for write binary mode
f = open(center+'.png', 'wb')

# r.content gives content,
# in this case gives image
f.write(r.content)

# close method of file object
# save and close the file
f.close()
```

Figure 4.1: Code snippet to retrieve and save lake image

The piece of code to capture and save the lake image is created as shown in Figure 4.1. A total of 58 lake images have been retrieved and saved, as shown in Appendix A. All the images taken are of type road map instead of the satellite map. The lake colour on the satellite map is mainly green due to the high nutrients and algae growth. This green colour is similar to the other green landscape, such as trees, and the green colour does not constant due to the reflection of sunlight on the water surface, as shown in Figure 4.2. Hence, the road map type of lake image is preferred in this project. For Putrajaya Lake, it is divided into two images so that a zoom level of 14 can be used for image retrieval. Therefore, the total number of lakes involved in this project is 57. Some regions have more than one lake: Cyberjaya, Shah Alam, and Bandar Bukit Raja; thus, these lakes are differentiated by naming it with numbers such as Cyberjaya Lake 1 and Cyberjaya Lake 2.

In this project, the minimum zoom level is 14, while the maximum zoom level is 19. The zoom level is maximized throughout the image retrieval process because the higher the zoom level, the smaller the distance represented by every pixel in the image, resulting in higher accuracy. For instance, when the lake width is 15 m and the zoom level is 14 with a pixel value of 9 m, two pixels each with a value of 18 m represent the lake width. Meanwhile, if the zoom level of 15 is applied, three pixels with each value of 5 m are displayed, resulting in a lake width of 15 m which is closer to the real value. It happens because the pixel is the smallest unit that can display on the screen, so it cannot be shown as a fractional part.

Two methods have been used to state the centre of the image, such as the lake’s name and the lake’s earth coordinates. However, some lake areas might be truncated when the centre is written as the lake’s name. As shown in Figure 4.4, the lake’s bottom area is cropped when the centre is stated as "tasikpb". It happens because the centre will be assumed as the red mark, as shown in Figure 4.3, causing the lake to be non-centred in the map image. Hence, the earth coordinates are preferred to ensure all the lakes can be centred in the map images. The longitude and latitude are recorded by clicking on the lake’s centre on the Google Map website. Next, a grey mark and a small window that contains the longitude and latitude of the grey mark will appear, as shown in

Figure 4.3. Therefore, the lake is now centred on the image retrieved, as shown in Figure 4.5.

Figure 4.2: Satellite map image

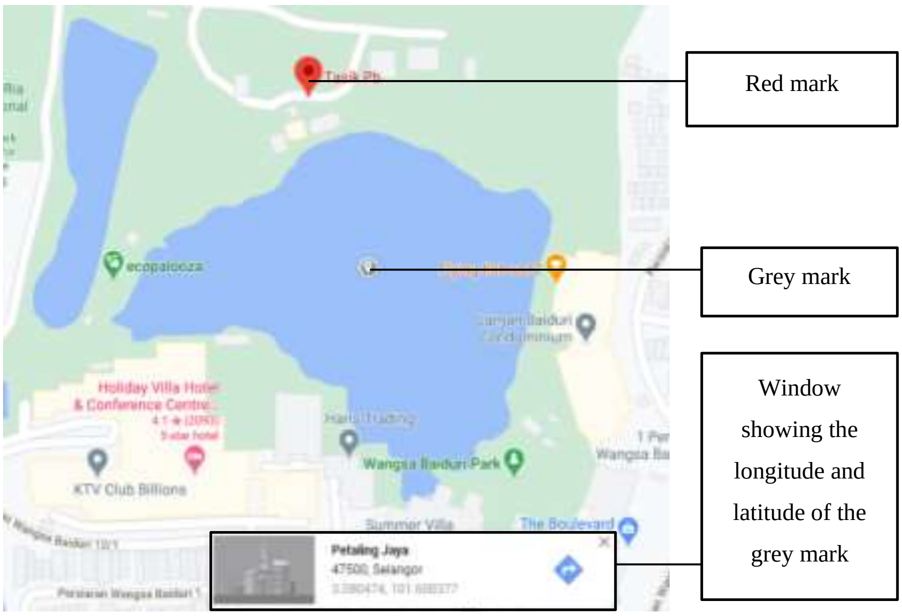

Figure 4.3: Record latitude and longitude of the lake centre

Figure 4.4: Truncated lake image when centre is written in terms of lake's name

Figure 4.5: Image obtained when centre is written in terms of longitude and latitude

All the labels on the map image are also removed by turning off their visibility in URL encoding. This prevents the wordings or marks on the usual map image from covering some lake area and further decreasing the accuracy. The zoom level and Earth coordinates are recorded and listed in Table 4.1 to calculate metres per pixel.

Table 4.1: Zoom level and coordinates of lakes in Selangor

Lake	Zoom level	Coordinates
Batu Dam	15	(3.283125,101.687703)
Klang Gates Dam	14	(3.247476,101.765675)
Semenyih Dam	14	(3.090539,101.897689)
Sungai Langat Dam	15	(3.211325,101.897001)
Alam Impian Lake	17	(3.024235,101.515225)
Aman Lake	18	(3.102837,101.625582)
Ampang Hilir Lake	17	(3.154256,101.744588)
Bandar Bukit Raja Lake 1	17	(3.085265,101.435051)
Bandar Bukit Raja Lake 2	17	(3.089374,101.434889)
Bandar Tun Hussein Onn Lake	17	(3.044636,101.761075)
Bersatu Lake	18	(3.308465,101.581862)
Beruang Bbsa Lake	16	(3.105551,101.486462)
Biru Seri Kundang Lake	16	(3.250284,101.525813)
Cempaka Lake	17	(2.959923,101.759818)
Cyberjaya Lake 1	17	(2.937110,101.642115)
Cyberjaya Lake 2	16	(2.937027,101.647474)
D' Island Lake	16	(2.964999,101.602333)
D' Kayangan Lake	19	(3.075213,101.541084)
Fasa 1L Lake	18	(2.908946,101.873467)
Indah Mewah Lake	16	(3.222288,101.676388)
Kebun Serendah Lake	17	(3.357507,101.616679)
Kelana Lake	17	(3.094793,101.597364)
Kelana Jaya Lake	16	(3.100731,101.596002)
Kiambang Serendah Lake	16	(3.377551,101.620652)
Kota Kemuning Lake	17	(3.001150,101.537512)
Kota Puteri Lake	17	(3.304229,101.436134)
Metropolitan Kepong Lake	16	(3.224439,101.646290)
Millennium Lake	16	(3.543516,101.671109)
Pb Lake	17	(3.080464,101.600434)
Perdana Lake	17	(3.141786,101.684708)
Prima Lake	15	(2.993269,101.602108)

Putrajaya Lake Part 1	14	(2.911117,101.682602)
Putrajaya Lake Part 2	14	(2.943847,101.695160)
Putra Perdana Lake	15	(2.954036,101.609220)
Residency Lake	15	(2.962581,101.590591)
Saujana Lake	18	(3.107370,101.577289)
Saujana Putra Lake	15	(2.945203,101.577110)
Seksyen 7 Lake	17	(3.077188,101.491932)
Semenyih Lake	16	(2.948359,101.861321)
Seri Aman Lake	17	(2.984084,101.584794)
Seri Serdang Lake	18	(3.004733,101.714276)
Serumpun Lake	19	(2.993416,101.715516)
Shah Alam Lake 1	17	(3.072088,101.514178)
Shah Alam Lake 2	17	(3.075928,101.516112)
Shah Alam Lake 3	18	(3.076252,101.520003)
Southlake Residence Lake	17	(3.067925,101.710795)
Sri Murni Lake	16	(3.235957,101.665081)
Sri Rampai Lake	17	(3.194879,101.728220)
Subang Dam	15	(3.175755,101.486245)
Sunway Lake 1	17	(3.062820,101.603509)
Sunway Lake 2	18	(3.069170,101.607232)
Sunway Serene Lake	17	(3.088246,101.605972)
Taman Dengkil Jaya Lake	17	(2.877000,101.672000)
Taman Subang Ria Lake	17	(3.082241,101.595698)
Teratai Lake 1	16	(2.938498,101.599512)
Teratai Lake 2	16	(2.930059,101.604933)
The Mines Lake	15	(3.035740,101.712057)
Titiwangsa Lake	16	(3.178547,101.707634)

```
img = cv2.imread(orifile)
head,tail = os.path.split(orifile)


img_hsv = cv2.cvtColor(img, cv2.COLOR_BGR2HSV)

BGR = np.array([255, 218, 170])
upper = BGR + 10
lower = BGR - 10

def find_mask(img):
    return cv2.inRange(img, lower, upper)

mask = find_mask(img)
cv2.imshow("Contour", mask)
```

Figure 4.6: Code snippet to convert the original map image into binary image

```
#find the largest water area on the image
labels_mask = measure.label(mask)
regions = measure.regionprops(labels_mask)
regions.sort(key=lambda x: x.area, reverse=True)
if len(regions) > 1:
    for rg in regions[1:]:  #the value 1 = one largest region
        labels_mask[rg.coords[:,0], rg.coords[:,1]] = 0
labels_mask[labels_mask!=0] = 1
mask = labels_mask

#convert and save the image
mask = 255 * (mask - mask.min()) / (mask.max() - mask.min())
mask = np.array(mask)
mask = mask.astype(np.float)
```

Figure 4.7: Code snippet to filter out non-lake regions

The code to convert the original map image into the binary image is created, as shown in Figure 4.6. The water region is successfully differentiated from the land region. However, it is found out that some map images have other water bodies, such as a river, as shown in Figure 4.8, which results in an inaccurate value of the lake area. Therefore, another piece of code is written, as shown in Figure 4.7, to remove the non-lake area to increase the accuracy. The area’s filtration is carried out by remaining the selected number of the largest area in the image. Hence, some lake area that is not suitable for the installation of solar panels is also eliminated. For instance, the middle part of Titiwangsa Lake is not suited for panel installation, as shown in Figure 4.8; thus, it is excluded and is ready for the calculation now, as shown in Figure 4.9. However, it is only applicable to the lake divided into parts readily once the image is retrieved from Google Maps. After converting the image into binary form and removing the non-lake area, the 58 resulting lake images are shown in Appendix B.

Figure 4.8: Lake Titiwangsa before image processing

Figure 4.9: Lake Titiwangsa after image processing

4.2 Lake area

```
#count white pixels and convert to real scale to calculate the lake area
pixels = cv2.countNonZero(mask)
print('the number of blue pixels is: ', pixels)
metre_per_pixels = 156543.03392*Math.cos(latitude*Math.pi/180)/Math.pow(2,zoom_level)
print('the metre per pixel is ', metre_per_pixels)
lake_area = (metre_per_pixels*metre_per_pixels)*pixels
print('the area is: ', lake_area ,'metre square')
```

Figure 4.10: Code snippet to calculate the lake area

Table 4.2 shows the area of lakes in Selangor. These lake areas are calculated by using the code written as shown in Figure 4.10. The area calculation depends on the number of white pixels and the pixels per metre. When the zoom level is constant, the larger the number of pixels, the larger the lake area. When the zoom level increases, the pixels per metre also increase, resulting in a larger area. The total lake area for the 57 lakes in Selangor is $25753279\ m^2$. Semenyih Dam has the largest lake area which is $3447047\ m^2$, while the Fasa 1L lake has the smallest lake area which is $3799\ m^2$.

Table 4.2: Area of the lakes in Selangor

Lake	Number of Pixels	Pixels per metre	Area/m^2
Batu Dam	100379	4.769473392	2283409
Klang Gates Dam	24675	9.539285398	2245375
Semenyih Dam	37869	9.540732155	3447047
Sungai Langat Dam	88353	4.769812504	2010129
Alam Impian Lake	27431	1.192665235	39019
Aman Lake	52274	0.596288835	18587
Ampang Hilir Lake	80556	1.192519175	114559
Bandar Bukit Raja Lake 1	40866	1.192597441	58123
Bandar Bukit Raja Lake 2	36539	1.192592828	51969
Bandar Tun Hussein Onn Lake	33618	1.192642724	47818
Bersatu Lake	43089	0.59616899	15314
Beruang Bbsa Lake	18588	2.385149215	105746

Biru Seri Kundang Lake	47781	2.384814715	271747
Cempaka Lake	36273	1.192735211	51603
Cyberjaya Lake 1	53542	1.192759672	76173
Cyberjaya Lake 2	38960	2.385519521	221710
D' Island Lake	130015	2.385459485	739840
D' Kayangan Lake	83339	0.298152175	7408
Fasa 1L Lake	10682	0.596394805	3799
Indah Mewah Lake	106713	2.384880605	606947
Kebun Serendah Lake	22129	1.192278547	31457
Kelana Lake	45018	1.192586735	64027
Kelana Jaya Lake	12995	2.385160093	73928
Kiambang Serendah Lake	42395	2.384508008	241053
Kota Kemuning Lake	49272	1.192690526	70090
Kota Puteri Lake	51550	1.192343073	73288
Metropolitan Kepong Lake	79155	2.384875563	450204
Millennium Lake	31917	2.384090366	181413
Pb Lake	45513	1.192602824	64733
Perdana Lake	26345	1.192533449	37466
Prima Lake	49953	4.770796464	1136955
Putrajaya Lake Part 1	28187	9.542298497	2566580
Putrajaya Lake Part 2	16082	9.542019743	1464268
Putra Perdana Lake	82763	4.770966165	1883861
Residency Lake	34243	4.770929395	779431
Saujana Lake	46244	0.596286276	16442
Saujana Putra Lake	36141	4.771004064	822659
Seksyen 7 Lake	62960	1.192606491	89549
Semenyih Lake	9370	2.385495268	53321
Seri Aman Lake	99813	1.192709099	141989
Seri Serdang Lake	48642	0.596343307	17298
Serumpun Lake	52797	0.298174739	4694
Shah Alam Lake 1	61279	1.192612193	87159
Shah Alam Lake 2	15952	1.192607901	22689

Shah Alam Lake 3	85971	0.596303769	30569
Southlake residence Lake	46963	1.192616841	66797
Sri Murni Lake	29927	2.384848505	170210
Sri Rampai Lake	15171	1.192472281	21573
Subang Dam	38410	4.769977727	873931
Sunway Lake 1	69331	1.192622531	98613
Sunway Lake 2	83927	0.596307726	29843
Sunway Serene Lake	30244	1.192594095	43015
Taman Dengkil Jaya Lake	117232	1.192823218	166801
Taman Subang Ria Lake	43382	1.192600832	61702
Teratai Lake 1	45726	2.385516378	260212
Teratai Lake 2	48588	2.385534388	276503
The Mines Lake	31754	4.770610235	722680
Titiwangsa Lake	24604	2.384982412	139951

4.3 PV Capacity, Annual Electricity Yield and Lake Utilization Rate

```
def float_range(start,stop,step):
    while start<stop:
        yield float(start)
        start += decimal.Decimal(step)

#get the number of solar panels
rows,cols = mask.shape
for i in float_range(0,rows,gap_btw_panels):
    a=int(i)
    p=0
    for j in np.arange(cols):
        if (mask[a,j]==255):
            p+=1
    lake_width = p*metre_per_pixels
    #print('The lake width for row ', cnt_row,  ' is ', lake_width, 'with i value of ', i)

    if (lake_width!=0):
        n=int((lake_width-0.02)/1.72)
        no_string = int (n/24)
        #print('n is', n)
        tn+=n
        tns+=no_string
        cnt_row += 1
        if (no_string > 0):
            cnt_row_string += 1
    i+=gap_btw_panels

power_per_panel = 250 #rated power per panel = 250 watt
psh = 1600   #annual peak sun hour = 1600 hours
pr = 0.8 #performance ratio
pvcapacity = tns*power_per_panel
e = tn*power_per_panel*psh*pr
es = tns*24*power_per_panel*psh*pr
lakeutilization1 = (tn*1.7)/lake_area
lakeutilization2 = (tns*24*1.7)/lake_area
```

Figure 4.11: Code snippet to calculate number of panels, string number of solar panels, lake utilization and annual electricity yield.

Table 4.3: PV capacity, annual electricity yield and lake utilization of lakes in Selangor

Lake	Number of strings	PV Capacity /MW	Annual Electricity Yield /MWh	Lake Utilization Rate /%
Batu Dam	26956	161.736	207022.08	48.17
Klang Gates Dam	26353	158.118	202391.04	47.89
Semenyih Dam	40568	243.408	311562.24	48.02
Sungai Langat Dam	23840	143.04	183091.2	48.39
Alam Impian Lake	406	2.436	3118.08	42.45
Aman Lake	194	1.164	1489.92	42.59
Ampang Hilir Lake	1286	7.716	9876.48	45.8
Bandar Bukit Raja Lake 1	602	3.612	4623.36	42.26
Bandar Bukit Raja Lake 2	560	3.36	4300.8	43.97
Bandar Tun Hussein Onn Lake	461	2.766	3540.48	39.33
Bersatu Lake	154	0.924	1182.72	41.03
Beruang Bbsa Lake	1096	6.576	8417.28	42.29
Biru Seri Kundang Lake	3120	18.72	23961.6	46.84
Cempaka Lake	502	3.012	3855.36	39.69
Cyberjaya Lake 1	843	5.058	6474.24	45.15
Cyberjaya Lake 2	2507	15.042	19253.76	46.13
D' Island Lake	8617	51.702	66178.56	47.52
D' Kayangan Lake	68	0.408	522.24	37.45
Fasa 1L Lake	9	0.054	69.12	9.66
Indah Mewah Lake	7085	42.51	54412.8	47.63
Kebun Serendah Lake	306	1.836	2350.08	39.69
Kelana Lake	684	4.104	5253.12	43.59
Kelana Jaya Lake	777	4.662	5967.36	42.88

Kiambang Serendah Lake	2765	16.59	21235.2	46.8
Kota Kemuning Lake	754	4.524	5790.72	43.89
Kota Puteri Lake	791	4.746	6074.88	44.04
Metropolitan Kepong Lake	5212	31.272	40028.16	47.23
Millennium Lake	2021	12.126	15521.28	45.45
Pb Lake	688	4.128	5283.84	43.36
Perdana Lake	306	1.836	2350.08	33.32
Prima Lake	13295	79.77	102105.6	47.71
Putrajaya Lake Part 1	30189	181.134	231851.52	47.99
Putrajaya Lake Part 2	16862	101.172	129500.16	46.98
Putra Perdana Lake	22430	134.58	172262.4	48.58
Residency Lake	8908	53.448	68413.44	46.63
Saujana Lake	148	0.888	1136.64	36.72
Saujana Putra Lake	9742	58.452	74818.56	48.32
Seksyen 7 Lake	985	5.91	7564.8	44.88
Semenyih Lake	585	3.51	4492.8	44.76
Seri Aman Lake	1603	9.618	12311.04	46.06
Seri Serdang Lake	179	1.074	1374.72	42.22
Serumpun Lake	18	0.108	138.24	15.65
Shah Alam Lake 1	918	5.508	7050.24	42.97
Shah Alam Lake 2	225	1.35	1728	40.46
Shah Alam Lake 3	321	1.926	2465.28	42.84
Southlake residence Lake	699	4.194	5368.32	42.7
Sri Murni Lake	1852	11.112	14223.36	44.39
Sri Rampai Lake	201	1.206	1543.68	38.01
Subang Dam	10020	60.12	76953.6	46.78
Sunway Lake 1	1116	6.696	8570.88	46.17
Sunway Lake 2	298	1.788	2288.64	40.74
Sunway Serene Lake	450	2.7	3456	42.68

Taman Dengkil Jaya Lake	1840	11.04	14131.2	45.01
Taman Subang Ria Lake	691	4.146	5306.88	45.69
Teratai Lake 1	2946	17.676	22625.28	46.19
Teratai Lake 2	3146	18.876	24161.28	46.42
The Mines Lake	8289	49.734	63659.52	46.8
Titiwangsa Lake	1581	9.486	12142.08	46.09
	299068 (Total)	1794.408 (Total)	2296842.24 (Total)	43.15 (Average)

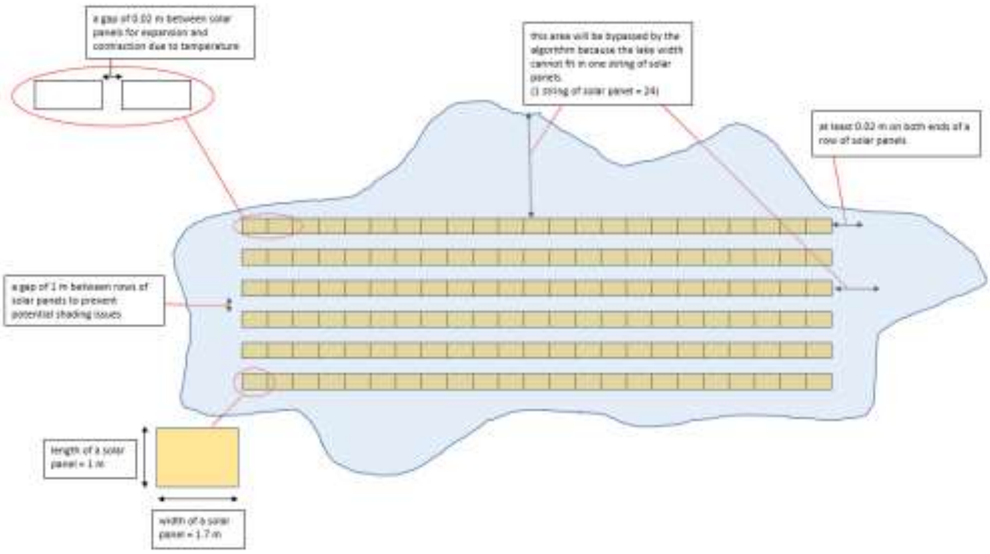

Figure 4.12: The criteria of floating solar system designed on the lakes

```
The lake width for row  1  is  19.078517719390856
number of panels:  11
number of strings:  0
The lake width for row  2  is  33.387406008934
number of panels:  19
number of strings:  0
The lake width for row  3  is  54.85073844324871
number of panels:  31
number of strings:  1
The lake width for row  4  is  54.85073844324871
number of panels:  31
number of strings:  1
The lake width for row  5  is  83.468515022335
number of panels:  48
number of strings:  2
```

Figure 4.13: The results for each row of solar panels are printed with respect to the lake width

As shown in Figure 4.11, the code is written to calculate the PV capacity on each lake based on the floating solar system designed, as shown in Figure 4.12. The results obtained are shown in Table 4.3. For every lake width of the lake, the number of strings is calculated and printed out as shown in Figure 4.13. Hence, the distribution and arrangement of solar panels on each lake can be foreseen, and the number of strings is totalled up at the end to calculate PV capacity. Since the number of solar panels per string in this project is 24, if the lake width cannot fit in 24 panels each of dimension 1.7 $m \times 1\ m$, then it will be bypassed by the algorithm. Hence, the narrow lake length or width that is not suitable for installing solar panels is omitted. During the design of rows of PV array, it is a practice to specify a fixed number of solar panels for each row so that it is easier to match the output power with the inverter size. For instance, if the lake width can fit in 50 panels, the maximum number of strings of solar panels will be 2, which is equivalent to 48 panels, and the remaining two panels will be left out. The results without considering the number of panels per string are also calculated, as shown in Appendix C-1. It is found out that the PV capacity, annual electricity yield and lake utilisation rate, as shown in Appendix C-1, are higher than those in Table 4.3. This happens because the number of panels installed on the lakes is maximised without leaving out any solar panel.

Moreover, a gap of 0.02 m is allocated between the adjacent solar panels, and another gap of 1 m is allocated between rows of solar panels. These gaps mean to prevent potential shading issues that may lead to low performance of the solar system and allow some space for expansion and contraction due to the temperature. Besides, this arrangement of solar panels ensures that the lake utilisation rate does not exceed 50 % to maintain a healthy ecosystem inside the lakes.

```
mask2 = imutils.rotate_bound(mask, angle=180) #south to north
mask3 = imutils.rotate_bound(mask, angle=90) # west to east
mask4 = imutils.rotate_bound(mask, angle=270) # east to west
```

Figure 4.14: Code snippet to rotate the default picture

In this project, the arrangement of solar panels is from north to south, and, by default, the lake image retrieved have its top facing north. The solar panels are chosen to face south because Malaysia is located in Northern Malaysia; thus, the sun will be in the Southern sky throughout the year. The solar panels are exposed to the sun for a longer period by facing south, resulting in better performance. For comparison purpose, another three directions of solar panels' arrangement, such as south to north, west to east and east to west, are also applied by using the code created as shown in Figure 4.14, and the results are obtained as shown in Appendix C-2, Appendix C-3 and Appendix C-4. The results from north to south direction are similar to south to north, as shown in Table 4.3 and Appendix C-2. This happens because both directions have a similar shape, and the difference is mainly caused by the different starting points, as shown in Figure 4.15 and Figure 4.16. This situation is also applicable to the direction of east to west and west to east, as shown in Figure 4.17 and Figure 4.18. These different results show that different facing directions of solar panels and different starting points for installing solar panels would affect the PV capacity calculated, further causing a difference in annual electricity yield and lake utilisation rate.

Figure 4.15: Calculation of PV capacity from north to south

Figure 4.16: Calculation of PV capacity from south to north

Figure 4.17: Calculation of PV capacity from east to west

Figure 4.18: Calculation of PV capacity from west to east

The solar capacity in Malaysia has reached the value of 1493 MW in 2020 (IRENA, 2021). By installing the solar panels on lakes in Selangor, the installed PV capacity can increase by 1794.408 MW, as shown in Table 4.3., resulting in a rise of 220 % in Malaysia's total PV capacity. In Malaysia, the long-term targets are 4000 MW of renewable capacity by the year 2030 (Annabeth, 2021). Hence, floating solar is a potential candidate in contributing towards this target.

The total annual electricity generation from the floating solar system on lakes in Selangor is around 2296.84 GWh, as shown in Table 4.3. This estimated value is more than 522 % higher than the total annual electricity yield of solar energy in 2018, which is 440 GWh.

Besides, the lake is not maximised in this study because it aims to estimate the potential of floating solar capacity. Also, the lakes considered are located in Selangor only, and the lake utilisation rate does not reach the threshold of 50 %. Hence, there is still space for improvement of the floating solar capacity.

4.4 Verification of result

First, the three lake samples with known size are created using the code written as shown in Figure 4.19, Figure 4.20 and Figure 4.21. These lake images are set as input to run through the algorithm in Python. The lake area, PV capacity and first-year electricity generation are also calculated manually to verify whether both results are similar.

```
#create a black image with size of 500x500
img1 = Image.new("RGB", (500,500), "black")

#paste a white rectangular shape with size of 300x250
img1.paste((255, 255, 255),(100,100,400,350))

#show the image created
img1.show()

#save the image
img1.save("C:/Users/Liew/OneDrive/Documents/floating solar study/python code/rectangle.png"
```

Figure 4.19: Code snippet to create a known size of rectangular lake

```
#create a black image with size of 400x400
img = Image.new("RGB", (400,400), "black")

#paste first rectangle with size of 200x50
img.paste((170,218,255), (150,95,350,150))

#paste second rectangle with size of 50x150
img.paste((170,218,255), (225,150,275,300))

#show the image
img.show()

#save the image
img.save("C:/Users/Liew/OneDrive/Documents/floating solar study/python code/tshape.png")
```

Figure 4.20: Code snippet to create a known size of t-shaped lake

```
# create a black image with size of 400x400
img = Image.new("RGB", (400,400), "black")

#draw a rectangle with heigt of 30 pixels and width of 40 pixels
draw = ImageDraw.Draw(img)
draw.polygon([(100,100),(100,160),(180,160)],(255,255,255))

#show the image
img.show()

#save the image
img.save("C:/Users/Liew/OneDrive/Documents/floating solar study/python code/triangle.png")
```

Figure 4.21: Code snippet to create a known size of right-angled triangle

4.4.1 Rectangular lake sample

4.4.1.1 Result from algorithm in Python using rectangular lake sample

The rectangular lake image created is shown in Figure 4.22, in which the white rectangular shape represents the lake area. The parameters desired with their units are calculated using the Python language, as shown in Figure 4.23.

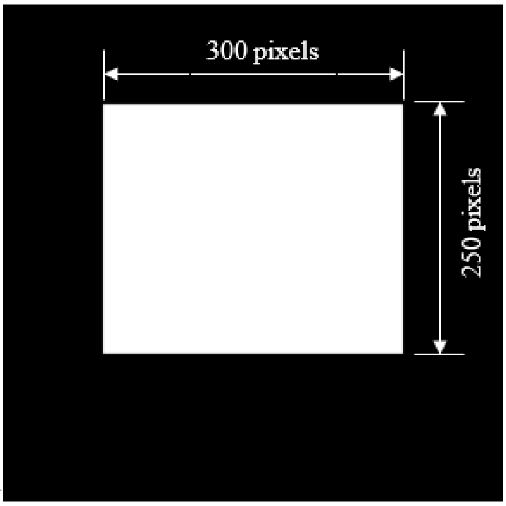

Figure 4.22: Rectangular lake

```
The number of blue pixels is:  75000
The metre per pixel is  2.384880605070011
Lake area:  426574.1625329326  metre square
Total row number of strings:  298
The gap between each row of solar panels is  0.8386164052607941  pixel
Number of strings:  5066
PV capacity:  30.396  MW
Total annual electricity yield:  38906.88  MWh
Lake utilization rate:  0.4845413017344734
```

Figure 4.23: Result from algorithm in Python using rectangular lake

4.4.1.2 Result from manual calculation using rectangular lake sample

Assume:

$zoom\ level = 16, latitude\ of\ lake = 3.222288\ ,$

$gap\ between\ adjacent\ solar\ panel = 0.02\ m,$

$width\ of\ solar\ panel = 1.7\ m, length\ of\ solar\ panel = 1\ m$

$$metre\ per\ pixel\ = 156543.03392\ \times \frac{\cos\left(\frac{latitude\ of\ lake \times \pi}{180}\right)}{2^{zoom\ level}}$$

$$= 156543.03392\ \times \frac{\cos\left(\frac{3.222288 \times \pi}{180}\right)}{2^{16}} = 2.384881$$

$$Gap\ between\ row\ of\ panels = 2\ metre = 2\ metre\ \times \frac{1\ pixel}{2.384881\ metre}$$

$$= 0.838616\ pixel$$

$$lake\ width = 2.384881\ \frac{metre}{pixel} \times 300\ pixel = 715.4643\ metre$$

$$lake\ length = 2.384881\ \frac{metre}{pixel} \times 250\ pixel = 596.2202\ metre$$

$$Lake\ area\ = 715.4643 \times 596.2202 = 426574\ m^2$$

Let $n = number\ of\ solar\ panels\ per\ row$

$$(n \times 1.7) + (n + 1) \times 0.02 < lake\ width$$

$$n < \frac{lake\ width - 0.02}{1.72}$$

$$n < \frac{715.4643\ - 0.02}{1.72}$$

$$n < 415.96$$

Since n must be an integer, $n = 415$

Since $number\ of\ panels\ per\ string\ = 24\ ,\ number\ of\ \ strings = \frac{415}{24} =$ 17.29

Since number of strings must be an integer, $number\ of\ \ strings = 17$

$$Rows\ of\ panels, r = \frac{lake\ height}{gap\ between\ row\ of\ panels} = \frac{250\ pixel}{0.838616\ pixel}$$

$$= \frac{596.2202\ m}{2\ m} = 298.11$$

Since r must be an integer, $r = 298$

$Total\ number\ of\ panels$

$$= r \times number\ of\ strings \times number\ of\ panels\ per\ string$$

$$= 298 \times 17 \times 24 = 121584$$

$$Total\ number\ of\ strings = r \times number\ of\ strings = 5066$$

$$PV\ capacity = number\ of\ panels \times rated\ power\ per\ panel$$

$$= 121584 \times 250\ W = 30.396\ MW$$

$Annual\ electricity\ yield$

$= total\ number\ of\ panels \times rated\ power\ per\ panel\ \times$

$peak\ sun\ hours\ per\ year \times performance\ ratio$

$= 121584 \times 250 \times 1600 \times 0.8$

$= 38906.88\ MWh$

$Lake\ utilization\ rate = \frac{total\ number\ of\ solar\ panels \times area\ of\ a\ solar\ panel}{lake\ area} =$

$\frac{121584 \times (1\ m \times 1.7\ m)}{426574\ m^2} = 48.45\ \%$

4.4.1.3 Comparison of results obtained from two methods using rectangular lake sample

Table 4.4: Comparison of results using rectangular lake sample

	Python algorithm	Manual calculation
Lake area (m^2)	426574	426574
Number of strings of panels	5066	5066
PV Capacity (MW)	30.396	30.396
Annual electricity yield (MWh)	38906.88	38906.88
Lake utilization rate (%)	48.45	48.45

From Table 4.4, the results obtained from the Python algorithm and manual calculation are the same. Therefore, by controlling the input as a fixed rectangular shape, the algorithm works in the desired way.

4.4.2 T-shaped lake sample

4.4.2.1 Result from algorithm in Python using t-shaped lake sample

The t-shaped lake is created as shown in Figure 4.24, with the lake's dimensions illustrated. The results obtained using the t-shaped lake image as input are also shown in Figure 4.25.

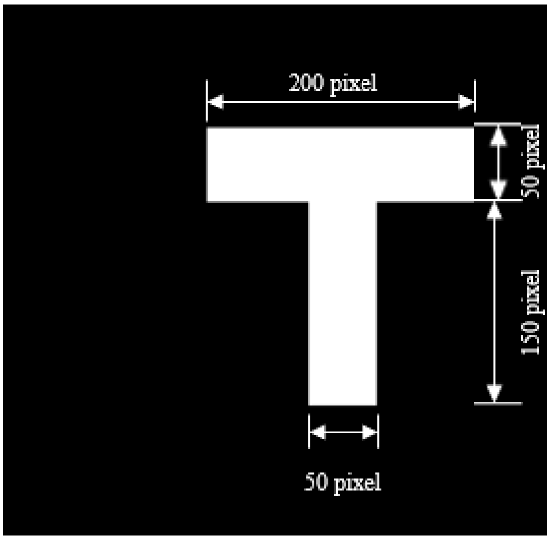

Figure 4.24: T-shaped lake

```
The number of blue pixels is:  18500
The metre per pixel is  9.539933060374485
Lake area:  1683690.9717338828  metre square
Total row number of strings:  977
The gap between each row of solar panels is  0.20964507689338974  pixel
Number of strings:  19917
PV capacity:  119.502  MW
Total annual electricity yield:  152962.56  MWh
Lake utilization rate:  0.48263821190604944
```

Figure 4.25: Result from algorithm in Python using t-shaped lake

4.4.2.2 Result from manual calculation for t-shaped lake sample

Assume:

$zoom\ level = 14, latitude\ of\ lake = 3.178178\ ,$

$gap\ between\ adjacent\ solar\ panel = 0.02\ m,$

$width\ of\ solar\ panel = 1.7\ m, length\ of\ solar\ panel = 1\ m$

$$metre\ per\ pixel\ = 156543.03392\ \times \frac{\cos\left(\frac{latitude\ of\ lake \times \pi}{180}\right)}{2^{zoom\ level}}$$

$$= 156543.03392\ \times \frac{\cos\left(\frac{3.178178 \times \pi}{180}\right)}{2^{14}} = 9.539933$$

$$Gap\ between\ row\ of\ panels = 2\ metre = 2\ metre\ \times \frac{1\ pixel}{9.539933\ metre}$$

$$= 0.209645\ pixel$$

$$lake\ width1 = 9.539933\ \frac{metre}{pixel} \times 200\ pixel = 1907.9866\ metre$$

$$lake\ width2 = 9.539933\ \frac{metre}{pixel} \times 50\ pixel = 476.9967\ metre$$

$$lake\ length1 = 9.539933\ \frac{metre}{pixel} \times 55\ pixel = 524.6963\ metre$$

$$lake\ length2 = 9.539933\ \frac{metre}{pixel} \times 150\ pixel = 1430.9900\ metre$$

$$Lake\ area\ = (1907.9866 \times 524.6963) + (476.9967 \times 1430.9900)$$

$$= 1683691\ m^2$$

Let $n = number\ of\ solar\ panels\ per\ row$

$$(n \times 1.7) + (n + 1) \times 0.02 < lake\ width$$

$$n < \frac{lake\ width - 0.02}{1.72}$$

$$n1 < \frac{1907.9866\ - 0.02}{1.72}$$

$$n1 < 1109.28$$

$$n2 < \frac{476.9967\ - 0.02}{1.72}$$

$$n2 < 277.31$$

Since n must be an integer, $n1 = 1109$ and $n1 = 277$

For n1, $number\ of\ \ strings = s1 = \frac{1109}{24} = 46.21$

$Number\ of\ panels\ per\ string\ = 24$

Since number of strings must be an integer, $s1 = 46$

For n2, $number\ of\ \ strings = s2 = \frac{277}{24} = 11.54$

Since number of strings must be an integer, $s2 = 11$

$$Rows\ of\ panels, r = \frac{lake\ height}{gap\ between\ row\ of\ panels}$$

$$r1 = \frac{55\ pixel}{0.209645\ pixel} = \frac{524.6963\ m}{2\ m} = 262.35$$

$$r2 = \frac{150\ pixel}{0.209645\ pixel} = \frac{1430.9900\ m}{2\ m} = 715.50$$

Since r must be an integer, $r1 = 262$ and , $r2 = 715$

Since $262.35 + 715.50 - 262 - 715 < 1$, there is no extra row that can be formed.

$Total\ number\ of\ panels$

$$= r \times number\ of\ strings \times number\ of\ panels\ per\ string$$

$$= (r1 \times s1 \times 24) + (r2 \times s2 \times 24)$$

$$= (262 \times 46 \times 24) + (715 \times 11 \times 24) = 478008$$

$$Total\ number\ of\ strings = r \times number\ of\ strings$$

$$= (r1 \times s1) + (r2 \times s2) = (262 \times 46) + (715 \times 11)$$

$$= 19917$$

$$PV\ capacity = number\ of\ panels \times rated\ power\ per\ panel$$

$$= 478008 \times 250\ W = 119.502\ MW$$

$Annual\ electricity\ yield$

$= total\ number\ of\ panels \times rated\ power\ per\ panel\ \times$

$peak\ sun\ hours\ per\ year \times performance\ ratio$

$= 478008 \times 250 \times 1600 \times 0.8 = 152962.56\ MWh$

$Lake\ utilization\ rate = \frac{total\ number\ of\ solar\ panels \times area\ of\ a\ solar\ panel}{lake\ area} = \frac{478008 \times (1\ m \times 1.7\ m)}{1683691\ m^2} = 48.26\ \%$

4.4.2.3 Comparison of results obtained from two methods using t-shaped lake sample

Table 4.5: Comparison of results using t-shaped lake sample

	Python algorithm	Manual calculation
Lake area (m^2)	1683691	1683691
Number of strings of panels	19917	19917
PV Capacity (MW)	119.502	119.502
Annual electricity yield (MWh)	152962.56	152962.56
Lake utilization rate (%)	48.26	48.26

From Table 4.5, the results obtained from the algorithm in Python and the manual calculation are the same. This has shown that the algorithm is working correctly for the t-shaped lake sample.

4.4.3 Triangular lake sample

4.4.3.1 Result from algorithm in Python using triangular lake sample

Moreover, another lake sample with a triangular shape is also created. For this shape, the lake width changes for every calculation, as shown in Figure 4.26. The parameters calculated with two different scales are also shown in Figure 4.27 and Figure 4.28.

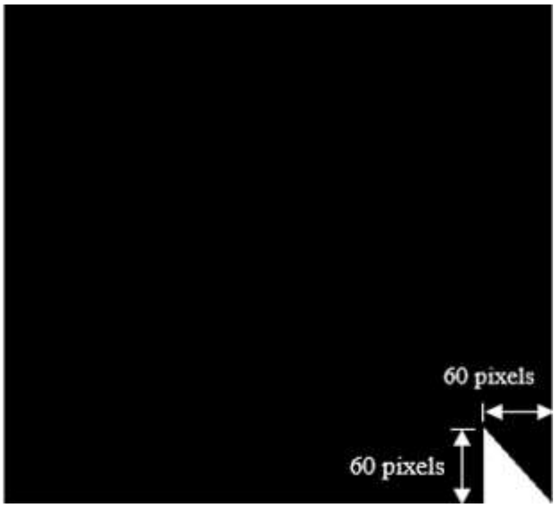

Figure 4.26: Triangular lake

```
The number of blue pixels is:  1830
The metre per pixel is  2
Lake area:  7320  metre square
Total row number of strings:  40
The gap between each row of solar panels is  1.0  pixel
Number of strings:  59
PV capacity:  0.354  MW
Total annual electricity yield:  453.12  MWh
Lake utilization rate:  0.32885245901639343
```

Figure 4.27: Result from algorithm in Python using triangular lake with a scale of 2 metre per pixel

```
The number of blue pixels is:  1830
The metre per pixel is  4
Lake area:  29280  metre square
Total row number of strings:  100
The gap between each row of solar panels is  0.5  pixel
Number of strings:  296
PV capacity:  1.776  MW
Total annual electricity yield:  2273.28  MWh
Lake utilization rate:  0.4124590163934426
```

Figure 4.28: Result from algorithm in Python using triangular lake with a scale of 4 metre per pixel

4.4.3.2 Result from manual calculation for triangular lake sample

Since the triangular lake sample has its length and width keeps changing, the calculation is made to be simpler by assuming scale the scale which is metre per pixel of the image as an integer. Meanwhile, this sample is tested using two scales, such as 2 metres per pixel and 4 metres per pixel.

Assume:

$gap\ between\ adjacent\ solar\ panel = 0.02\ m,$

$width\ of\ solar\ panel = 1.7\ m,\ length\ of\ solar\ panel = 1\ m$

<u>When $metre\ per\ pixel = 2$</u>

$$Gap\ between\ row\ of\ panels = 2\ metre = 2\ metre\ \times \frac{1\ pixel}{2\ metre} = 1\ pixel$$

$$lake\ width = 2\ \frac{metre}{pixel}\ \times 60\ pixel = 120\ metre$$

$$lake\ length = 2\ \frac{metre}{pixel}\ \times 60\ pixel = 120\ metre$$

$$Lake\ area\ = \frac{1}{2}(120 \times 120\ ) = 7200\ m^2$$

<u>When $metre\ per\ pixel = 4$</u>

$$Gap\ between\ row\ of\ panels = 2\ metre = 2\ metre\ \times \frac{1\ pixel}{4\ metre}$$

$$= 0.5\ pixel$$

$$lake\ width = 4\ \frac{metre}{pixel}\ \times 60\ pixel = 240\ metre$$

$$lake\ length = 4\ \frac{metre}{pixel}\ \times 60\ pixel = 240\ metre$$

$$Lake\ area\ = \frac{1}{2}(120 \times 120\ ) = 28800\ m^2$$

Since the number of solar panels installed on the lakes changes with respect to the lake width and lake length, the number of solar panels and the number of strings are calculated in Microsoft Excel as shown in Table 4.6 and Table 4.7.

Table 4.6: Number of strings calculated using triangular lake sample with a scale of 2 metre per pixel

Row	Number of pixels	Lake width/m	Number of panels that can be installed	Number of strings
1	1	2	1	0
2	2	4	2	0
3	3	6	3	0
4	4	8	4	0
5	5	10	5	0
6	6	12	6	0
7	7	14	8	0
8	8	16	9	0
9	9	18	10	0
10	10	20	11	0
11	11	22	12	0
12	12	24	13	0
13	13	26	15	0
14	14	28	16	0
15	15	30	17	0
16	16	32	18	0
17	17	34	19	0
18	18	36	20	0
19	19	38	22	0
20	20	40	23	0
21	21	42	24	1
22	22	44	25	1
23	23	46	26	1
24	24	48	27	1
25	25	50	29	1
26	26	52	30	1
27	27	54	31	1
28	28	56	32	1

29	29	58	33	1
30	30	60	34	1
31	31	62	36	1
32	32	64	37	1
33	33	66	38	1
34	34	68	39	1
35	35	70	40	1
36	36	72	41	1
37	37	74	43	1
38	38	76	44	1
39	39	78	45	1
40	40	80	46	1
41	41	82	47	1
42	42	84	48	2
43	43	86	49	2
44	44	88	51	2
45	45	90	52	2
46	46	92	53	2
47	47	94	54	2
48	48	96	55	2
49	49	98	56	2
50	50	100	58	2
51	51	102	59	2
52	52	104	60	2
53	53	106	61	2
54	54	108	62	2
55	55	110	63	2
56	56	112	65	2
57	57	114	66	2
58	58	116	67	2
59	59	118	68	2
60	60	120	69	2

				59 (Total number of strings)

Table 4.7: Number of strings calculated using triangular lake sample with a scale of 4 metre per pixel

Row	Number of pixels	Lake width/m	Number of panels that can be installed	Number of strings
0.5	0.5	2	1	0
1	1	4	2	0
1.5	1.5	6	3	0
2	2	8	4	0
2.5	2.5	10	5	0
3	3	12	6	0
3.5	3.5	14	8	0
4	4	16	9	0
4.5	4.5	18	10	0
5	5	20	11	0
5.5	5.5	22	12	0
6	6	24	13	0
6.5	6.5	26	15	0
7	7	28	16	0
7.5	7.5	30	17	0
8	8	32	18	0
8.5	8.5	34	19	0
9	9	36	20	0
9.5	9.5	38	22	0
10	10	40	23	0
10.5	10.5	42	24	1
11	11	44	25	1
11.5	11.5	46	26	1
12	12	48	27	1

12.5	12.5	50	29	1
13	13	52	30	1
13.5	13.5	54	31	1
14	14	56	32	1
14.5	14.5	58	33	1
15	15	60	34	1
15.5	15.5	62	36	1
16	16	64	37	1
16.5	16.5	66	38	1
17	17	68	39	1
17.5	17.5	70	40	1
18	18	72	41	1
18.5	18.5	74	43	1
19	19	76	44	1
19.5	19.5	78	45	1
20	20	80	46	1
20.5	20.5	82	47	1
21	21	84	48	2
21.5	21.5	86	49	2
22	22	88	51	2
22.5	22.5	90	52	2
23	23	92	53	2
23.5	23.5	94	54	2
24	24	96	55	2
24.5	24.5	98	56	2
25	25	100	58	2
25.5	25.5	102	59	2
26	26	104	60	2
26.5	26.5	106	61	2
27	27	108	62	2
27.5	27.5	110	63	2
28	28	112	65	2

28.5	28.5	114	66	2
29	29	116	67	2
29.5	29.5	118	68	2
30	30	120	69	2
30.5	30.5	122	70	2
31	31	124	72	3
31.5	31.5	126	73	3
32	32	128	74	3
32.5	32.5	130	75	3
33	33	132	76	3
33.5	33.5	134	77	3
34	34	136	79	3
34.5	34.5	138	80	3
35	35	140	81	3
35.5	35.5	142	82	3
36	36	144	83	3
36.5	36.5	146	84	3
37	37	148	86	3
37.5	37.5	150	87	3
38	38	152	88	3
38.5	38.5	154	89	3
39	39	156	90	3
39.5	39.5	158	91	3
40	40	160	93	3
40.5	40.5	162	94	3
41	41	164	95	3
41.5	41.5	166	96	4
42	42	168	97	4
42.5	42.5	170	98	4
43	43	172	99	4
43.5	43.5	174	101	4
44	44	176	102	4

44.5	44.5	178	103	4
45	45	180	104	4
45.5	45.5	182	105	4
46	46	184	106	4
46.5	46.5	186	108	4
47	47	188	109	4
47.5	47.5	190	110	4
48	48	192	111	4
48.5	48.5	194	112	4
49	49	196	113	4
49.5	49.5	198	115	4
50	50	200	116	4
50.5	50.5	202	117	4
51	51	204	118	4
51.5	51.5	206	119	4
52	52	208	120	5
52.5	52.5	210	122	5
53	53	212	123	5
53.5	53.5	214	124	5
54	54	216	125	5
54.5	54.5	218	126	5
55	55	220	127	5
55.5	55.5	222	129	5
56	56	224	130	5
56.5	56.5	226	131	5
57	57	228	132	5
57.5	57.5	230	133	5
58	58	232	134	5
58.5	58.5	234	136	5
59	59	236	137	5
59.5	59.5	238	138	5
60	60	240	139	5

				293 (Total number of strings)

<u>When $metre\ per\ pixel = 2$</u>

$Total\ number\ of\ strings = 59$ (From Table 4.6)

$$Total\ number\ of\ panels$$
$$= number\ of\ strings \times number\ of\ panels\ per\ string$$
$$= 59 \times 24 = 1416$$

$$PV\ capacity = number\ of\ panels\ \times rated\ power\ per\ panel$$
$$= 1416 \times 250\ W\ = 0.354\ MW$$

$Annual\ electricity\ yield$

$= total\ number\ of\ panels \times rated\ power\ per\ panel\ \times$

$peak\ sun\ hours\ per\ year \times performance\ ratio$

$= 1416 \times 250 \times 1600 \times 0.8 = 453.12\ MWh$

$Lake\ utilization\ rate = \frac{total\ number\ of\ solar\ panels \times area\ of\ a\ solar\ panel}{lake\ area} =$

$\frac{1416 \times (1\ m \times 1.7\ m)}{7200\ m^2} = 33.43\ \%$

<u>When $metre\ per\ pixel = 4$</u>

$Total\ number\ of\ strings = 293$ (From Table 4.7)

$$Total\ number\ of\ panels$$
$$= number\ of\ strings \times number\ of\ panels\ per\ string$$
$$= 293 \times 24 = 7032$$

$$PV\ capacity = number\ of\ panels\ \times rated\ power\ per\ panel$$
$$= 7032 \times 250\ W\ = 1.758\ MW$$

$Annual\ electricity\ yield$

$= total\ number\ of\ panels \times rated\ power\ per\ panel\ \times$

$peak\ sun\ hours\ per\ year \times performance\ ratio$

$= 7032 \times 250 \times 1600 \times 0.8 = 2250.24\ MWh$

$Lake\ utilization\ rate = \frac{total\ number\ of\ solar\ panels \times area\ of\ a\ solar\ panel}{lake\ area} =$

$\frac{7032 \times (1\ m \times 1.7\ m)}{28800\ m^2} = 41.51\ \%$

4.4.3.3 Comparison of results obtained from two methods using triangular lake sample

Table 4.8: Comparison of results using triangular lake sample with a scale of 2 metre per pixel

	Python algorithm	Manual calculation	Percentage error (%)
Lake area (m^2)	7320	7200	1.67
Number of strings of panels	59	59	0
PV Capacity (MW)	0.354	0.354	0
Annual electricity yield (MWh)	453.12	453.12	0
Lake utilization rate (%)	32.89	33.43	1.62

Table 4.9: Comparison of results using triangular lake sample with a scale of 4 metre per pixel

	Python algorithm	Manual calculation	Percentage error (%)
Lake area (m^2)	29280	28800	1.67
Number of strings of panels	296	293	1.02
PV Capacity (MW)	1.776	1.758	1.02
Annual electricity yield (MWh)	2273.28	2250.24	1.02
Lake utilization rate (%)	41.25	41.51	0.63

When the triangular lake sample is used as the input, it is found out that there is an error in the lake area calculated. This is different from the rectangular and t-shaped lake sample, which has no error. The error is due to the triangular lake created because the triangle shape should have a smooth slanting line on the hypotenuse side, as shown in Figure 4.29. However, the triangle shape created will have a stair-step line, as shown in Figure 4.30. The image created is made up of pixels that are the smallest unit displayed on the screen. For instance, when a particular distance is equivalent to 0.8 pixels, 1 pixel will be used to represent that distance. Therefore, the results obtained from the Python algorithm are slightly higher than the actual results.

Two different scales are used to compare the percentage error, as shown in Table 4.8 and Table 4.9. It is shown that the percentage error in the calculation of PV capacity and annual electricity yield is higher for the case of 4 metres per pixel. When the zoom level is lower, the higher the value of metre per pixel, and the number of solar panels installed on the lakes is also increased. Meanwhile, the percentage error in the lake area and the lake utilisation rate are lower when the zoom level is lower. This error is also applicable to the images retrieved from Google Cloud Platform because all the Selangor lakes have an irregular shape.

Figure 4.29: Normal triangle

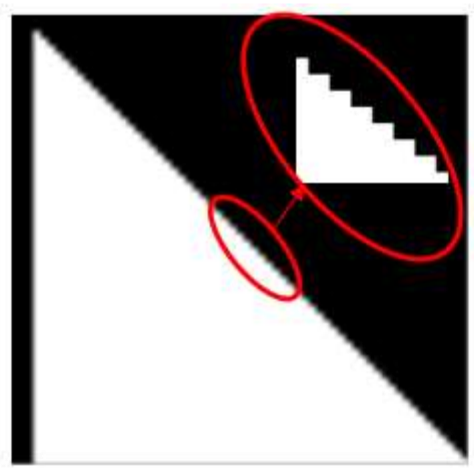

Figure 4.30: Triangular lake sample created

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The aim and objectives which are set at the beginning of the project are achieved. A total of 57 lakes in Selangor have been captured by applying different zoom levels. The lake area on the image is then identified using several image processing techniques in Python. Some water areas that are not part of the lake are also filtered out to obtain a better result. The area of each lake is also calculated and recorded. The total lake area of the 57 lakes in Selangor is 25753279 m^2. The PV capacity and the first-year electricity yield for each lake are also estimated individually and summed up, which are 1794.41 MW and 2296.84 GWh. Estimation of the PV capacity and the electricity yield is done based on a floating solar system designed. The size of the solar panels, the rated power per panel, the gaps between rows of solar panels are set to a value for the calculation. The percentage of the lake area covered by the solar panels is also set to be below 50 % to maintain the existing ecosystem inside all the lakes. The verification of the results has been carried out by creating several known sizes of the lake samples. The results obtained from the verification process are satisfactory, and there might be an error of 1-2 % because the distance of the lake will be rounded up into the nearest integer pixel. This error can be minimized by maximizing the zoom level. It is also found out that the PV capacity obtained is different when the orientations of solar panels are changed according to the facing direction such as west, east, north and south. The south-facing direction is chosen in this study because Malaysia is located in the Northern hemisphere, so the south direction allows a maximum capture of sunlight.

The results obtained, such as the PV capacity, have shown a positive sign for the Malaysian government to develop and invest in floating solar farms. It is another alternative solution to the ground-mounted solar system that can increase renewable energy capacity and reduce the fossil fuel plants' carbo footprint. Although floating solar might have a higher capital cost than the ground-mounted solar system, floating solar has its unique benefits, such as eliminating land costs, higher efficiency of solar panels and lower operation and management costs. Hence, it is recommended to involve floating solar as part of the electricity generation in Malaysia.

5.2 Recommendations for future work

The floating solar in this project involves the lakes in Selangor state only. Hence, it can be extended to other states in Malaysia to increase the sample size and get a better insight. Besides, the number of solar panels per string is set to be a fixed value of 24 in this study; thus, this value can be adjusted or customized according to different lakes to optimize the lake area's coverage. For instance, different values for the number of panels per string, such as 18, 20, 22 and 24, are used to calculate PV capacity. The value that results in the maximum PV capacity is then selected.

The tilting angle of the solar panels can also be considered to obtain higher accuracy of the results. For instance, the length of the solar panels is calculated by using the Eq 5.1 below.

$$l1 = l2 \times cos\beta \tag{5.1}$$

where

$l1 = length\ of\ solar\ panel\ with\ tilt\ angle, m$

$l2 = length\ of solar\ panel, m$

$\beta = tilt\ angle\ of\ solar\ panel\ measured\ from\ the\ horizontal\ plane, °$

Moreover, the floating solar system on the sea can also be studied in the future as Malaysia is surrounded by the sea. For floating solar farms on the sea, more factors have to be considered, such as the strength of the supporting structure to overcome the wave, the safety of the submarine cable and the corrosion of the floating solar's structure due to chemicals in seawater. Our neighbouring country Singapore has built their first floating solar farm on the sea. Hence, it is also possible to install floating solar panels on the sea in Malaysia.

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APPENDICES

APPENDIX A: Original Map Images

Original Map Image A-5.1: Batu Dam

Original Map Image A-2: Klang Gates Dam

Original Map Image A-3: Semenyih Dam

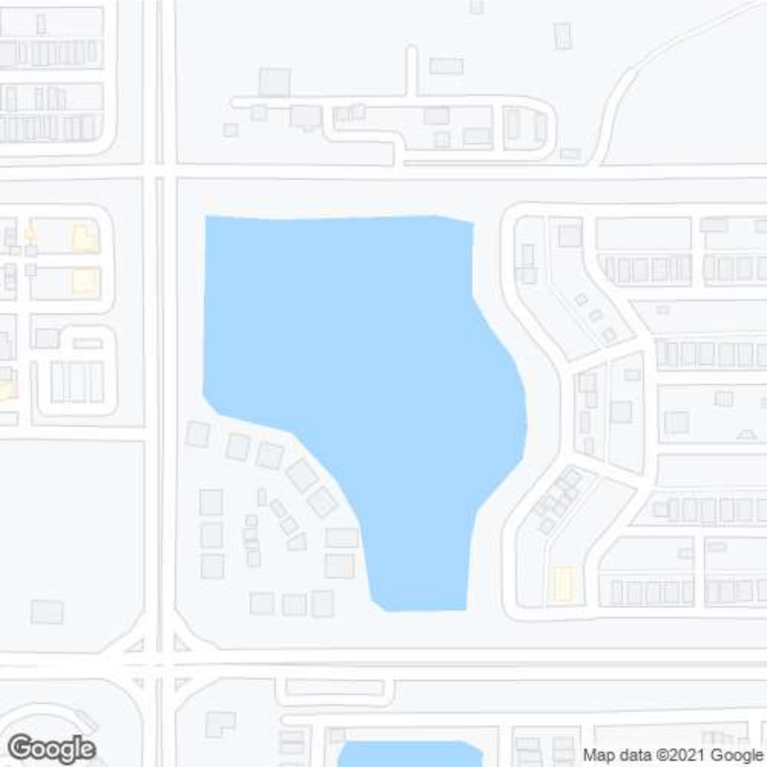
Original Map Image A-4: Sungai Langat Dam

Original Map Image A-5: Alam Impian Lake

Original Map Image A-6: Aman Lake

Original Map Image A-7: Ampang Hilir Lake

Original Map Image A-8: Bandar Bukit Raja Lake 1



Original Map Image A-9: Bandar Bukit Raja Lake 2

Original Map Image A-10: Bandar Tun Hussein Onn Lake

Original Map Image A-11: Bersatu Lake

Original Map Image A-12: Beruang Bbsa Lake

Original Map Image A-13: Biru Seri Kundang Lake

Original Map Image A-14: Cempaka Lake

Original Map Image A-15: Cyberjaya Lake 1

Original Map Image A-16: Cyberjaya Lake 2

Original Map Image A-17: D' Island Lake

Original Map Image A-18: D' Kayangan Lake

Original Map Image A-19: Fasa 1L Lake

Original Map Image A-20: Indah Mewah Lake

Original Map Image A-21: Kebun Serendah Lake

Original Map Image A-22: Kelana Lake

Original Map Image A-23: Kelana Jaya Lake

Original Map Image A-24: Kiambang Serendah Lake

Original Map Image A-25: Kota Kemuning Lake

Original Map Image A-26: Kota Puteri Lake

Original Map Image A-27: Metropolitan Kepong Lake

Original Map Image A-28: Millennium Lake

Original Map Image A-29: Pb Lake

Original Map Image A-30: Perdana Lake

Original Map Image A-31: Prima Lake

Original Map Image A-32: Putrajaya Lake Part 1

Original Map Image A-33: Putrajaya Lake Part 2

Original Map Image A-34: Putra Perdana Lake

Original Map Image A-35: Residency Lake

Original Map Image A-36: Saujana Lake

Original Map Image A-37: Saujana Putra Lake

Original Map Image A-38: Seksyen 7 Lake

Original Map Image A-39: Semenyih Lake

Original Map Image A-40: Seri Aman Lake

Original Map Image A-41: Seri Serdang Lake

Original Map Image A-42: Serumpun Lake

Original Map Image A-43: Shah Alam Lake 1

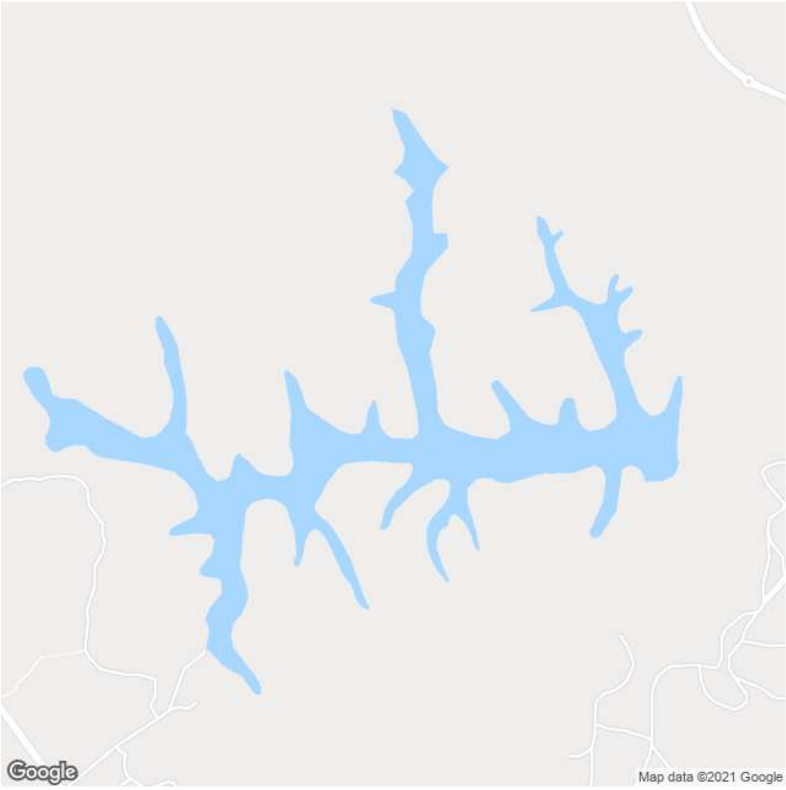
Original Map Image A-44: Shah Alam Lake 2

Original Map Image A-45: Shah Alam Lake 3

Original Map Image A-46: Southlake Residence Lake

Original Map Image A-47: Sri Murni Lake

Original Map Image A-48: Sri Rampai Lake



Original Map Image A-49: Subang Dam

Original Map Image A-50: Sunway Lake 1

Original Map Image A-51: Sunway Lake 2

Original Map Image A-52: Sunway Serene Lake

Original Map Image A-53: Taman Dengkil Jaya Lake

Original Map Image A-54: Taman Subang Ria Lake

Original Map Image A-55: Teratai Lake 1

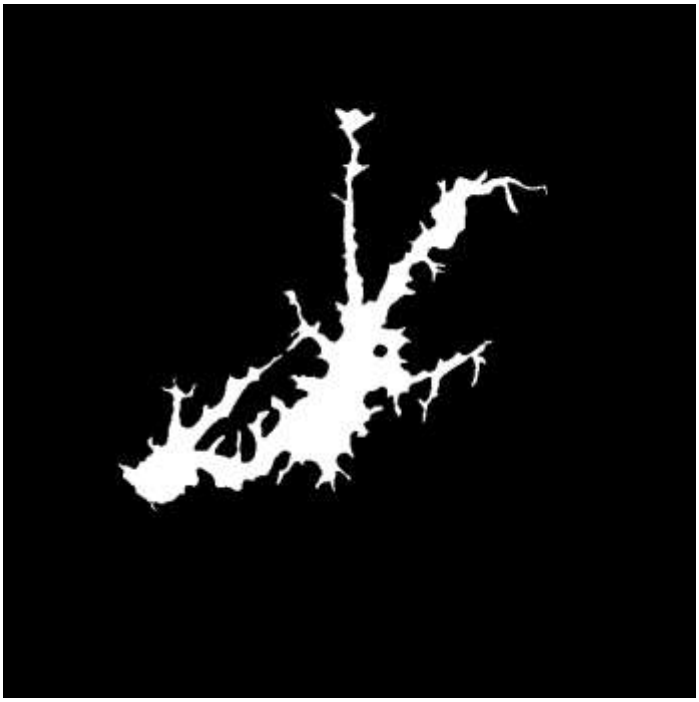
Original Map Image A-56: Teratai Lake 2

Original Map Image A-57: The Mines Lake

Original Map Image A-58: Titiwangsa Lake

APPENDIX B: Final Processed Images

Final Processed Image B-5.2: Batu Dam

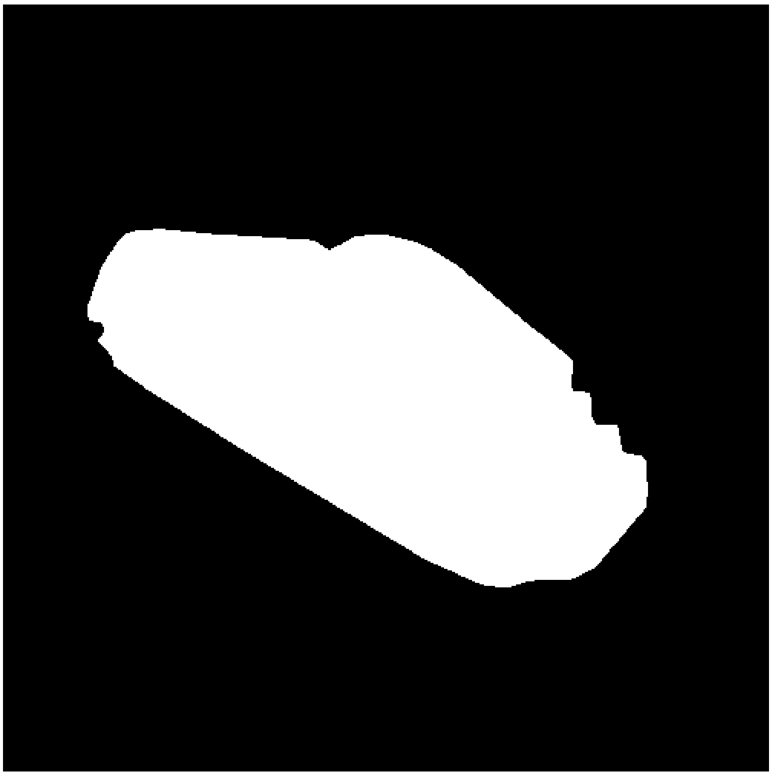


Final Processed Image B-2: Klang Gates Dam

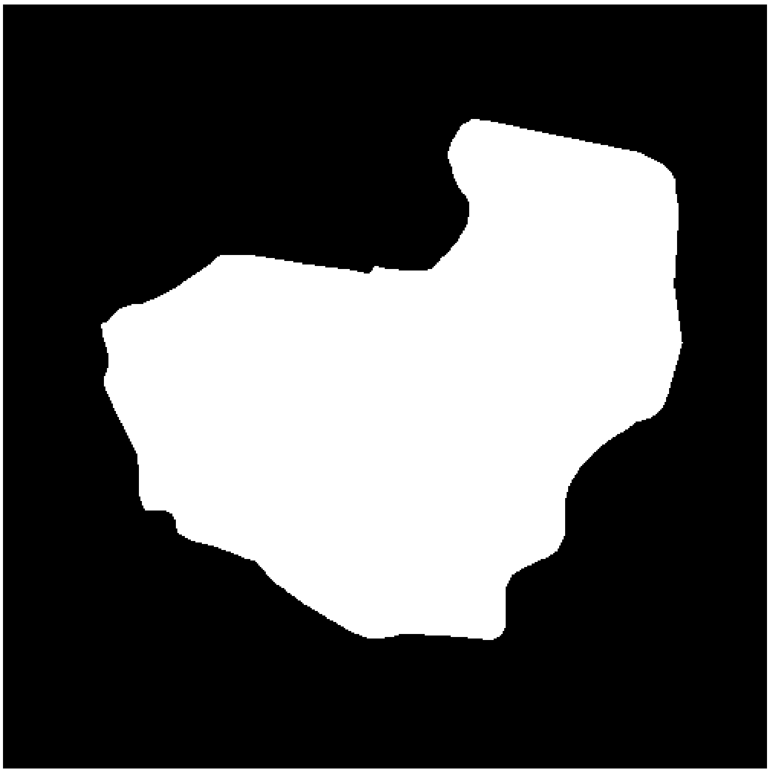
Final Processed Image B-3: Semenyih Dam

Final Processed Image B-4: Sungai Langat Dam

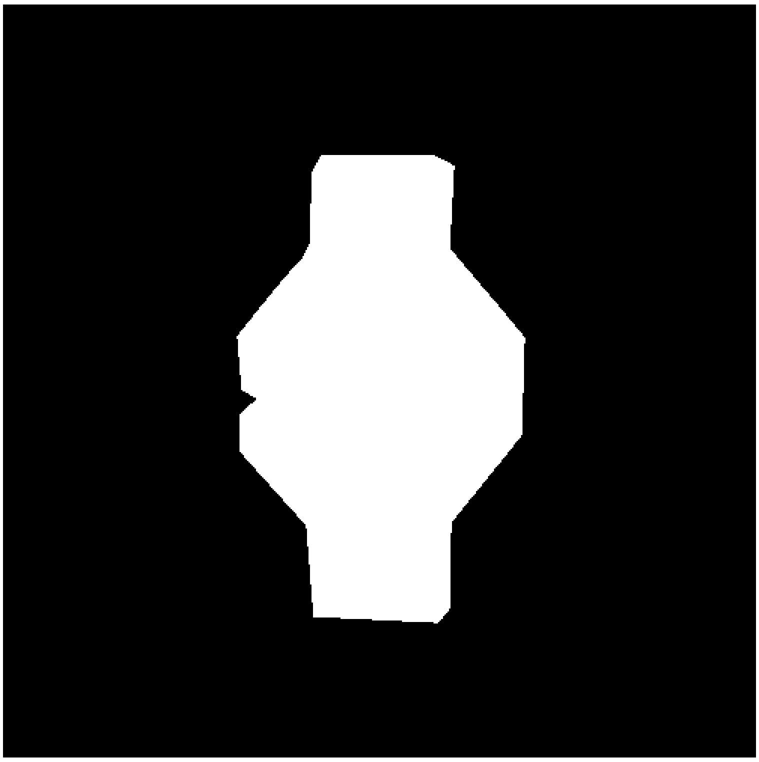
Final Processed Image B-5: Alam Impian Lake



Final Processed Image B-6: Aman Lake



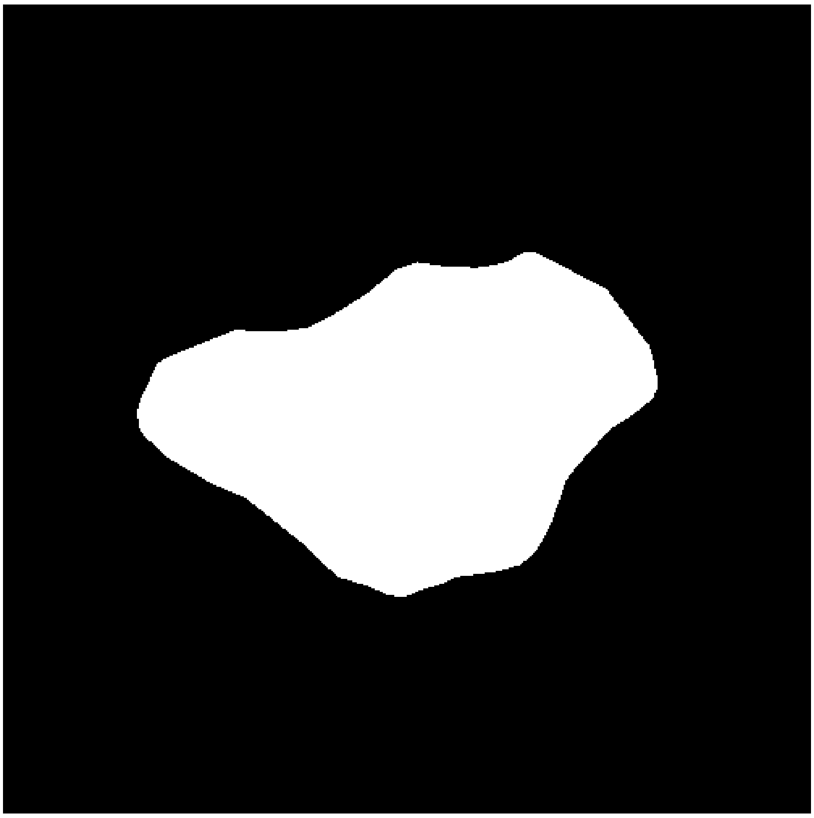
Final Processed Image B-7: Ampang Hilir Lake



Final Processed Image B-8: Bandar Bukit Raja Lake 1

Final Processed Image B-9: Bandar Bukit Raja Lake 2

Final Processed Image B-10: Bandar Tun Hussein Onn Lake



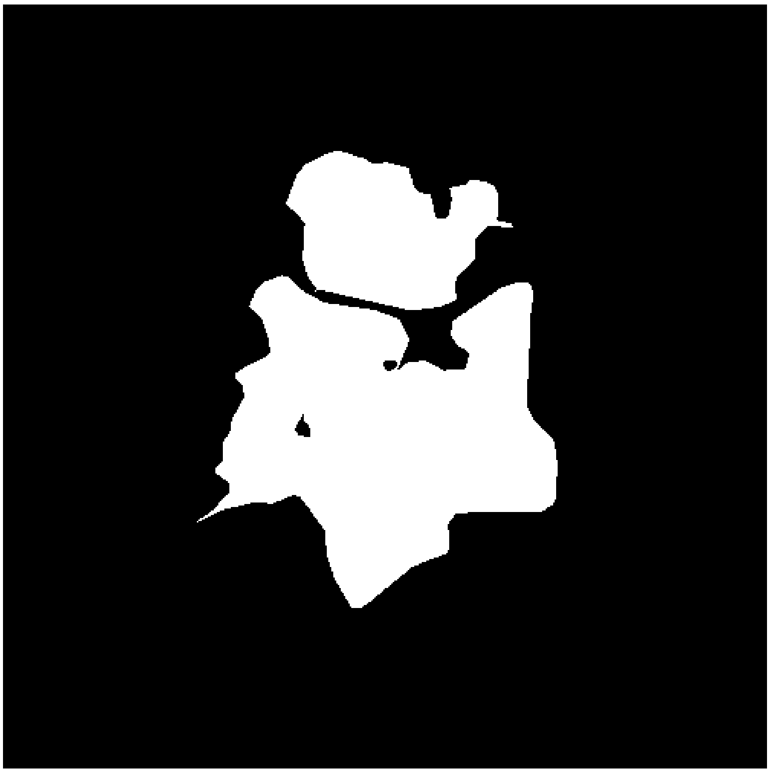
Final Processed Image B-11: Bersatu Lake

Final Processed Image B-12: Beruang Bbsa Lake

Final Processed Image B-13: Biru Seri Kundang Lake

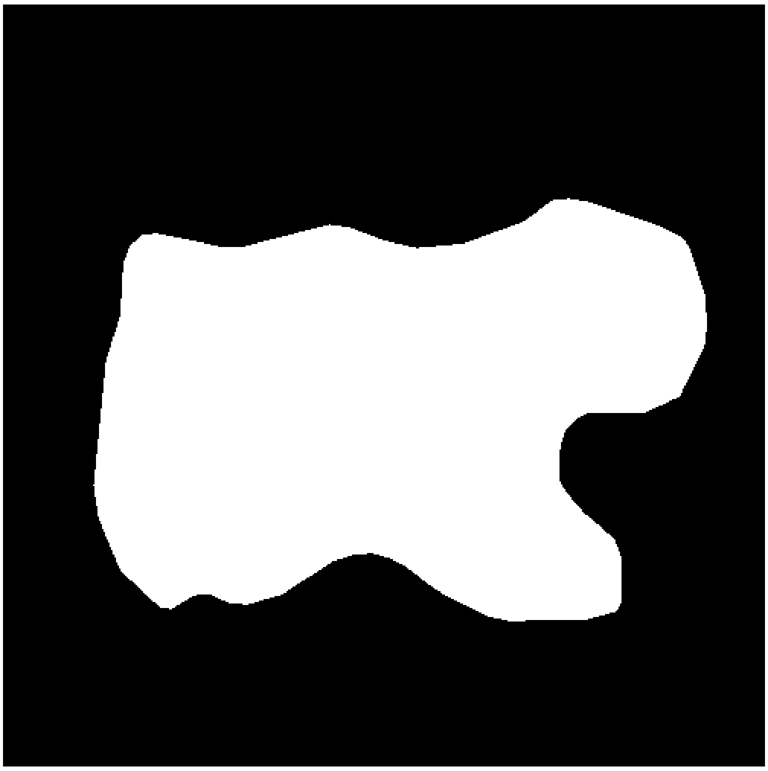
Final Processed Image B-14: Cempaka Lake

Final Processed Image B-15: Cyberjaya Lake 1

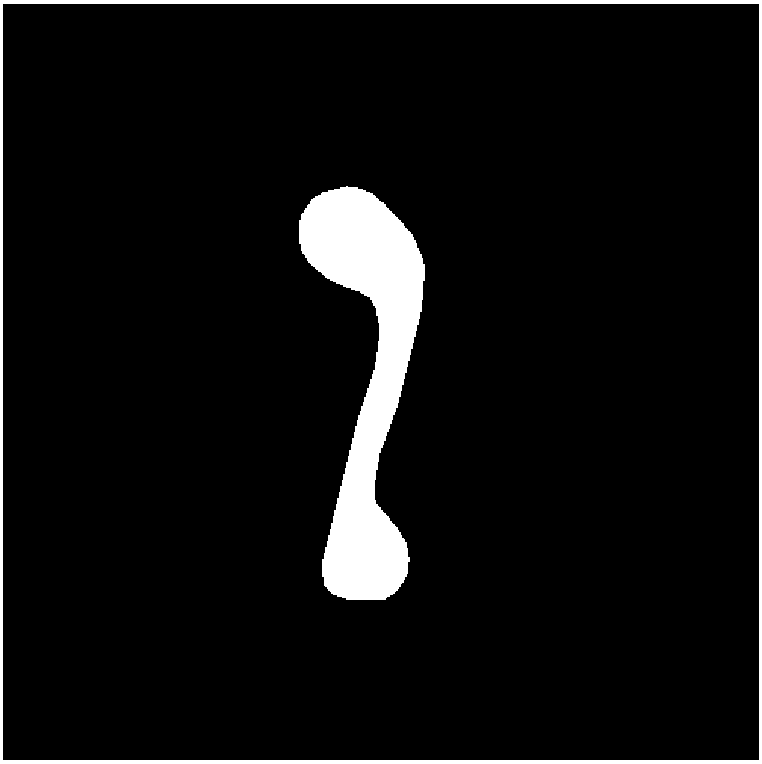


Final Processed Image B-16: Cyberjaya Lake 2

Final Processed Image B-17: D' Island Lake

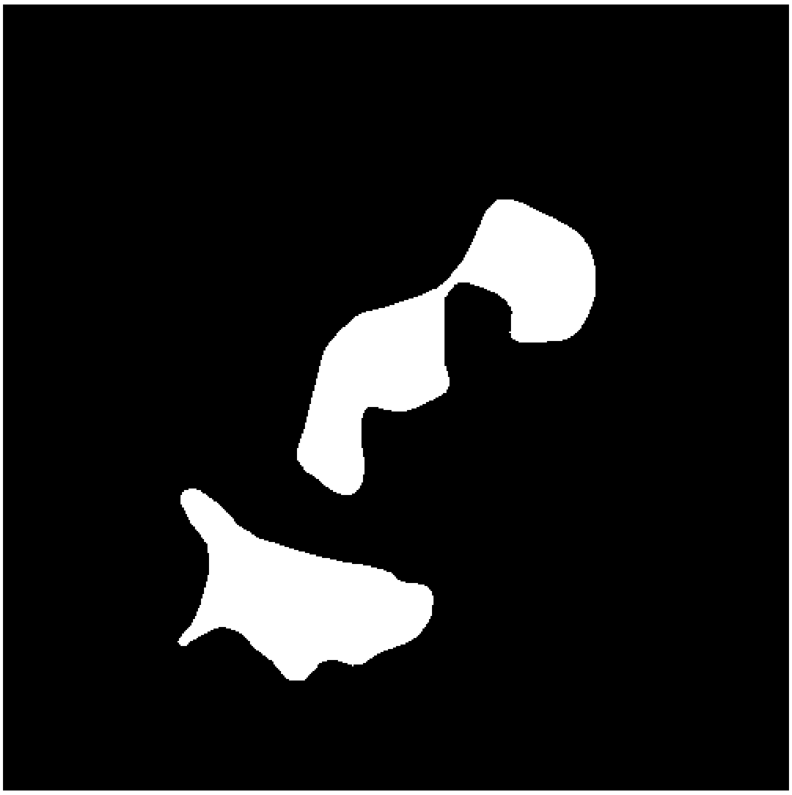


Final Processed Image B-18: D' Kayangan Lake

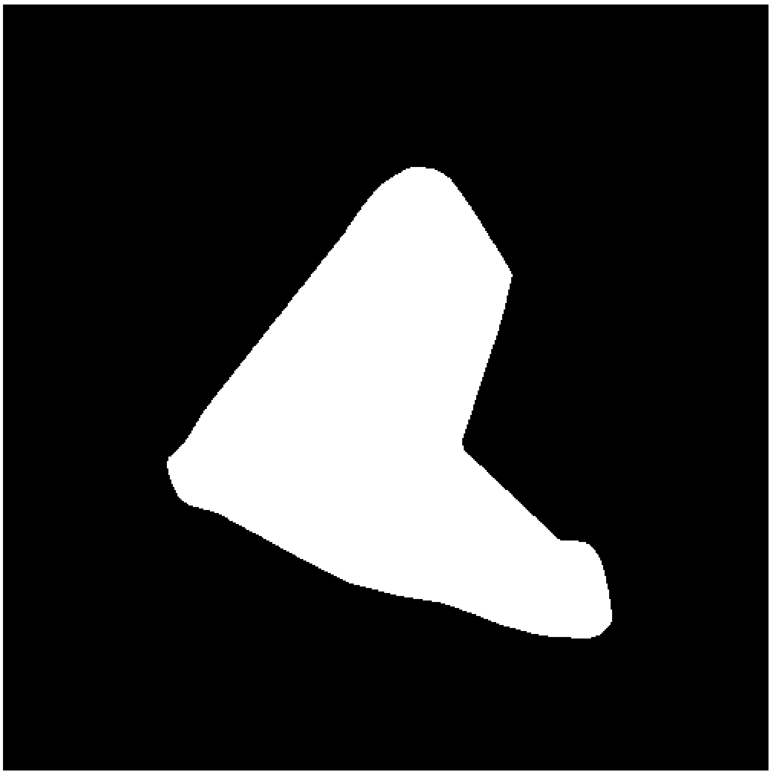


Final Processed Image B-19: Fasa 1L Lake

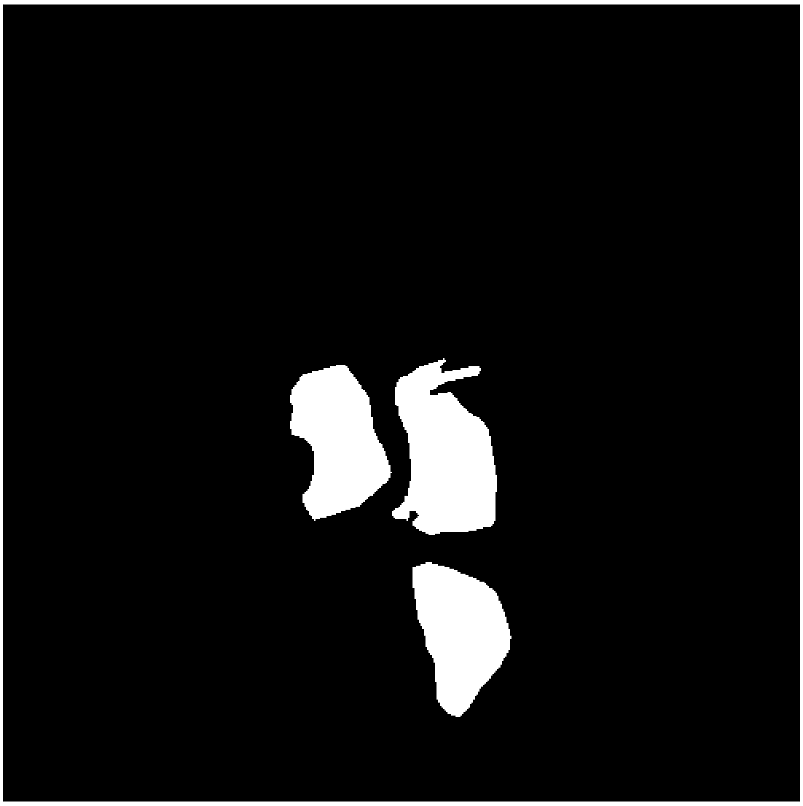
Final Processed Image B-20: Indah Mewah Lake



Final Processed Image B-21: Kebun Serendah Lake

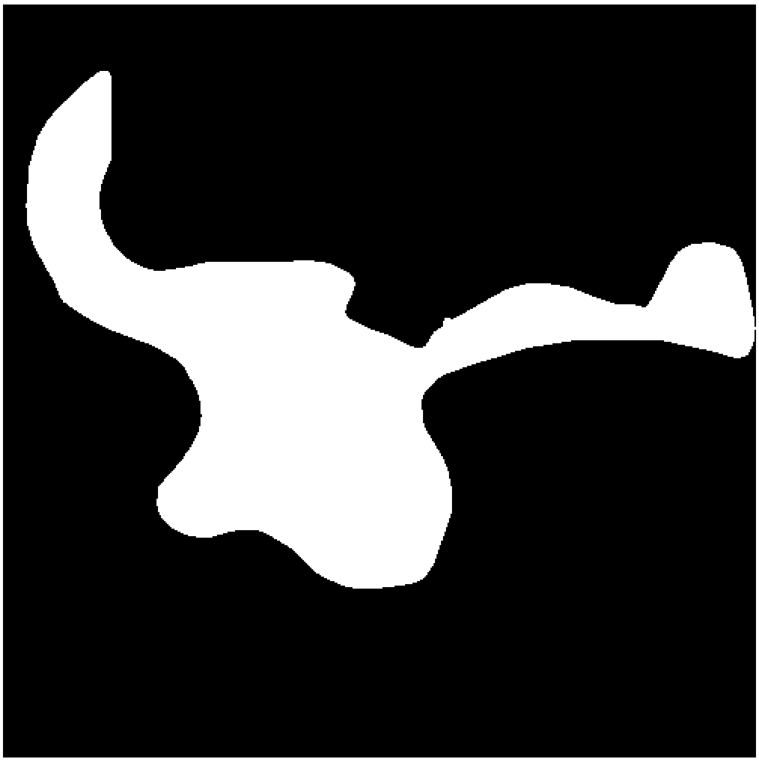


Final Processed Image B-22: Kelana Lake



Final Processed Image B-23: Kelana Jaya Lake

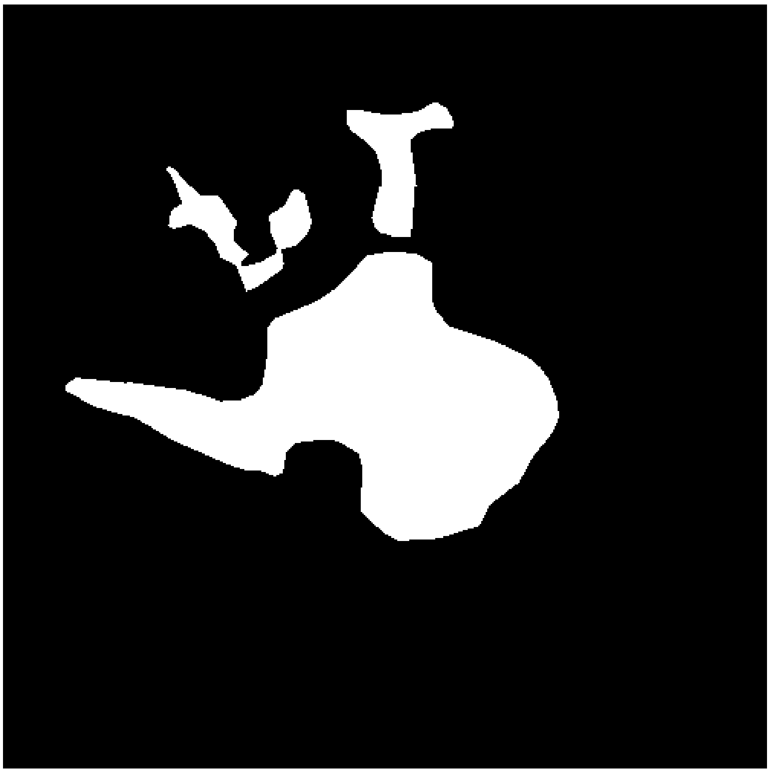
Final Processed Image B-24: Kiambang Serendah Lake



Final Processed Image B-25: Kota Kemuning Lake

Final Processed Image B-26: Kota Puteri Lake

Final Processed Image B-27: Metropolitan Kepong Lake



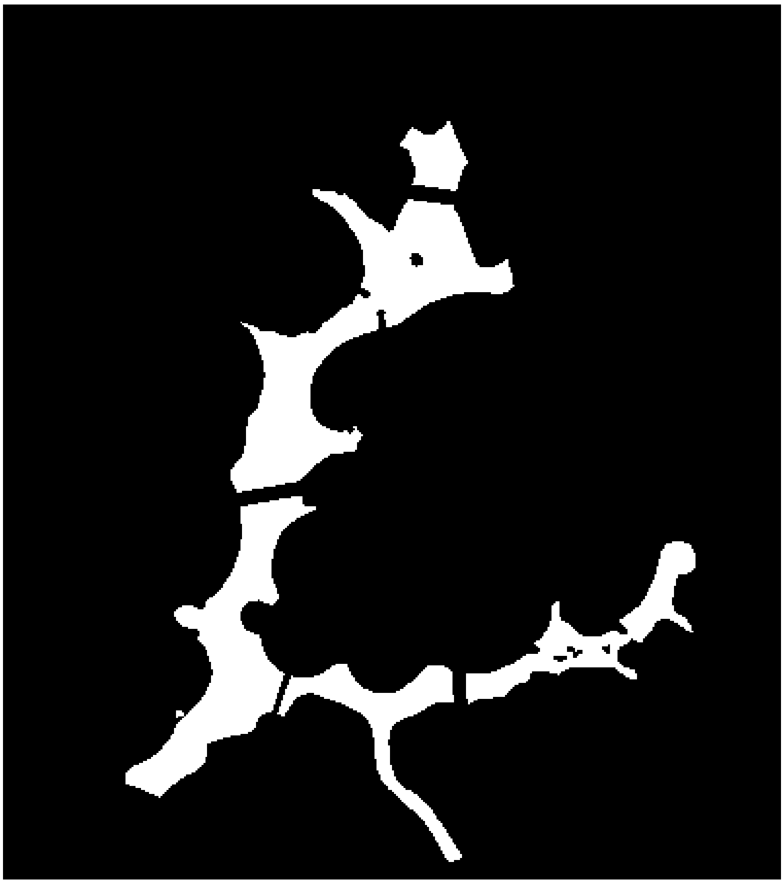
Final Processed Image B-28: Millennium Lake

Final Processed Image B-29: Pb Lake

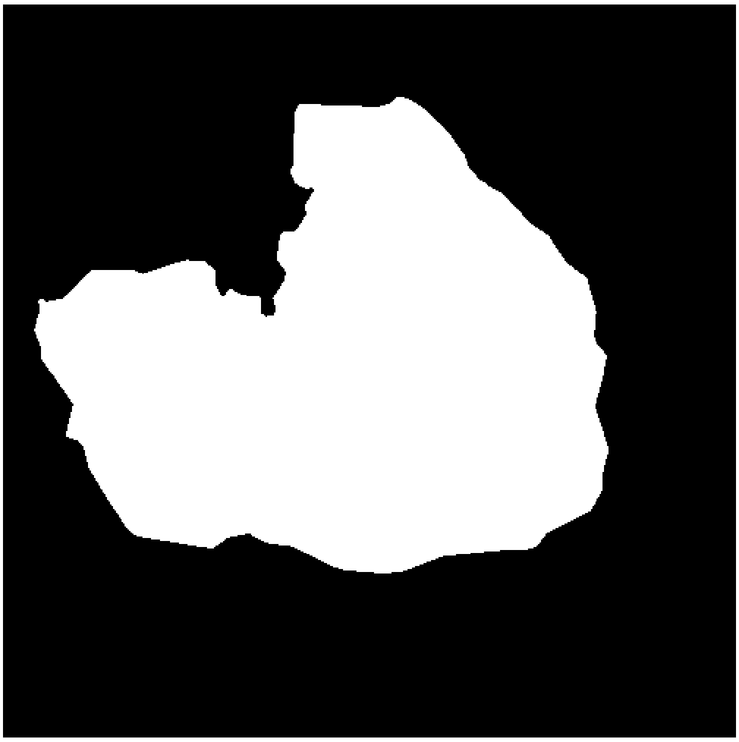
Final Processed Image B-30: Perdana Lake

Final Processed Image B-31: Prima Lake

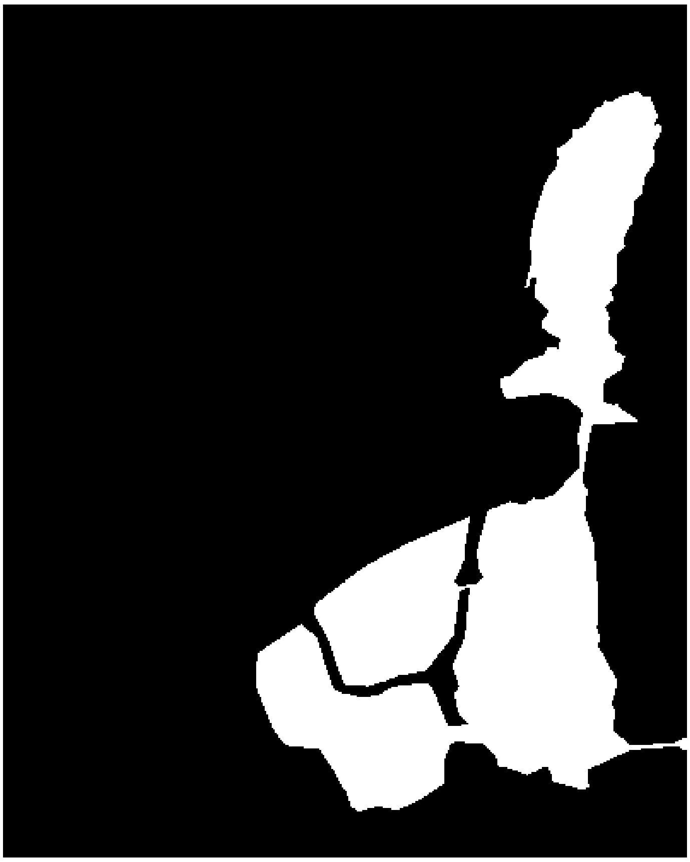
Final Processed Image B-32: Putrajaya Lake Part 1



Final Processed Image B-33: Putrajaya Lake Part 2



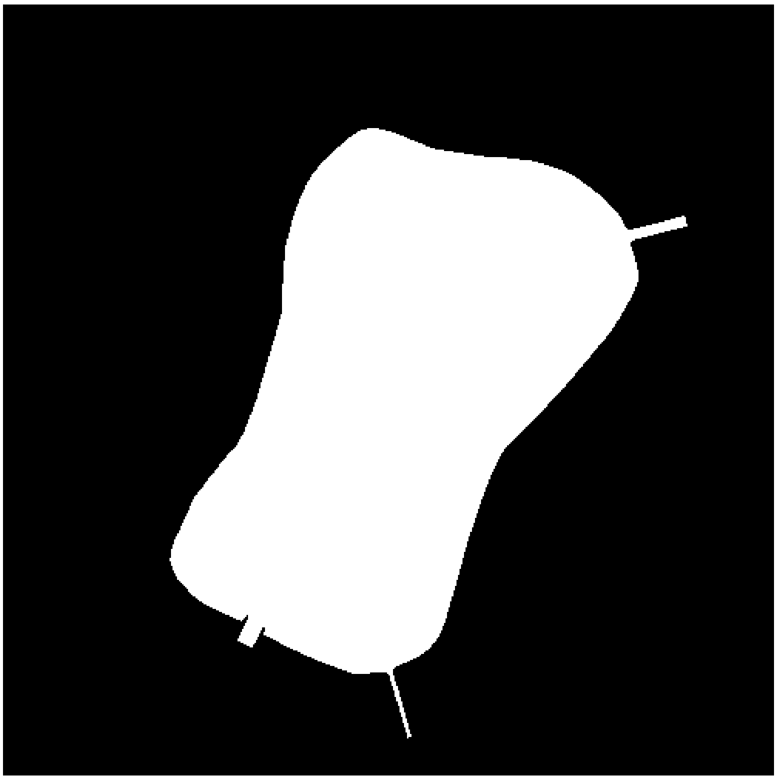
Final Processed Image B-34: Putra Perdana Lake



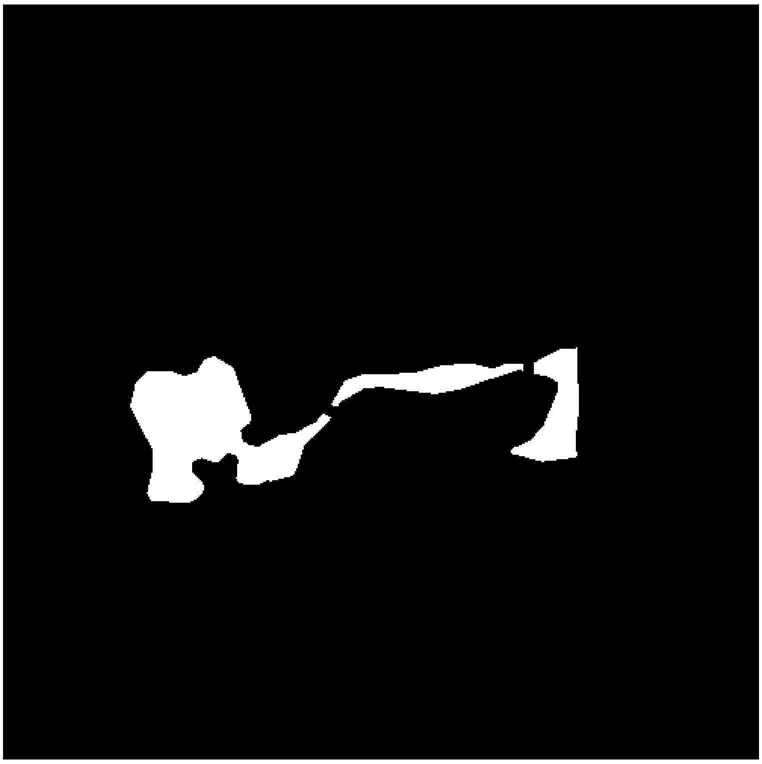
Final Processed Image B-35: Residency Lake

Final Processed Image B-36: Saujana Lake

Final Processed Image B-37: Saujana Putra Lake

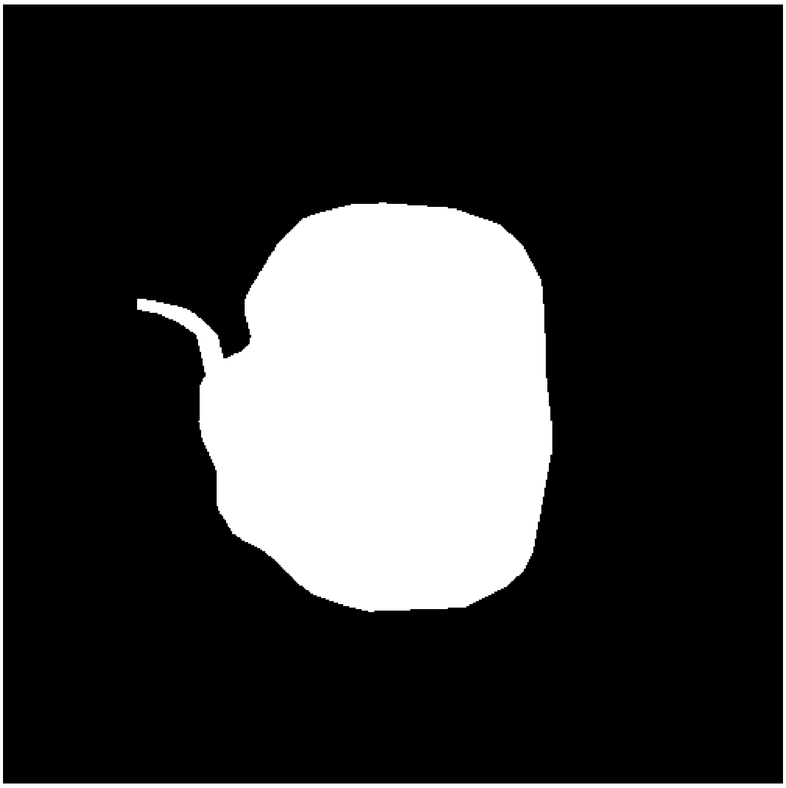


Final Processed Image B-38: Seksyen 7 Lake

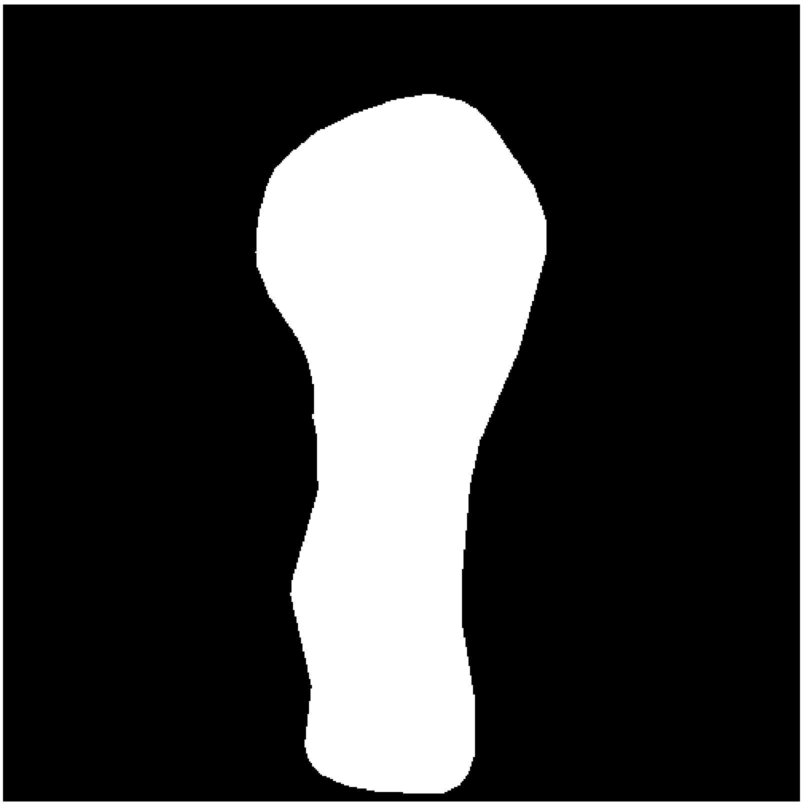


Final Processed Image B-39: Semenyih Lake

Final Processed Image B-40: Seri Aman Lake

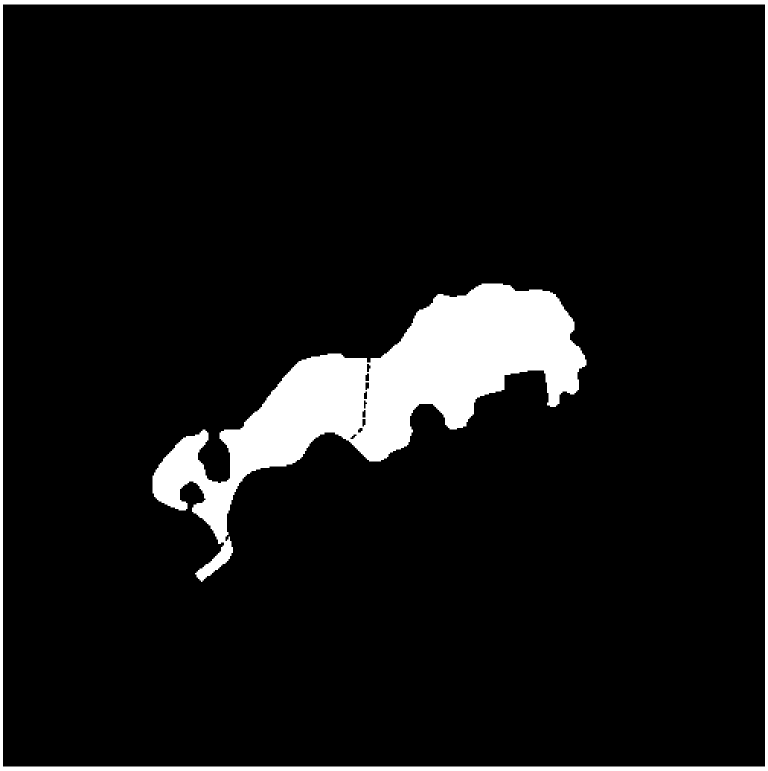


Final Processed Image B-41: Seri Serdang Lake



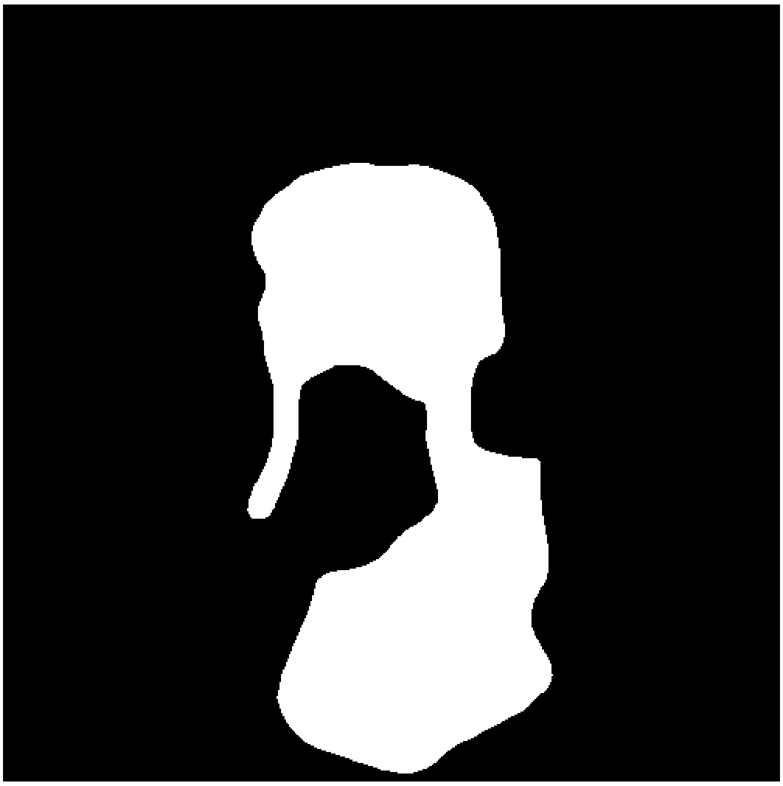
Final Processed Image B-42: Serumpun Lake

Final Processed Image B-43: Shah Alam Lake 1



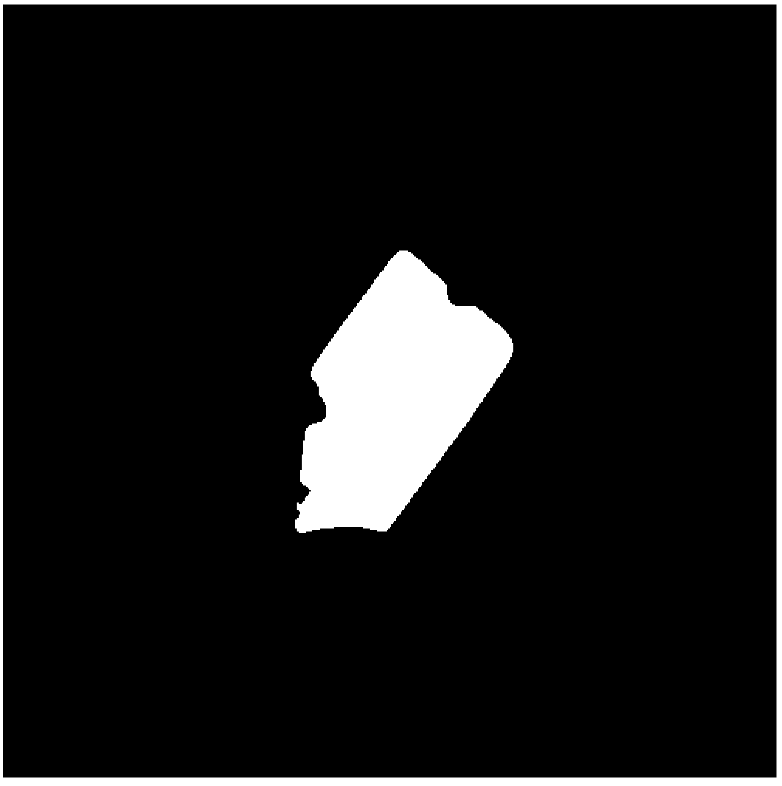
Final Processed Image B-44: Shah Alam Lake 2

Final Processed Image B-45: Shah Alam Lake 3



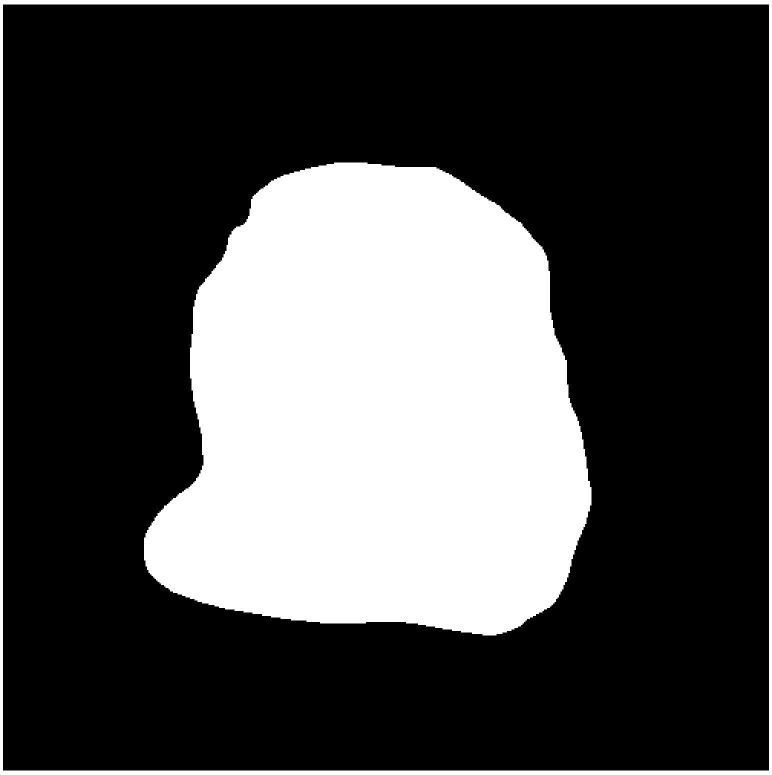
Final Processed Image B-46: Southlake Residence Lake

Final Processed Image B-47: Sri Murni Lake



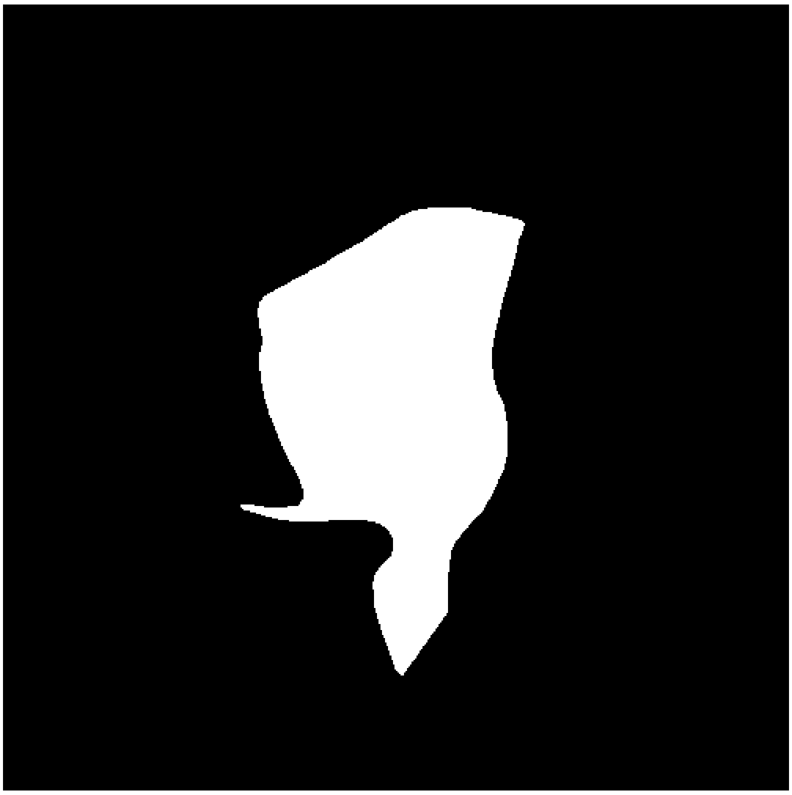
Final Processed Image B-48: Sri Rampai Lake

Final Processed Image B-49: Subang Dam



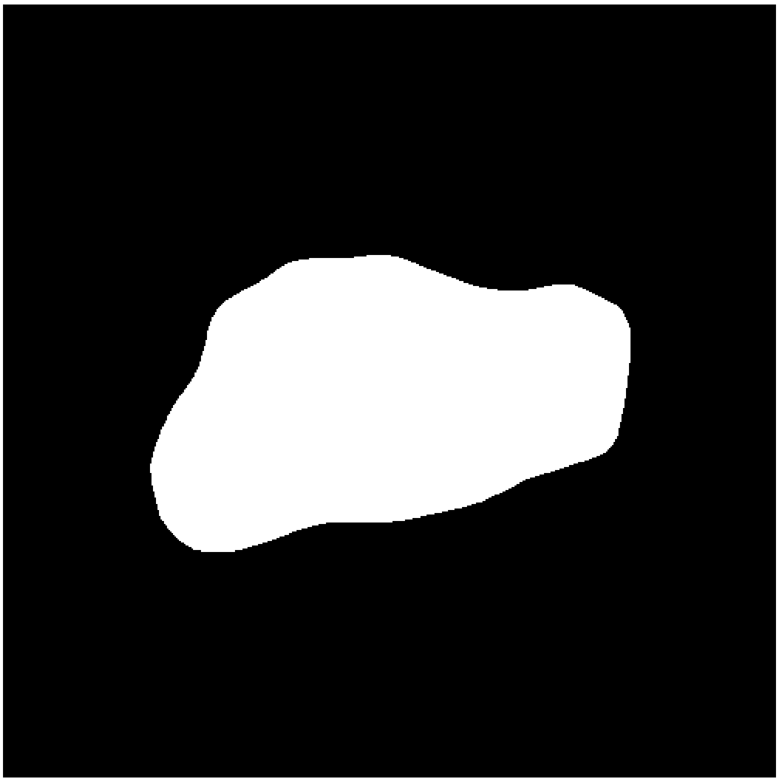
Final Processed Image B-50: Sunway Lake 1

Final Processed Image B-51: Sunway Lake 2



Final Processed Image B-52: Sunway Serene Lake

Final Processed Image B-53: Taman Dengkil Jaya Lake



Final Processed Image B-54: Taman Subang Ria Lake

Final Processed Image B-55: Teratai Lake 1

Final Processed Image B-56: Teratai Lake 2

Final Processed Image B-57: The Mines Lake

Final Processed Image B-58: Titiwangsa Lake

APPENDIX C: Results for Comparison of PV Capacity, Annual Electricity Yield and Lake Utilization Rate

Table C-1: PV Capacity, Annual Electricity Yield and Lake Utilization Rate Without Consideration of Solar Panels Per String

Lake name	Number of panels	PV Capacity/ MW	Annual electricity yield/ MW	Lake utilization rate/ %
Batu Dam	663014	165.7535	212164.48	49.36
Klang Gates Dam	651965	162.99125	208628.8	49.36
Semenyih Dam	1000893	250.22325	320285.76	49.36
Sungai Langat Dam	583823	145.95575	186823.36	49.37
Alam Impian Lake	11270	2.8175	3606.4	49.1
Aman Lake	5361	1.34025	1715.52	49.03
Ampang Hilir Lake	33201	8.30025	10624.32	49.27
Bandar Bukit Raja Lake 1	16818	4.2045	5381.76	49.19
Bandar Bukit Raja Lake 2	15016	3.754	4805.12	49.12
Bandar Tun Hussein Onn Lake	13778	3.4445	4408.96	48.98
Bersatu Lake	4423	1.10575	1415.36	49.1
Beruang Bbsa Lake	30561	7.64025	9779.52	49.13
Biru Seri Kundang Lake	78851	19.71275	25232.32	49.33
Cempaka Lake	14855	3.71375	4753.6	48.94
Cyberjaya Lake 1	22049	5.51225	7055.68	49.21
Cyberjaya Lake 2	64226	16.0565	20552.32	49.25
D' Island Lake	214727	53.68175	68712.64	49.34
D' Kayangan Lake	2128	0.532	680.96	48.83
Fasa 1L Lake	1059	0.26475	338.88	47.38
Indah Mewah Lake	176168	44.042	56373.76	49.34
Kebun Serendah Lake	9058	2.2645	2898.56	48.95

Kelana Lake	18516	4.629	5925.12	49.16
Kelana Jaya Lake	21380	5.345	6841.6	49.16
Kiambang Serendah Lake	69910	17.4775	22371.2	49.3
Kota Kemuning Lake	20279	5.06975	6489.28	49.19
Kota Puteri Lake	21200	5.3	6784	49.18
Metropolitan Kepong Lake	130643	32.66075	41805.76	49.33
Millennium Lake	52547	13.13675	16815.04	49.24
Pb Lake	18721	4.68025	5990.72	49.16
Perdana Lake	10749	2.68725	3439.68	48.77
Prima Lake	329990	82.4975	105596.8	49.34
Putrajaya Lake Part 1	745271	186.31775	238486.72	49.36
Putrajaya Lake Part 2	424705	106.17625	135905.6	49.31
Putra Perdana Lake	547316	136.829	175141.12	49.39
Residency Lake	226067	56.51675	72341.44	49.31
Saujana Lake	4725	1.18125	1512	48.85
Saujana Putra Lake	238878	59.7195	76440.96	49.36
Seksyen 7 Lake	25923	6.48075	8295.36	49.21
Semenyih Lake	15453	3.86325	4944.96	49.27
Seri Aman Lake	41134	10.2835	13162.88	49.25
Seri Serdang Lake	4979	1.24475	1593.28	48.93
Serumpun Lake	1332	0.333	426.24	48.24
Shah Alam Lake 1	25201	6.30025	8064.32	49.15
Shah Alam Lake 2	6529	1.63225	2089.28	48.92
Shah Alam Lake 3	8849	2.21225	2831.68	49.21
Southlake residence Lake	19282	4.8205	6170.24	49.07
Sri Murni Lake	49276	12.319	15768.32	49.22
Sri Rampai Lake	6221	1.55525	1990.72	49.02
Subang Dam	253448	63.362	81103.36	49.3
Sunway Lake 1	28551	7.13775	9136.32	49.22

Sunway Lake 2	8615	2.15375	2756.8	49.08
Sunway Serene Lake	12412	3.103	3971.84	49.05
Taman Dengkil Jaya Lake	48293	12.07325	15453.76	49.22
Taman Subang Ria Lake	17887	4.47175	5723.84	49.28
Teratai Lake 1	75432	18.858	24138.24	49.28
Teratai Lake 2	80155	20.03875	25649.6	49.28
The Mines Lake	209580	52.395	67065.6	49.3
Titiwangsa Lake	40546	10.1365	12974.72	49.25
	7473239 (Total)	1868.30975 (Total)	2391436.48 (Total)	49.14 (Average)

Table C-2: PV capacity, annual electricity yield and lake utilization rate for arrangement of solar panels from direction of south to north

Lake name	Number of strings	PV Capacity/ MW	Annual electricity yield/ MW	Lake utilization rate/ %
Batu Dam	26959	161.754	207045.12	48.17
Klang Gates Dam	26355	158.13	202406.4	47.89
Semenyih Dam	40565	243.39	311539.2	48.01
Sungai Langat Dam	23839	143.034	183083.52	48.39
Alam Impian Lake	405	2.43	3110.4	42.35
Aman Lake	194	1.164	1489.92	42.59
Ampang Hilir Lake	1285	7.71	9868.8	45.77
Bandar Bukit Raja Lake 1	603	3.618	4631.04	42.33
Bandar Bukit Raja Lake 2	561	3.366	4308.48	44.04
Bandar Tun Hussein Onn Lake	460	2.76	3532.8	39.25
Bersatu Lake	155	0.93	1190.4	41.29

Beruang Bbsa Lake	1094	6.564	8401.92	42.21
Biru Seri Kundang Lake	3120	18.72	23961.6	46.84
Cempaka Lake	501	3.006	3847.68	39.61
Cyberjaya Lake 1	843	5.058	6474.24	45.15
Cyberjaya Lake 2	2507	15.042	19253.76	46.13
D' Island Lake	8616	51.696	66170.88	47.51
D' Kayangan Lake	68	0.408	522.24	37.45
Fasa 1L Lake	9	0.054	69.12	9.66
Indah Mewah Lake	7084	42.504	54405.12	47.62
Kebun Serendah Lake	305	1.83	2342.4	39.56
Kelana Lake	683	4.098	5245.44	43.52
Kelana Jaya Lake	776	4.656	5959.68	42.83
Kiambang Serendah Lake	2770	16.62	21273.6	46.88
Kota Kemuning Lake	752	4.512	5775.36	43.77
Kota Puteri Lake	791	4.746	6074.88	44.04
Metropolitan Kepong Lake	5208	31.248	39997.44	47.2
Millennium Lake	2022	12.132	15528.96	45.48
Pb Lake	690	4.14	5299.2	43.49
Perdana Lake	304	1.824	2334.72	33.12
Prima Lake	13297	79.782	102120.96	47.72
Putrajaya Lake Part 1	30181	181.086	231790.08	47.98
Putrajaya Lake Part 2	16854	101.124	129438.72	46.96
Putra Perdana Lake	22425	134.55	172224	48.57
Residency Lake	8912	53.472	68444.16	46.65
Saujana Lake	147	0.882	1128.96	36.48
Saujana Putra Lake	9744	58.464	74833.92	48.33
Seksyen 7 Lake	984	5.904	7557.12	44.83
Semenyih Lake	585	3.51	4492.8	44.76
Seri Aman Lake	1607	9.642	12341.76	46.18

Seri Serdang Lake	178	1.068	1367.04	41.98
Serumpun Lake	18	0.108	138.24	15.65
Shah Alam Lake 1	919	5.514	7057.92	43.02
Shah Alam Lake 2	226	1.356	1735.68	40.64
Shah Alam Lake 3	321	1.926	2465.28	42.84
Southlake residence Lake	699	4.194	5368.32	42.7
Sri Murni Lake	1852	11.112	14223.36	44.39
Sri Rampai Lake	199	1.194	1528.32	37.64
Subang Dam	10025	60.15	76992	46.8
Sunway Lake 1	1121	6.726	8609.28	46.38
Sunway Lake 2	294	1.764	2257.92	40.19
Sunway Serene Lake	451	2.706	3463.68	42.78
Taman Dengkil Jaya Lake	1842	11.052	14146.56	45.06
Taman Subang Ria Lake	692	4.152	5314.56	45.76
Teratai Lake 1	2947	17.682	22632.96	46.21
Teratai Lake 2	3144	18.864	24145.92	46.39
The Mines Lake	8291	49.746	63674.88	46.81
Titiwangsa Lake	1581	9.486	12142.08	46.09
	299060 (Total)	1794.36 (Total)	2296780.8 (Total)	43.14 (Average)

Table C-3: PV capacity, annual electricity yield and lake utilization rate for arrangement of solar panels from direction of east to west

Lake name	Number of strings	PV Capacity /MW	Annual electricity yield /MW	Lake utilization rate /%
Batu Dam	27126	162.756	208327.68	48.47
Klang Gates Dam	26285	157.71	201868.8	47.76

Semenyih Dam	40615	243.69	311923.2	48.07
Sungai Langat Dam	23708	142.248	182077.44	48.12
Alam Impian Lake	385	2.31	2956.8	40.26
Aman Lake	164	0.984	1259.52	36
Ampang Hilir Lake	1264	7.584	9707.52	45.02
Bandar Bukit Raja Lake 1	627	3.762	4815.36	44.01
Bandar Bukit Raja Lake 2	562	3.372	4316.16	44.12
Bandar Tun Hussein Onn Lake	497	2.982	3816.96	42.41
Bersatu Lake	127	0.762	975.36	33.84
Beruang Bbsa Lake	1191	7.146	9146.88	45.95
Biru Seri Kundang Lake	3123	18.738	23984.64	46.89
Cempaka Lake	547	3.282	4200.96	43.25
Cyberjaya Lake 1	835	5.01	6412.8	44.72
Cyberjaya Lake 2	2544	15.264	19537.92	46.82
D' Island Lake	8713	52.278	66915.84	48.05
D' Kayangan Lake	49	0.294	376.32	26.99
Fasa 1L Lake	34	0.204	261.12	36.51
Indah Mewah Lake	7139	42.834	54827.52	47.99
Kebun Serendah Lake	311	1.866	2388.48	40.34
Kelana Lake	691	4.146	5306.88	44.03
Kelana Jaya Lake	817	4.902	6274.56	45.09
Kiambang Serendah Lake	2794	16.764	21457.92	47.29
Kota Kemuning Lake	722	4.332	5544.96	42.03
Kota Puteri Lake	795	4.77	6105.6	44.26
Metropolitan Kepong Lake	5273	31.638	40496.64	47.79
Millennium Lake	2010	12.06	15436.8	45.21
Pb Lake	675	4.05	5184	42.54

Perdana Lake	377	2.262	2895.36	41.07
Prima Lake	13465	80.79	103411.2	48.32
Putrajaya Lake Part 1	30052	180.312	230799.36	47.77
Putrajaya Lake Part 2	17082	102.492	131189.76	47.6
Putra Perdana Lake	22324	133.944	171448.32	48.35
Residency Lake	9122	54.732	70056.96	47.75
Saujana Lake	146	0.876	1121.28	36.23
Saujana Putra Lake	9581	57.486	73582.08	47.52
Seksyen 7 Lake	1001	6.006	7687.68	45.61
Semenyih Lake	443	2.658	3402.24	33.9
Seri Aman Lake	1591	9.546	12218.88	45.72
Seri Serdang Lake	169	1.014	1297.92	39.86
Serumpun Lake	48	0.288	368.64	41.72
Shah Alam Lake 1	944	5.664	7249.92	44.19
Shah Alam Lake 2	192	1.152	1474.56	34.53
Shah Alam Lake 3	319	1.914	2449.92	42.58
Southlake residence Lake	749	4.494	5752.32	45.75
Sri Murni Lake	1952	11.712	14991.36	46.79
Sri Rampai Lake	216	1.296	1658.88	40.85
Subang Dam	9964	59.784	76523.52	46.52
Sunway Lake 1	1106	6.636	8494.08	45.76
Sunway Lake 2	288	1.728	2211.84	39.37
Sunway Serene Lake	468	2.808	3594.24	44.39
Taman Dengkil Jaya Lake	1875	11.25	14400	45.86
Taman Subang Ria Lake	635	3.81	4876.8	41.99
Teratai Lake 1	3034	18.204	23301.12	47.57
Teratai Lake 2	3167	19.002	24322.56	46.73
The Mines Lake	8560	51.36	64740.8	48.33
Titiwangsa Lake	1524	9.144	11704.32	44.43

	300017 (Total)	1800.102 (Total)	2303130.56 (Total)	43.81 (Average)

Table C-4: PV capacity, annual electricity yield and lake utilization rate for arrangement of solar panels from direction of west to east

Lake name	Number of strings	PV Capacity /MW	Annual electricity yield /MW	Lake utilization rate /%
Batu Dam	27126	162.756	208327.68	48.47
Klang Gates Dam	26281	157.686	201838.08	47.75
Semenyih Dam	40624	243.744	311992.32	48.08
Sungai Langat Dam	23703	142.218	182039.04	48.11
Alam Impian Lake	386	2.316	2964.48	40.36
Aman Lake	162	0.972	1244.16	35.56
Ampang Hilir Lake	1264	7.584	9707.52	45.02
Bandar Bukit Raja Lake 1	626	3.756	4807.68	43.94
Bandar Bukit Raja Lake 2	562	3.372	4316.16	44.12
Bandar Tun Hussein Onn Lake	496	2.976	3809.28	42.32
Bersatu Lake	129	0.774	990.72	34.37
Beruang Bbsa Lake	1188	7.128	9123.84	45.84
Biru Seri Kundang Lake	3120	18.72	23961.6	46.84
Cempaka Lake	547	3.282	4200.96	43.25
Cyberjaya Lake 1	832	4.992	6389.76	44.56
Cyberjaya Lake 2	2548	15.288	19568.64	46.89
D' Island Lake	8710	52.26	66892.8	48.03
D' Kayangan Lake	50	0.3	384	27.54
Fasa 1L Lake	34	0.204	261.12	36.51
Indah Mewah Lake	7141	42.846	54842.88	48
Kebun Serendah Lake	312	1.872	2396.16	40.47

Kelana Lake	689	4.134	5291.52	43.9
Kelana Jaya Lake	816	4.896	6266.88	45.03
Kiambang Serendah Lake	2794	16.764	21457.92	47.29
Kota Kemuning Lake	718	4.308	5514.24	41.8
Kota Puteri Lake	795	4.77	6105.6	44.26
Metropolitan Kepong Lake	5275	31.65	40512	47.8
Millennium Lake	2009	12.054	15429.12	45.18
Pb Lake	675	4.05	5184	42.54
Perdana Lake	377	2.262	2895.36	41.07
Prima Lake	13464	80.784	103403.52	48.32
Putrajaya Lake Part 1	30049	180.294	230776.32	47.77
Putrajaya Lake Part 2	17083	102.498	131197.44	47.6
Putra Perdana Lake	22322	133.932	171432.96	48.34
Residency Lake	9128	54.768	70103.04	47.78
Saujana Lake	147	0.882	1128.96	36.48
Saujana Putra Lake	9577	57.462	73551.36	47.5
Seksyen 7 Lake	995	5.97	7641.6	45.33
Semenyih Lake	450	2.7	3456	34.43
Seri Aman Lake	1591	9.546	12218.88	45.72
Seri Serdang Lake	169	1.014	1297.92	39.86
Serumpun Lake	46	0.276	353.28	39.98
Shah Alam Lake 1	946	5.676	7265.28	44.28
Shah Alam Lake 2	192	1.152	1474.56	34.53
Shah Alam Lake 3	318	1.908	2442.24	42.44
Southlake residence Lake	748	4.488	5744.64	45.69
Sri Murni Lake	1953	11.718	14999.04	46.81
Sri Rampai Lake	214	1.284	1643.52	40.47
Subang Dam	9975	59.85	76608	46.57
Sunway Lake 1	1106	6.636	8494.08	45.76

Sunway Lake 2	289	1.734	2219.52	39.51
Sunway Serene Lake	470	2.82	3609.6	44.58
Taman Dengkil Jaya Lake	1876	11.256	14407.68	45.89
Taman Subang Ria Lake	635	3.81	4876.8	41.99
Teratai Lake 1	3038	18.228	23331.84	47.63
Teratai Lake 2	3164	18.984	24299.52	46.69
The Mines Lake	8560	51.36	64740.8	48.33
Titiwangsa Lake	1525	9.15	11712	44.46
	300019 (Total)	1800.114 (Total)	2303145.92 (Total)	43.79 (Average)

APPENDIX D: Floating solar system design

SKU: SM-250W30V-P

Specification	Quick Overview	Package List

Material: Polycrystalline Silicon

Max. Power: 250W

Open-circuit: 37.56V

Max. Power Point Voltage: 31.44V

Short-circuit current: 8.59A

Max. Power Point Current: 7.95A

Number of Cells: 60pcs

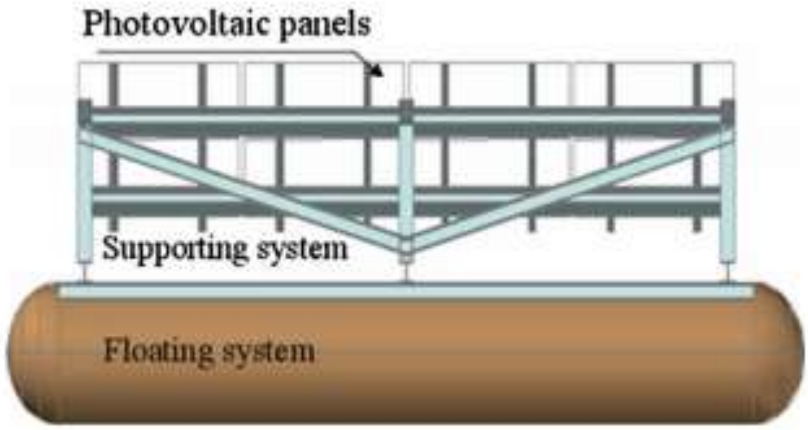
Size: 1640 x 990 x 40mm

Solar Panel Frame: Silver/ Blk Anodized Aluminum

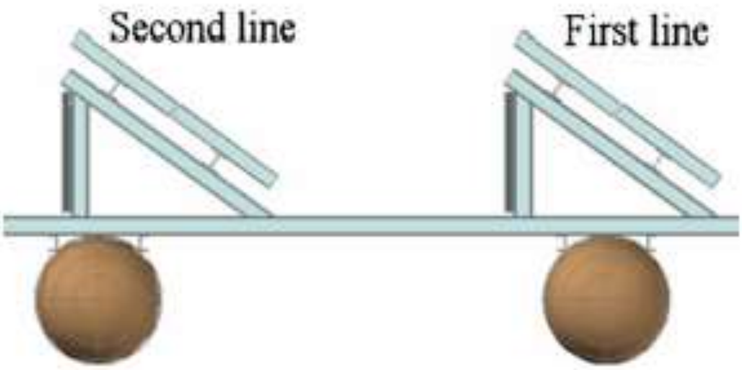
Solar Panels Glass: 3.2mm, High Transmission, AR Coated Tempered Glass

Floating solar system design D-1: Specifications of solar panels in this study (Solarmo, 2020)

Floating solar system design D-2: Floating system (Lee, Joo and Yoon, 2014)



Floating solar sytem design D-3: Rear view of floating solar system (Lee, Joo and Yoon, 2014)



Floating solar system design D-4: Side view of floating solar system (Lee, Joo and Yoon, 2014)