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# GROUNDWATER CONCEPTUAL MODEL FOR PADDY IRRIGATION

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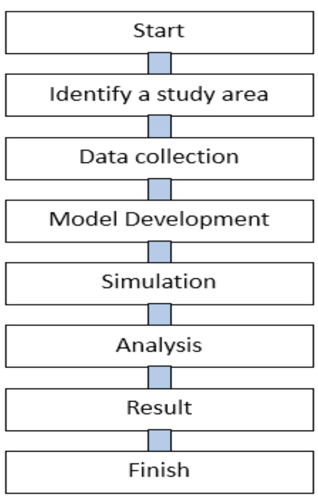
**Graphical abstract**




**Abstract**

Hydrological modelling is representative of current, past or future hydrologic balance. It has been used widely in water-related problem such as drought, flood, water contamination and irrigation. Crops irrigation requires a lot of water to irrigate the root zone layer especially for paddy crops. With the current issues of water such as drought and pollution, an alternative source is needed to overcome the problem of water scarcity. Generally Malaysia depends on the surface water to irrigate the crops with no aided of groundwater. This study focuses on the availability of groundwater resources to irrigate the paddy crops. Hence, a conceptual model of groundwater flow was developed to shows the current situation of the groundwater flow at the study area. Several models were developed to see if groundwater can be extracted using wells and be used as an alternative source for irrigation. The study area is located at Sawah Sempadan, which is one of Malaysia's greeneries areas under Tanjung Karang Rice Irrigation Scheme (TAKRIS). The conceptual model is built by using Visual MODFLOW 4.2. The conceptual model shows the current water balance, water table elevation and equipotential head in the study area. Simulations with pump wells have been done to shows the availability of groundwater sources for paddy irrigation. The result shows that groundwater flows from area of higher elevation towards the lower elevated area. It is also shows that groundwater extraction could not be too excessive as it may dry up the aquifer storage.

*Keywords*: Groundwater extraction, paddy irrigation



## 1.0 INTRODUCTION

Malaysia is a rich country with natural resources such as water and petroleum. In Malaysia, surface water is the major sources of water for domestic or non-domestic uses. This is due to the tropical climate where Malaysia receives an average rainfall of 2000-3000mm/yr [1]. It is the only surface water source for Malaysia as this country does not experienced snowmelts. The rainfall fills the water storage such as dam, lakes, river and groundwater aquifer.

However, there are also natural catastrophe that involves water, which are floods and drought that still occur and could affect the water resources. Those catastrophes are not only affecting the water resources but also can cause loss of lives, injuries, property damage and economic damages. In 2014, Malaysia experience a hot and dry season on January and February with high temperature between 34°C to 36°C. During this season, the evapotranspiration (ET) increase and rainfall decrease resulting in reduction of water storage in dam, river and lakes [2].

Agriculture industry is the most affected industry because of the drought [3]. This is because most of agriculture areas in Malaysia are depending on surface water to irrigate the crops. Insufficient of water to irrigate the crops will affect the yield [4].

The study area is located at Sawah Sempadan, Tanjung Karang Selangor. The major crops planted on the study area are paddy. In this area, paddy is cultivated two times a year usually from August to January (main/wet season) and February to July (off/dry season). Paddy is a crop that needs stagnant water to lives. Sawah Sempadan is one of the irrigation service areas under the scheme of Tanjung Karang Rice Irrigation Scheme (TAKRIS). In TAKRIS, there is no surface water storage such as dam or lake to be used as the source of paddy irrigation. The only source for

TAKRIS is the water supply from Bernam River where the supply is diverted at the Bernam River Headwork (BRH) into the feeder canal and conveyed into Tengi River. Then, the water conveyed into the main canal at Tengi River Headwork. The distance from BRH to TRH is about 36 km. From the main canal, the water then is distributed via tertiary canal and diverted directly to paddy field by field off-take pipe. A standard irrigation blocks receive water in their paddy plots direct from two tertiary canals. The scheme is divided into three irrigation service areas (ISA) where water delivery is staggered by one month starting from July in main season and February in off-season. In this way, pre-saturation of the whole project area is completed within three months. The pre-saturation irrigation supply starts in July for main season and January for wet season. Pre-saturation supply is to saturate the root zone layer. The period for pre-saturation supply is 30 days followed by supplementary supply for another 85 days to keep the water ponding. The supply will end two weeks before the last paddy lots harvested [5]. The water demand estimation for a hectare of paddy lot per season is 1000-1500 mm. The recommended design pre-saturation and supplementary irrigation requirements for the rice irrigation systems are 2.31 l/s/ha (20 mm/day) and 1.16 l/s/ha (10 mm/day), respectively [6]. The highest demand of water is during the pre-saturation period where 200 mm of water is needed to saturate the root zone layer.

With the increasing water demand and the problem of water shortage because of drought, an alternative water resource is needed to overcome those problems. Groundwater resources could be the alternative water resources to irrigate the crops if there were surface water crisis. Groundwater is water located below the ground surface in soil pore spaces and rock fractures. In nature, surface water and groundwater are intimately connected via the water cycle. Surface water, flowing or stagnant, percolates downward through the soil and becomes part of the groundwater table. The groundwater then either becomes stored (temporarily or permanently) or flows down gradient and is often forced to the surface in areas such as springs, seeps, and wetlands [7]. Based on JICA study in 1982, groundwater storage in Malaysia is estimated 5000 $m^3$ with annual groundwater recharge of 64 $m^3$ annually. Malaysia's groundwater resources can be categorized into five types of bedrock, which is alluvium (sand and gravel), limestone, sedimentary basins, fractured sandstone and fractured igneous rock.

In this study, a groundwater model is built in order to identify the groundwater profile in terms of its available storage and flow direction. Movement in the atmosphere and land surface is relatively easy to visualize, but the movement of groundwater is not. Groundwater moves along flow paths of varying lengths in transmitting water from areas of recharge to areas of discharge [8]. The source of groundwater is infiltration of precipitation through unsaturated zone. Before groundwater can be extract, certain procedure must be follow. Geophysical surveys need to be done to know the soil layer properties, type of bedrock and available underground water storage. Most common geophysical survey is soil resistivity method where its measure of how much the soil resists the flow of electricity. As the soil resistance is lowers it indicates the soil holds much water because water is conductance for electricity [9]. Then, tubes well need to be drill and build to extract the groundwater. Pumping test is important to know available storage of groundwater and permissible groundwater extraction rate. Generally, a submersible pump is used to pump out the groundwater. The water then can be used directly or stored in the tank.

At Kuala Selangor where the study area is located, there are two existing tube wells were developed by the Department of Mineral and Geoscience Malaysia (DMGM) by using rotary mud drilling machine (BOMAG & Holy Machine Model CD80). The tube wells were developed for the purpose of groundwater resources potential study for future groundwater development plan. Some of the water wells were constructed for the emergency plan or as an alternative source of water if forest fire happens since most of the study areas are covered with peat soil. One study was done in 2014 to evaluate the performance and characteristics of the Tube Wells. Based on the results of this study, one of the tube well was identified as the most efficient tube well in Kuala Selangor with the average efficiency of 96% while the other one was categorized as high productive wells with specific capacity greater than 18 $m^2 hr^{-1}$ [10]. From this study it can be found that there are high possibility the groundwater wells to be utilized because both existing tube wells in this area was found to be high productive and efficient wells.

It is believed that the excess groundwater extraction leads to groundwater storage depletion, water contamination, land subsidence and others environmental effects. Land subsidence occurs when there is a loss of support below ground. Groundwater stored in aquifer also act as support system to the land. But when the overuse of groundwater it makes the soil collapses, compacts, and drops. Excessive pumping of groundwater can lower the groundwater table, and cause wells to no longer be able to reach groundwater. Besides, excessive pumping in coastal areas can cause saltwater to move inland and upward, resulting in saltwater intrusion and contaminate the fresh groundwater sources [11].

In the Shiroishi lowland plain, southwestern Kyushu Island of Japan, land subsidence and salinity intrusion due to intense withdrawals of groundwater have become the main environmental issues for public concern. In this study, an integrated surface and groundwater model was established and applied to the Shiroishi site to simulate groundwater flow hydraulics, aquifer compaction and solute transport in the alluvial lowland plain. A groundwater optimization model was also formulated to search for an optimal safe yield of groundwater extraction without violating salinity intrusion and other constraints. The simulated results show that groundwater levels in the aquifer greatly vary in response to varying climatic and pumping conditions. Consequently, land subsidence has rapidly occurred throughout the area with the central prone in Shiroishi basin. As a result of pumping and land subsidence, seawater has been intruded along the coast. In case of relative sea level rise, seawater intrusion appears to extend much farther in land from the coast. From the viewpoint of agricultural water management, pumping for irrigation with an optimal pumping amount that is a new finding from the optimization model will sustain groundwater quality in the study area [12].

Moreover, conjunctive use of surface water and groundwater for irrigation should plays an important role both as a source of recharge to the groundwater and as a cause of discharge by pumping. Therefore, reliable estimates of distributed groundwater recharge and discharge are critical in analysing groundwater budgets. One study was done in 2003 in Nasunogahara basin, Japan to study the effect of conjunctive use of water for paddy field irrigation on groundwater budget in an Alluvial Fan. Results of the model in this study indicate that the calculated water table elevations were able to describe the actual behaviour of the shallow aquifer adequately. From the model simulation runs, it was also found that although paddy fields are big users of groundwater by pumping, the irrigation water applied is used in a cyclic manner to recharge the shallow aquifer. The percentage of the recharge from paddy fields to the total net recharge is 21 %, which is mainly provided from paddy fields irrigated by canal water. These facts indicate the importance of the conjunctive use of surface water and groundwater for irrigation in maintaining the hydrologic system of the basin [13].

This current study is focused at the Sawah Sempadan area (see Figure 1). The purpose of this study is to shorten the period of pre-saturation irrigation supply. Sawah Sempadan area is under the ISA 1, where ISA is the short form of irrigation service area. Sawah Sempadan and Sungai Burong is the first area of Tanjung Karang Rice Irrigation Scheme (TAKRIS) to receive irrigation supply. The period of pre-saturation supply is a month where the paddy fields receive irrigation supply on January and July as the crops is cultivated two seasons per year. In order to shorten the period of pre-saturation supply, an alternative irrigation is needed. Another problem is insufficient water supply to irrigate the paddy field most probably during the peak irrigation demand and dry season. This is happen because water supplies for each block at paddy field are not flow at the same time. Insufficient of water supply for paddy field irrigation will cause the rice yield is not mature enough. In order to fulfil the irrigation demand in a paddy field, we need an alternative water source, which is groundwater.

The objectives of this research are (1) To develop a conjunctive use model for irrigation at paddy field area, (2) To suggest a solution for water crisis during irrigation period and (3) To utilize both surface and groundwater for paddy irrigation.

## 2.0 METHODOLOGY

### 2.1 Model boundary

Figure 1 shows the study area where red box highlighted on the figure is the background image for the model. An appropriate set of boundary conditions is required by every model to represent the system's relationship with the surrounding systems. In case of a groundwater flow model, boundary conditions will describe the exchange of flow between the model and the external system. Surface water bodies such as rivers and lakes may either contribute water to the groundwater system, or act as groundwater discharge zones, depending on the hydraulic gradient between the surface water body and the groundwater system. In this study, Tengi River and feeder canal flows along the study area and is expected to influence the flow conditions of the groundwater aquifer. Hence, it had been identified as a River Boundary for the model. This boundary can be classified as open boundary. Some assumptions have been made because of lack of information about the river. The thickness is assumed to be 1 m thick and the river stage on the average of 10 m from the average mean sea level (AMSL).

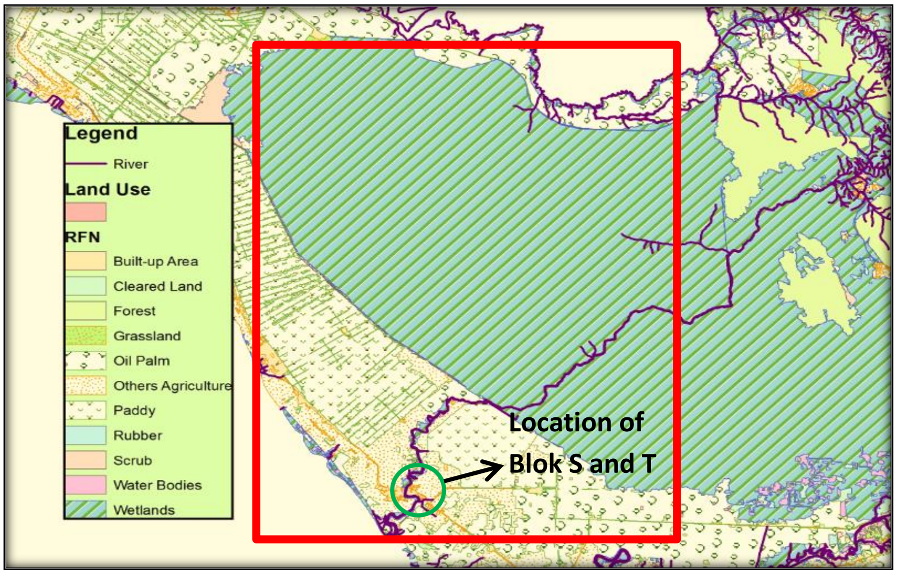



**Figure 1** Study area

## 2.2 Hydrogeological setting

In this study, the information needed in the Visual MODFLOW working environment are including porosity, hydraulic conductivity, specific storage and specific yield. These data were obtained according to its soil layer type determined from the previous groundwater modelling report at Bestari Jaya as shown in Table 1.

## 2.3 Hydrological setting

Both groundwater recharge and evapotranspiration data is based on the records from Department of Irrigation and Drainage Malaysia. The groundwater recharge is 255 mm/yr where 15% of rainfall was assumed to be stored in the groundwater aquifer. The evapotranspiration recorded is 1400 mm/yr.

## 2.4 Extraction Well

Two pumping well was assign in the model which located at Blok S and Blok T. The extraction rate is as Table 2:

**Table 1** Extraction rate of groundwater

| Pump Well | Days 1-10 ($m^3$/d) | Days 11-95 ($m^3$/d) |
|---|---|---|
| S | 12000 | 11000 |
| T | 6000 | 5500 |

The rate is based on the water requirement for pre-saturation supply and supplementary supply where pre-saturation need 20mm/day for 10 days and supplementary supply require 10mm/day for 85 days before harvesting [6]. The depth of both well is 90 meter. The purpose of the extraction of groundwater is to simulate the effect of the pumping activity at the study area.

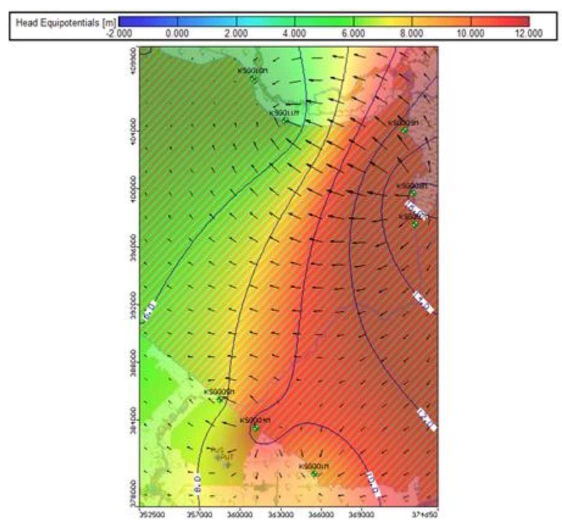



**Figure 2** Head distribution and the direction of groundwater

## 2.5 General Assumption

A conceptual groundwater model is a basic graphical representation of a complex natural aquifer system and a simplification of the real world condition while taking into consideration to make it as real as possible. Thus several assumptions are made in this study:

i. The obtained field data truly represents the whole modelled area.

ii. Groundwater recharge rate was assumed at 15% of rainfall.

iii. The time period of model was set for 1 year consisting of 365 days.

iv. Only steady-state system was considered.

**Table 2** Soil layer properties distribution

| Layer | Hydraulic Conductivity X and Y direction (m/s) | Hydraulic Conductivity Z direction (m/s) | Specific Storage (1/m) | Specific Yield | Total Porosity | Effective Porosity |
|---|---|---|---|---|---|---|
| 1 (Clay) | 3.20E-10 | 3.20E-11 | 1.30E-03 | 0.12 | 0.55 | 0.03 |
| 2 (Silt Clayey) | 3.00E-08 | 3.00E-09 | 3.00E-04 | 0.13 | 0.42 | 0.03 |
| 3 (Sand Silty) | 1.00E-05 | 1.00E-06 | 7.50E-06 | 0.23 | 0.35 | 0.10 |
| 4 (Sand) | 6.50E-05 | 6.50E-06 | 7.50E-06 | 0.23 | 0.35 | 0.20 |
| 5 (Schist) | 3.60E-07 | 3.60E-08 | 1.70E-01 | 0.026 | 0.38 | 0.26 |

## 3.0 RESULT AND DISCUSSION

### 3.1 Groundwater Flow Direction and Head Equipotential

One study was done in 2014 to simulating the groundwater flow in Sag El Naam Basin, North Darfur State, Sudan. The main objective of this study is to improve the understanding and evaluate the complex hydro geological situation and the groundwater flow regime in Sag El Naam Basin, based on visual MODFLOW which is the same software used in this current study. Arc GIS was used for conceptual model construction. A quietest software was used for calculating aquifers' hydraulic properties. The model was run and calibrated using trail-and error techniques. The aquifer hydraulic conductivity, storativity, recharge, and constant head boundary (CHB) were adjusted during calibration to obtain acceptable match between calculated and observed heads and fluxes. Generally this study successfully formulated a new method of groundwater modeling, confirmed that visual MODFLOW can be used as a comparative technique for evaluation of groundwater flow regime in Sag El Naam Basin [14].

Based on the result of this study, MODFLOW was used to identified groundwater flow direction and head equipotential for the study area in this current study. Figure 2 shows the equipotential head distribution and the direction of groundwater flow before groundwater extraction activity. From the figure, it is seen that the groundwater flows from the east to west, and also to other low water table area. The contour line as seen from

Figure 3 is the water table elevation. The highest water table elevation is 16m, recorded at the west of the study area. From the water table elevation information, the flow direction of groundwater can be generalized to flow from high water table to low water table area. There is no significance different between before and after groundwater extraction activity. This may be due to small amount of groundwater extraction. No lakes or water storage found in the study area making the river and canals are the only boundary conditions for the model. Besides, the result is not accurate as some input data is assumed.

### 3.2 Groundwater Hydraulic Heads

Hydraulics heads or known as a drawdown is a specific measurement of liquid pressure above a geodetic datum. The black contour line is the drawdown before pumping activity while the red line contour is the drawdown after pumping activity. The contour map as shown in Figure 3 is the drawdown at the Layer 1 of the model after groundwater extraction activity. Sawah Sempadan paddy field area which locates at the southeast in the figure experience significance drops of hydraulic heads due groundwater extraction.

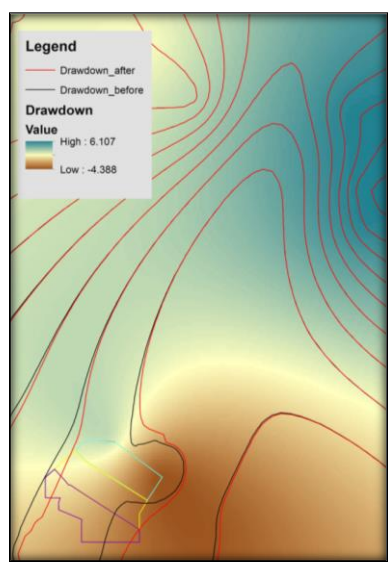



**Figure 3** Hydraulics heads contour

### 3.3 Water Balance of the Model

Water balance illustrated the magnitude of flow water in the model. The bar chart will have both the IN list and the OUT list. The IN bar tells a summary of the input of the system from each individual source term, while the OUT bar represent the output of the system through each individual sink term.

Figure 5 descibes the water balance of the steady state model when pumping activity is performed. There is no significances different between pumping and no pumping bar chart. For the normal scenario without pumping activity, the input is recharge while the output is evapotranspiration.

The total volume of groundwater extraction is 8.395M $m^3$ or 5% from the output as in Table 3. Excessive extraction of groundwater in this study area can depletes the groundwater resources. As illustrated in Figure 4, paddy field area at Sawah Sempadan turn to dry condition after simulation with 10% of the input, 18M $m^3$. The dry area is at the south of the study area, which it is Sawah Sempadan paddy field region.

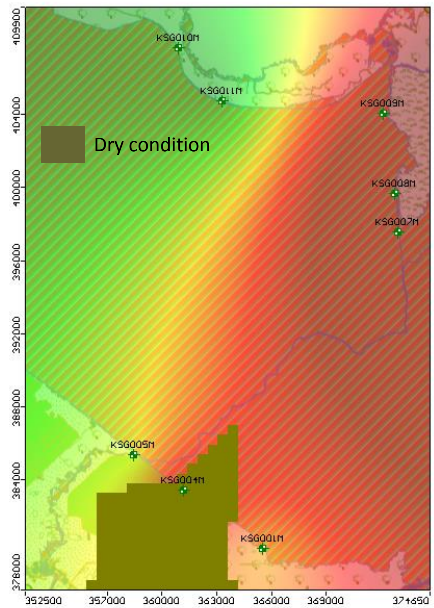



**Figure 4** Simulation with 10% input

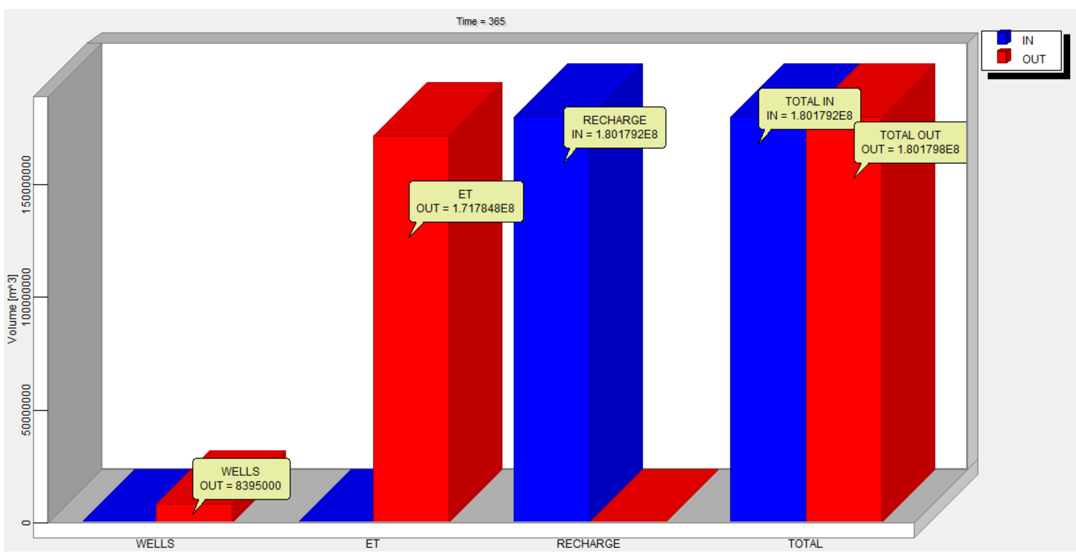



**Figure 5** Water balance model

**Table 3** Input and output percentages of the model

| | Natural Condition | | With Extraction | |
|---|---|---|---|---|
| | **In (%)** | **Out (%)** | **In (%)** | **Out (%)** |
| Wells | 0 | 0 | 0 | 5 |
| Recharge | 100 | 0 | 100 | 0 |
| Evapotranspiration | 0 | 100 | 0 | 95 |
| Total | 100 | 100 | 100 | 100 |

## 4.0 CONCLUSIONS

In this project, a conceptual model of steady state of groundwater flow simulation has been developed by using Visual MODFLOW 4.2. Through this model, the natural groundwater contour and flow direction in Sawah Sempadan and feeder canal area was determined. Furthermore, the groundwater flow direction of groundwater extraction was also determined. Also, the water balance graph showing the total inflow and outflow out was acquired.

The extraction of groundwater for paddy field irrigation to fully substitute the irrigation supply from surface water is not suitable. The aquifer storage may dry up due to continuous groundwater pumping throughout the season. However groundwater still can be extracted to overcome insufficient supply during peak irrigation supply which is during pre-saturation supply.

Based on the model result, the groundwater extraction could not be too excessive as it may dry up the aquifer storage. From this study also, it can be seen that groundwater flows from area of higher elevation towards the lower elevated area. It can be concluded, the model should incorporate more field data and accurate data, particularly for important parameters such as soil layer distribution and boundary conditions for better result.

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