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SOFTWARE DEVELOPMENT FOR ANALYZING THE ADAPTABILITY OF IRRIGATION INFRASTRUCTURE TO CLIMATE CHANGE

PENGEMBANGAN PERANGKAT LUNAK UNTUK MENGANALISA KEMAMPUAN ADAPTASI INFRASTRUKTUR IRIGASI TERHADAP PERUBAHAN IKLIM

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ABSTRAK

Sebuah perangkat lunak komputer telah dikembangkan untuk menganalisa kemampuan adaptasi infrastruktur irigasi terhadap perubahan iklim. Perangkat lunak ini dirancang untuk menghitung penurunan intensitas tanam dan peningkatan kebutuhan debit puncak akibat perubahan iklim. Agar mudah digunakan, input dan output data ditulis dalam format file MS Excel, seperti yang banyak digunakan dalam perhitungan teknik. Perangkat lunak ini telah diuji coba di Daerah Irigasi Jatiluhur pada Saluran Tarum Utara dengan total luas irigasi 85.287 ha yang terdiri dari 126 blok sekunder. Berdasarkan perhitungan, perubahan iklim akan menurunkan intensitas tanam dari 100% hingga 71% untuk waktu tanam Oktober hingga Maret, dan untuk waktu tanam April hingga September akan menurunkan intensitas tanam dari 83% menjadi 54% untuk semua skenario perubahan iklim (RCP_2.6 hingga RCP_8.5). Perubahan iklim akan meningkatkan evapotranspirasi, dan dalam beberapa bulan akan menurunkan curah hujan, sehingga kebutuhan debit puncak juga akan terpengaruh. Pada Bendung Utama Leuweung Seureuh, debit puncak akan meningkat dari 72,18 m^3/s menjadi 76,14 m^3/s. Akibatnya, debit di hilir saluran juga meningkat. Di saluran primer Citarum Utara Timur (SI TUT), debit akan meningkat dari 29,58 m^3/s menjadi 30,63 m^3/s, sedangkan saluran primer Citarum Barat Utara (SI TUB), debit akan meningkat dari 34,12 m^3/s menjadi 36,18 m^3/s.

Kata kunci: ***climate-proof, perubahan iklim, intensitas tanam, kebutuhan debit puncak, MATLAB, MS Excel***

ABSTRACT

Computer software for climate-proof irrigation infrastructure has been developed. The software is designed to compute decreasing cropping intensity and increasing peak discharge requirements due to climate change. To be user-friendly, the data input and output are written in MS Excel file format, which is widely used in engineering calculation. The tool has been tested in the Jatiluhur Irrigation Area in North Tarum Canal with a total irrigation area of 85.287 hectares, consisting of 126 secondary blocks. Based on the calculation, climate change will decrease cropping intensity from 100% up to 71% from October to March and from April to September, it will decrease the cropping intensity from 83% to 54% for all scenarios of climate change (RCP_2.6 to RCP_8.5). Because climate change will increase evapotranspiration, and in several months will decrease precipitation, then the peak discharge requirement will also affect. In the main Leuweung Seureuh Weir, the peak discharge will increase from 72.18 m^3/s up to 76.14 m^3/s. Consequently, the discharges in the canal downstream are also increasing. In the primary canal North Citarum East (SI TUT), the discharge will increase from 29.58 m^3/s to 30.63 m^3/s while primary canal North Citarum West (SI TUB), the discharge will increase from 34.12 m^3/s to 36.18 m^3/s.

Keywords: **climate-proof, climate change, cropping intensity, peak discharge requirement, MATLAB, MS Excel**

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I. INTRODUCTION

The common practice in designing irrigation areas in Indonesia is using a series book of Planning Criteria (Kriteria Perencanaan, KP) by the Ministry of Public Work and Housing (Direktorat Irigasi dan Rawa, 2013). Based on the criteria, the water availability for a half-month period is first predicted using historical discharge data. Then, irrigation scheduling is determined for a half-month period. Sofiyuddin & Rahmandani (2019) have developed a tool called SMOPI to do this task. A similar study also has been conducted by Serang (2012) and Hukom, Limantara, & Andawayanti, (2012).

However, with the coming issues of climate change, the existing irrigation infrastructures become prone to fail to operate in the future due to the changes in water availability and the change of irrigation water demand (Elliott et al., 2014; Europian Comission, 2021). In designing the irrigation canal, the dimensions of the canal should be adequate to convey the changing irrigation water demand.

The impact of climate change on irrigation water in Taoyuan, northern Taiwan has been studied Lee & Huang (2014). Based on the projections and a water balance model in paddy fields, the future crop water requirement, effective rainfall, and the demand for water for irrigation can be compared between the present (2004–2011) and the future (2046–2065). The results clearly show that climate change would lead both rainfall and the temperature to rise; this would cause effective rainfall and crop water requirements to increase during cropping seasons in the future. Overall, growing effective rainfall neutralizes increasing crop water requirement, the difference in average irrigation water requirement between the present and future is insignificant (<2.5%). However, based on a five-year return period, the future irrigation requirement is 7.1% more than the present in the first cropping season, but it is insignificantly less (2.1%) than the present in the second cropping season.

Several authors also have studied the impact of climate change on water resources, such as by Amisigo, McCluskey, & Swanson (2015) in a study of the impacts of projected climate change on water availability and crop production in the Volta Basin in Ghana, and by Al-Kalbani, Price, Abahussain, Ahmed, & O'Higgins (2014) in arid mountain regions, Al Jabal Al Akhdar; northern Sultanate of Oman.

In Indonesia, Boer & Suhartono (2012) analyzed climate change impacts on food sector. Further, Lestari, Suprayogo, & Prijono (2019), Septri (2015), and Ulfa (2021) discussed climate change impacts on irrigation water, especially for rice.

With the coming of climate change issues, to secure food crop resilience, it is necessary to do climate-proof to this rice field area, to support their operation in the future. Therefore, it is necessary to develop methodologies and tools in supporting climate-proof analysis. The objective of this paper is to develop a tool for climate-proof irrigation infrastructure. To be easy to operate, the tool should be developed using widely known software, such as MS Excel, for its input and output (Jaya, Purba, & Despa, 2022).

II. METHOD

2.1. Study Location

The material from this study is taken from the data collected by TA ADB 7189-INO Package E: Mainstreaming Climate Change in Citarum River Basin. The project was started in January 2011 to March 2013, then extended for one year till March 2014. The tool was developed at the Geomatics Laboratory, Department of Civil and Environmental Engineering, FATETA, IPB University. Additional data were added during the analysis and writing of the paper from January 2023 until recently.

The study location is Jatiluhur Irrigation Area in North Tarum Canal. North Tarum Canal is one of the irrigation areas that received water from Jatiluhur Reservoir. The water flowing out from the Jatiluhur reservoir at the Lower Citarum basin will be diverted into three Tarum canals: East, West, and North Tarum Canal (ETC, WTC, NTC) to supply 240,000 ha irrigation schemes. The management of water allocation and water distribution is under Perusahaan Jasa Tirta (PJT) II, a state own company.

WTC and ETC received water from the Citarum River at Curug Weir, downstream of the Jatiluhur reservoir. Further, downstream of Curug Weir, Walahar Weir could be found, where some parts of Citarum water are again diverted to Leuweung Seureuh Weir. From Leuweung Seureuh Weir, NTC receives irrigation water. Schematically it could be shown in Figure 1. Geographically, the map of the North Tarum Canal is shown in Figure 2.

As mentioned before, at Leuweung Seureuh Weir Citarum water is divided into five canals (it is shown schematically as in Figure 3, namely:

1. NTC East branch (SI TUT = Saluran Induk Tarum Utara Timur)

2. NTC West Branch (SI TUB = Saluran Induk Tarum Utara Barat)
3. Bengle Secondary canal (SS. Bengle = Saluran Sekunder Bengle)
4. Majalaya Secondary Canal (SS. Majalaya = Saluran Sekunder Majalaya)
5. Drain Ciwadas (SP Ciwadas = Saluran Pembuang Ciwadas)

The total area irrigated by the water of the Leuweung Seureuh Weir is 85.287 hectares, consisting of 126 secondary blocks.

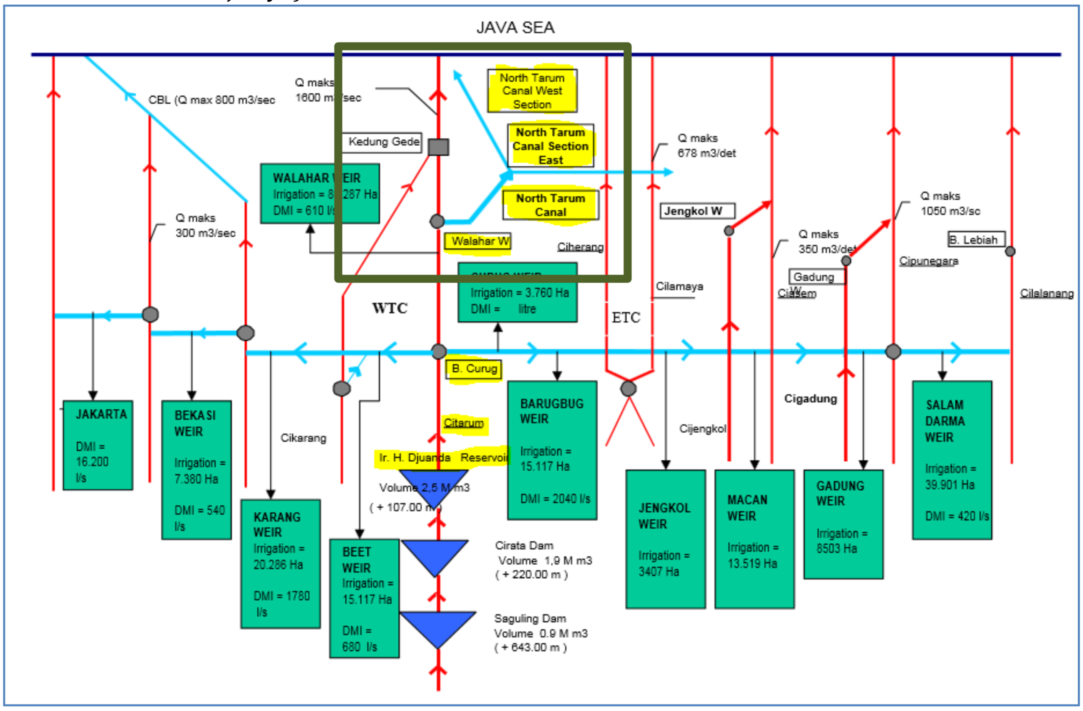

Figure 1 North Tarum Canal (NTC) Water Flow Scheme (yellow highlight)

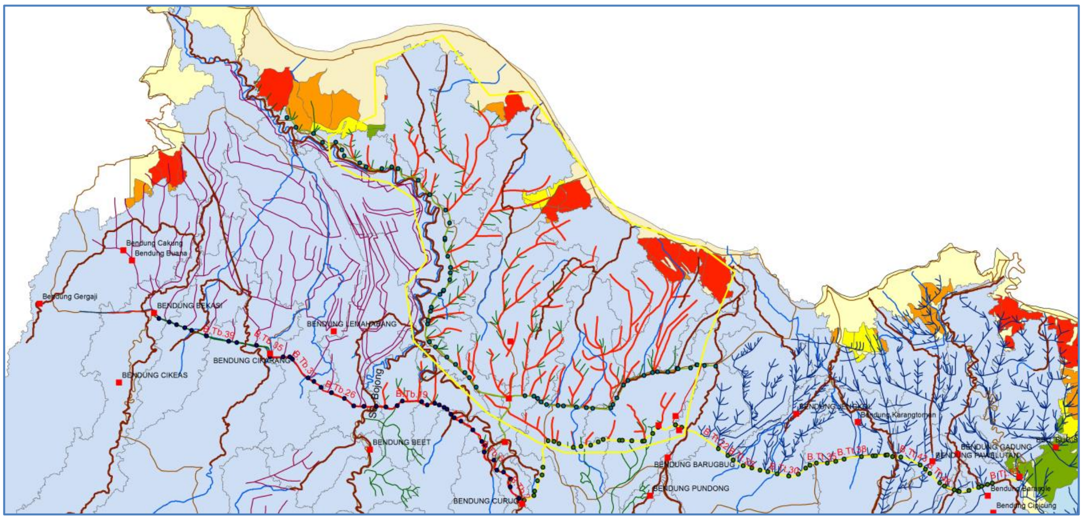

Figure 2 The Map of North Tarum Canal (yellow line)

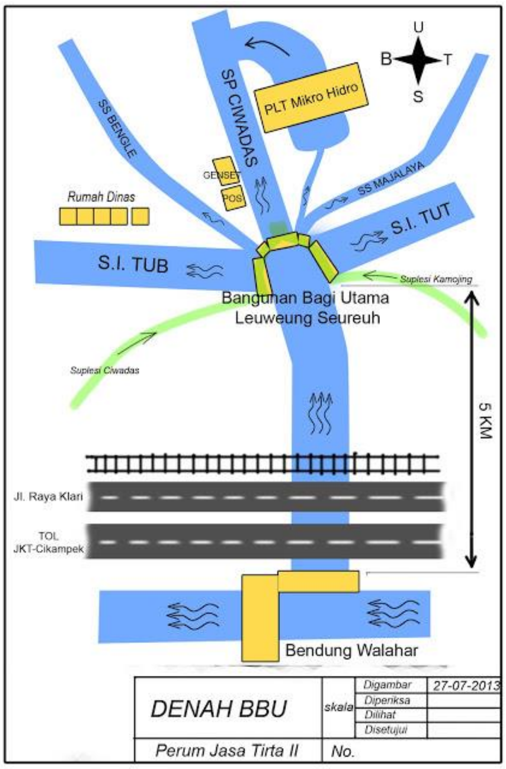

Figure 3 Leuweung Seureuh Weir

2.2. Climate Change Scenario

In this paper, the climate change scenario data and prediction are taken from the ADB report by (Boer et al., 2013). Based on the report, the projections of rainfall and temperature are conducted by using the GCM outputs from the Climate Models Intercomparison Project 3 (CMIP3) with SRES scenarios and from the Climate Models Intercomparison Project 5 (CMIP5) with new RCP scenarios used by the IPCC for their fifth assessment report (IPCC AR5). The scenario known as Representative Concentration Pathways (RCP) is the new generation of climate change scenarios after the Special Report on Emission Scenarios (SRES). Detailed analysis from this study also utilized the output of statistical and dynamical downscaling approaches for climate change projections, particularly for assessing current and future extreme climate events. Two regional climate models, namely RegCM and PRECIS are used for conducting dynamical downscaling.

2.3. Architecture of the Tool

The tool is designed modularly, where it consists of:

a. Input module
b. Output module
c. Database module
d. Calculation module
e. Interface module

Graphically, it is shown as in Figure 4.

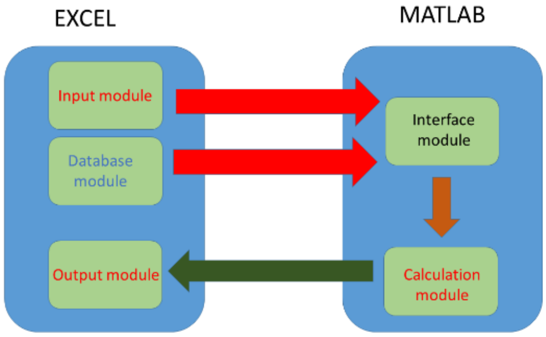

Figure 4 Architecture of the Tools

To be user-friendly, the tool for climate-proof irrigation infrastructure is developed modularly using MS Excel format as the input. The input required is a cropping pattern, planting time, half-monthly available discharge, and the list name of the irrigation block. The output also as MS Excel, showed water distribution for each block, and their cropping intensity based on the allocation of irrigation water.

For each irrigation block, its irrigation scheduling, its total area, and its canal route information are required. This canal route information is important for each hydraulic structure because cumulative discharge for all canals and downstream structures must be calculated at each node. The static data of irrigation scheduling, its total area, and its canal route information is saved in a database module. Database module also stores crop coefficient and its stage. Database module is also stored in MS Excel format.

The input module and the database module are stored in one Excel file with different sheet names. Connection of the input with database were conducted by calculation module. To be easy to operate, the tool also provided a friendly user interface module. The calculation module and the interface module are written using MATLAB script, because running calculations in MATLAB is more efficient and faster. If it is not running in MATLAB, each MS Excel workbook should be updated manually one by one, based on the input data and database data, and then the result of the calculation is saved in output.

III. RESULTS AND DISCUSSIONS

3.1. Input, output, and Interface Module

The output of the tool did not only show the cropping intensity in each tertiary block, but it could also show the maximum discharge flowing from primary canal to secondary canal and then to tertiary canal. It means the tool also could be used to analyze the adequacy of the canal network in conveying water for various cropping patterns.

It could be used for new design of irrigation infrastructure or it could also be used to improve the existing irrigation infrastructure for the changing cropping patterns. Figure 5 showed the graphical sketch of the Input-Process-Output of the tool.

The aims of the tool among others are to obtain the maximum irrigable area constrained by available irrigation water. Mathematically it could be written as:

Maximize: $\sum A_i \leq A$ .... (1)

Where:
A: Total irrigation area (in ha)
A_i: Tertiary block i (in ha), where i is: 1, 2, 3 … n
n: Total block number

Subject to constraints:

$$c_{ij} \times A_i \leq Q_j \quad \text{.................................... (2)}$$

Where:
c_{ij}: Crop water requirements at block i for time j, where j is half-month period: 1, 2, … 24
Q_j: Half-month available-discharge for time j

By determining cropping pattern for block A_i, c_{ij} for each half-monthly period could be determined. The equation above could be solved using Linear Programming Model (LP) by inputting the available discharge Q_j for each half-monthly period.

Here, the input of the tool could be grouped into climate change scenarios, irrigation blocks and its area, water requirements, and hydrometeorology data. The output A_i will be obtained after the LP problem above is solved. Water allocation Q_j for each block for half-month period could be calculated using equation $c_{ij} \times A_i \leq Q_j$. Using the canal routing information from database module, discharges in each tertiary canal, each secondary canal, up to each primary canal could be calculated, and then the total discharge required in the weir could be summed up. This calculation is conducted using MATLAB script in calculation module.

Both the input and output files are in Excel format. There is no Excel Macro used in the Excel files, because the calculation is handled in MATLAB engine.

Figure 6 shows an input file required for this tool. The input file is an MS Excel file so that the user can easily change some or all the input value(s). The parameters that can be adjusted are:

a. Climate change scenario: RCP-2.6, RCP-4.5, RCP-6.0, RCP-8.5 or Baseline
b. Adjustment water losses for each irrigation scheduling group
c. Rice variety for wet and dry seasons
d. Saturation depth, water layer depth, and percolation rate
e. Land preparation duration
f. Starting time for land preparation

Next, the user should input hydrometeorology data as shown in Figure 7. Here data required among others are dependable flow, monthly precipitation, and monthly evapotranspiration. The hydrometeorology input could be obtained from observation data or simulation output such as the SWAT hydrology model.

Figure 8 shows an input file for all irrigation blocks in the area. The information required for each block is Block Name, Irrigation Scheduling group, area (in ha), and info on its canal route upstream. Because this input is relative static, then this input is saved in database module.

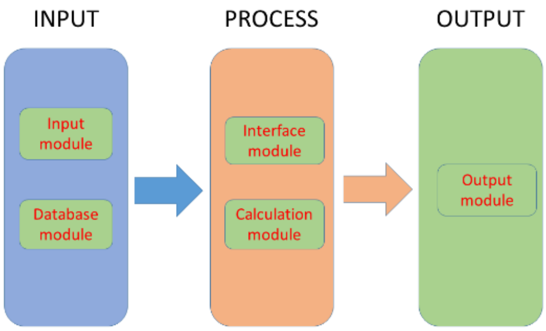

Figure 5 Input-Process-Output of the Tool

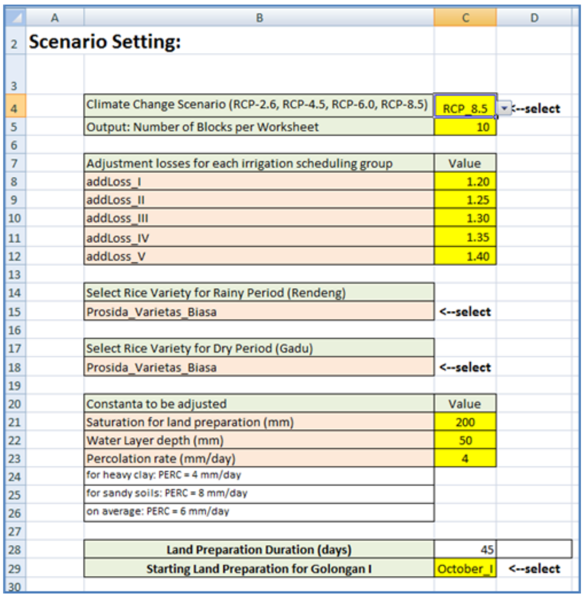

Figure 6 Excel Input to Calculate Crop Intensity and Peak Discharge

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Months	Flowout for Land Use 1 (m3/s) Term 1	Term 2	Term 3	Months	Flowout for Land Use 2 (m3/s) Term 1	Term 2	Term 3	Months	Flowout for Land Use 3 (m Term 1	Term 2	Term 3	198
January	408.0	394.8	457.1	January	419.5	405.1	464.4	January	#####	#####	468.6	5
February	423.1	452.2	502.1	February	433.6	463.9	510.9	Februar	#####	#####	510.4	6
March	439.2	483.7	476.1	March	448.1	492.3	482.8	March	#####	#####	479.0	6
April	514.4	521.9	530.8	April	520.0	527.5	535.4	April	#####	#####	533.4	6
May	457.8	453.3	443.4	May	457.6	453.1	442.9	May	#####	#####	441.5	5
June	319.7	347.5	333.6	June	315.7	343.8	330.0	June	#####	#####	327.8	4
July	218.7	240.6	226.2	July	213.7	236.2	222.2	July	#####	#####	222.7	3
August	115.9	131.2	113.9	August	103.6	128.0	110.6	August	#####	#####	113.8	2
September	49.0	57.7	41.6	September	48.6	57.1	40.5	Septeml	52.1	60.3	42.3	2
October	69.5	42.4	48.1	October	75.2	45.2	50.3	Octobe	72.5	44.9	49.6	
November	220.8	228.6	210.0	November	233.0	237.8	215.6	Novemb	#####	#####	216.5	6
December	394.5	391.0	421.3	December	407.3	400.8	427.9	Decemb	#####	#####	438.4	6
												on

Months	Output from SWAT: Precipitation (mm/month) Term 1	Term 2	Term 3	Precip	days	mm/day	Re	Months	Output from SWAT: Potent Term 1	Term 2	Term 3
January	215.2	215.2	215.2	215.174	31	6.94	4.86	January	59.4	55.3	65.0
February	164.5	164.5	164.5	164.535	28	5.88	4.11	Februar	54.3	58.7	59.8
March	159.5	159.5	159.5	159.537	31	5.15	3.60	March	76.5	81.8	84.0
April	185.8	185.8	185.8	185.813	30	6.19	4.34	April	76.9	80.2	83.2
May	123.9	123.9	123.9	123.935	31	4.00	2.80	May	65.5	68.8	70.1
June	37.7	37.7	37.7	37.7079	30	1.26	0.88	June	56.8	56.5	60.5
July	26.4	26.4	26.4	26.4361	31	0.85	0.60	July	58.9	61.7	66.4
August	11.0	11.0	11.0	10.9841	31	0.35	0.25	August	68.0	71.7	77.2
September	20.2	20.2	20.2	20.1687	30	0.67	0.47	Septeml	74.4	84.0	86.8
October	86.9	86.9	86.9	86.8648	31	2.80	1.96	Octobe	90.1	99.0	99.5
November	173.3	173.3	173.3	173.29	30	5.78	4.04	Novemb	86.3	88.3	91.7
December	166.8	166.8	166.8	166.787	31	5.38	3.77	Decemb	70.0	75.5	72.9

Figure 7 Input Hydrometeorology Data

Irrigation Scheme — number of blocks: 126

ID	Block_Sekunder	GOLONGAN	AREAS (ha)	Canal Routing
1	SS. Majalaya (B.MI.1-2)	I	490.0	B. Lws; B.MI.1; SS. Majalaya (B.MI.1-2)
2	SS. Bengle 1-7	I	1065.0	B. Lws; B.Bengle.1; SS. Bengle 1-7
3	SS. Palawad.1	I	242.0	B. Lws; B.Bengle.1; B.Bengle.2; SS. Palawad.1
4	SS. Kawista	I	551.0	B. Lws; Ciwadas; B.R.1; SS. Kawista
5	SS. Ranggon (B.R.0-3)	I	1835.0	B. Lws; Ciwadas; B.R.1; SS. Ranggon (B.R.0-3)
6	SS. Ranggon (B.R.4-6)	II	932.0	B. Lws; Ciwadas; B.R.1; B.R.4; SS. Ranggon (B.R.4-6)
7	SS. Huma (B.H.1-2)	II	485.0	B. Lws; Ciwadas; B.R.1; B.R.4; B.H.1; SS. Huma (B.H.1-2)
8	SS. Huma (B.H.3)	III	513.0	B. Lws; Ciwadas; B.R.1; B.R.4; B.H.1; B.H.3; SS. Huma (B.H.3)
9	SS. Pantongan 1	II	279.0	B. Lws; Ciwadas; B.R.1; B.R.4; B.H.1; B.Pt.1; SS. Pantongan 1
10	SS. Pantongan (B.Pt.2-3)	III	569.0	B. Lws; Ciwadas; B.R.1; B.R.4; B.H.1; B.Pt.1; B.Pt.2; SS. Pantongan (B.Pt.2-3)
11	SS. Ranggon (B.R.7-9)	III	972.0	B. Lws; Ciwadas; B.R.1; B.R.4; B.R.7; SS. Ranggon (B.R.7-9)
12	SS. Cikangkung (B.Ck.1-3)	IV	293.0	B. Lws; Ciwadas; B.R.1; B.R.4; B.R.7; B.R.10; SS. Cikangkung (B.Ck.1-3)
13	SS. Ranggon (B.R.10)	IV	679.0	B. Lws; Ciwadas; B.R.1; B.R.4; B.R.7; B.R.10; SS. Ranggon (B.R.10)
14	SS. Cilebar (B.Clb.1-2)	V	303.0	B. Lws; Ciwadas; B.R.1; B.R.4; B.R.7; B.R.10; B.R.11; SS. Cilebar (B.Clb.1-2)
15	SS. Tanjung Sari (B.Tjs.1-2)	V	420.0	B. Lws; Ciwadas; B.R.1; B.R.4; B.R.7; B.R.10; B.R.11; SS. Tanjung Sari (B.Tjs.1-2)
16	SS. Ranggon (B.R.11-13)	V	1012.0	B. Lws; Ciwadas; B.R.1; B.R.4; B.R.7; B.R.10; B.R.11; SS. Ranggon (B.R.11-13)
17	Sal.Tersier B.Tut.1-3	I	265.0	B. Lws; S.I. T.U.T.; B.Tut.1; Sal.Tersier B.Tut.1-3
18	SS. Telagasari (B.Tls.1-4)	I	818.0	B. Lws; S.I. T.U.T.; B.Tut.1; B.Tls.1; SS. Telagasari (B.Tls.1-4)
19	SS. Lewo 1-2	I	447.0	B. Lws; S.I. T.U.T.; B.Tut.1; B.Tls.1; B.Tls.3; B.Lw.1; SS. Lewo 1-2
20	SS. Lewo 3-4	II	659.0	B. Lws; S.I. T.U.T.; B.Tut.1; B.Tls.1; B.Tls.3; B.Lw.1; B.Lw.3; SS. Lewo 3-4
21	SS. Buaya 1-2	II	697.0	B. Lws; S.I. T.U.T.; B.Tut.1; B.Tls.1; B.Tls.3; B.Lw.1; B.Lw.3; B.By.1; SS. Buaya 1-2
22	SS. Telagasari 5-7	II	1418.0	B. Lws; S.I. T.U.T.; B.Tut.1; B.Tls.1; B.Tls.3; B.Tls.5; SS. Telagasari 5-7
23	SS. Lemahduhur (B.Ld.1-2)	III	841.0	B. Lws; S.I. T.U.T.; B.Tut.1; B.Tls.1; B.Tls.3; B.Tls.5; B.Tls.8; B.Ld.1; SS. Lemahduhur (B.Ld.1-2)
24	SS. Telagasari (B.Tls. 8-9)	III	941.0	B. Lws; S.I. T.U.T.; B.Tut.1; B.Tls.1; B.Tls.3; B.Tls.5; B.Tls.8; SS. Telagasari (B.Tls. 8-9)
25	SS. Telagasari (B.Tls. 10a-10)	IV	667.0	B. Lws; S.I. T.U.T.; B.Tut.1; B.Tls.1; B.Tls.3; B.Tls.5; B.Tls.8; B.Tls.10; SS. Telagasari (B.Tls. 10a-10)
26	SS. Telagasari (B.Tls. 11-12)	V	764.0	B. Lws; S.I. T.U.T.; B.Tut.1; B.Tls.1; B.Tls.3; B.Tls.5; B.Tls.8; B.Tls.10; B.Tls.11; SS. Telagasari (B.Tls. 11-12)
27	SS. Kuntul (B.Ktl.1-3)	V	490.0	B. Lws; S.I. T.U.T.; B.Tut.1; B.Tls.1; B.Tls.3; B.Tls.5; B.Tls.8; B.Tls.10; B.Tls.11; B.Ktl.1; SS. Kuntul (B.Ktl.1-3)
28	B. Tut 1-3	I	1891.9	B. Lws; S.I. T.U.T.; B.Tut.1; B. Tut 1-3
29	SS. Belendung (B.Bld.1)	I	276.0	B. Lws; S.I. T.U.T.; B.Tut.1; B.Tut.2; B.Bld.1; SS. Belendung (B.Bld.1)
30	SS. Derwolong (B.Dw.1-3)	I	553.0	B. Lws; S.I. T.U.T.; B.Tut.1; B.Tut.3; B.Dw.1; SS. Derwolong (B.Dw.1-3)

Figure 8 Irrigation Block Input

When the user has updated and saved the input file, then the Excel program should be closed. Next, the user should run or launch the tool that is called 'Irrigation_Infrastructure.exe'. When the tool is running, the interface will be shown like in Figure 9.

If the user has given all input files and running the program, then he could find the results in the folder he chose for the output. Figure 10 shows an example of the contents of the output folder.

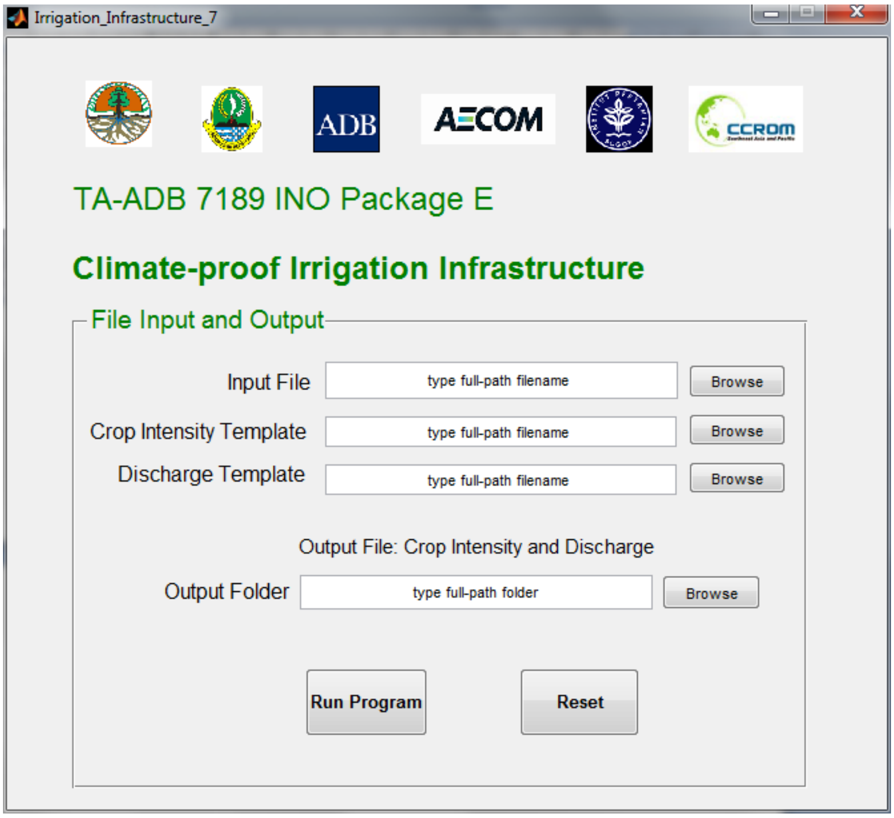

Figure 9 Program 'Irrigation Infrastructure'

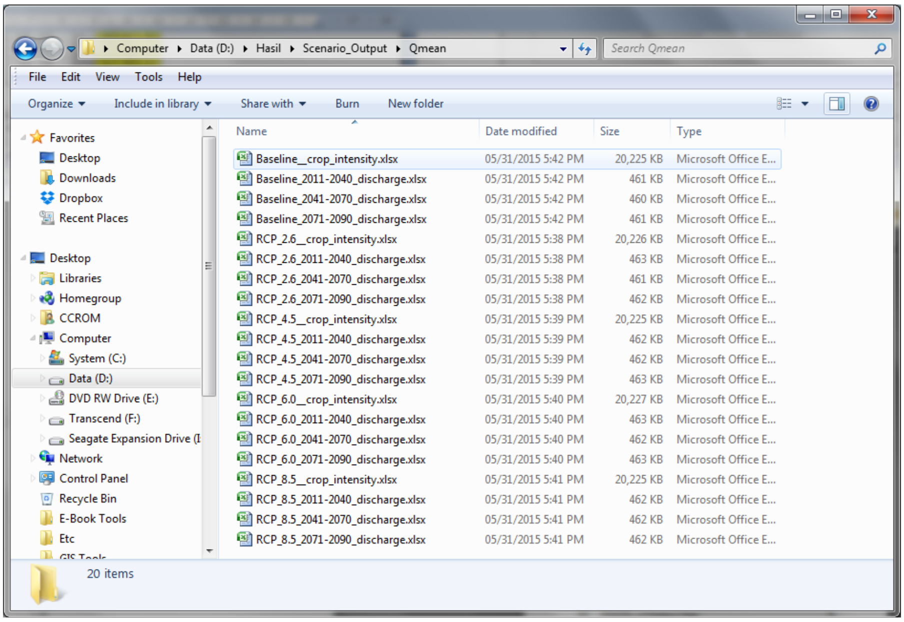

Figure 10 Contents of Output Folder for All Scenarios

Each file in Figure 10 is the output for each climate change scenario. In each scenario, there is a worksheet to summarize crop intensity and peak discharge as shown in Figure 11 and Figure 12. Figure 12 shows examples of crop intensity output. The highlight yellow column in the figure is for planting time P1: October to March, and P2 is for planting time April to September.

The output of predicted peak discharge for each block is shown as in Figure 11. The highlight column in Figure 12 shows the peak discharge for each block.

M128 | f_x =SUM(M2:M127)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1	ID	Block_Sekunder	GOLONGA	AREAS (ha)		P1A	P1B	P1C	P2A	P2B	P2C		P1	P2	Total	Intensity (%)	
2	1	SS. Majalaya (B.Ml.1-2)	I	490.0		159.8	165.0	165.2	196.0	196.0	98.0		490.0	490.0	980.0	200.0%	
3	2	SS. Bengle 1-7	I	1065.0		363.5	354.4	347.1	426.0	426.0	213.0		1,065.0	1,065.0	2,130.0	200.0%	
4	3	SS. Palawad.1	I	242.0		83.3	79.5	79.2	96.8	96.8	48.4		242.0	242.0	484.0	200.0%	
5	4	SS. Kawista	I	551.0		178.2	186.1	186.8	220.4	220.4	110.2		551.0	551.0	1,102.0	200.0%	
6	5	SS. Ranggon (B.R.0-3)	I	1835.0		632.0	620.2	582.8	734.0	734.0	367.0		1,835.0	1,835.0	3,670.0	200.0%	
7	6	SS. Ranggon (B.R.4-6)	II	932.0		321.6	322.6	287.8	372.8	186.4	372.8		932.0	932.0	1,864.0	200.0%	
8	7	SS. Huma (B.H.1-2)	II	485.0		158.4	159.7	166.9	194.0	97.0	194.0		485.0	485.0	970.0	200.0%	
9	8	SS. Huma (B.H.3)	III	513.0		162.0	175.3	175.7	92.3	146.7	205.2		513.0	444.2	957.2	186.6%	
10	9	SS. Pantongan 1	II	279.0		93.0	92.7	93.3	111.6	55.8	111.6		279.0	279.0	558.0	200.0%	
11	10	SS. Pantongan (B.Pt.2-3)	III	569.0		179.1	194.6	195.3	102.4	164.3	227.6		569.0	494.3	1,063.3	186.9%	
12	11	SS. Ranggon (B.R.7-9)	III	972.0		316.7	329.7	325.6	175.0	297.2	388.8		972.0	861.0	1,833.0	188.6%	
13	12	SS. Cikangkung (B.Ck.1-3)	IV	293.0		97.7	97.6	97.7	52.7	52.7	117.2		293.0	222.7	515.7	176.0%	
14	13	SS. Ranggon (B.R.10)	IV	679.0		226.2	228.0	224.8	122.2	122.2	271.6		679.0	516.0	1,195.0	176.0%	
15	14	SS. Cilebar (B.Clb.1-2)	V	303.0		93.0	103.7	106.2	54.5	54.5	54.5		303.0	163.6	466.6	154.0%	
16	15	SS. Tanjung Sari (B.Tjs.1-2)	V	420.0		140.0	139.5	140.5	75.6	75.6	75.6		420.0	226.8	646.8	154.0%	
17	16	SS. Ranggon (B.R.11-13)	V	1012.0		340.8	341.4	329.7	182.2	182.2	182.2		1,012.0	546.5	1,558.5	154.0%	
18	17	Sal.Tersier B.Tut.1-3	I	265.0		90.3	87.4	87.3	106.0	106.0	53.0		265.0	265.0	530.0	200.0%	
19	18	SS. Telagasari (B.Tls.1-4)	I	818.0		287.6	274.3	256.2	327.2	327.2	163.6		818.0	818.0	1,636.0	200.0%	

M128 | f_x =SUM(M2:M127)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1	ID	Block_Sekunder	GOLONGA	AREAS (ha)		P1A	P1B	P1C	P2A	P2B	P2C		P1	P2	Total	Intensity (%)	
2	1	SS. Majalaya (B.Ml.1-2)	I	490.0		159.8	165.0	165.2	196.0	196.0	98.0		490.0	490.0	980.0	200.0%	
3	2	SS. Bengle 1-7	I	1065.0		363.5	354.4	347.1	426.0	426.0	213.0		1,065.0	1,065.0	2,130.0	200.0%	
4	3	SS. Palawad.1	I	242.0		83.3	79.5	79.2	96.8	96.8	48.4		242.0	242.0	484.0	200.0%	
5	4	SS. Kawista	I	551.0		178.2	186.1	186.8	220.4	220.4	110.2		551.0	551.0	1,102.0	200.0%	
6	5	SS. Ranggon (B.R.0-3)	I	1835.0		632.0	620.2	582.8	734.0	734.0	367.0		1,835.0	1,835.0	3,670.0	200.0%	
7	6	SS. Ranggon (B.R.4-6)	II	932.0		321.6	322.6	287.8	372.8	186.4	372.8		932.0	932.0	1,864.0	200.0%	
8	7	SS. Huma (B.H.1-2)	II	485.0		158.4	159.7	166.9	194.0	97.0	194.0		485.0	485.0	970.0	200.0%	
9	8	SS. Huma (B.H.3)	III	513.0		162.0	175.3	175.7	92.3	146.7	205.2		513.0	444.2	957.2	186.6%	
10	9	SS. Pantongan 1	II	279.0		93.0	92.7	93.3	111.6	55.8	111.6		279.0	279.0	558.0	200.0%	
11	10	SS. Pantongan (B.Pt.2-3)	III	569.0		179.1	194.6	195.3	102.4	164.3	227.6		569.0	494.3	1,063.3	186.9%	
12	11	SS. Ranggon (B.R.7-9)	III	972.0		316.7	329.7	325.6	175.0	297.2	388.8		972.0	861.0	1,833.0	188.6%	
13	12	SS. Cikangkung (B.Ck.1-3)	IV	293.0		97.7	97.6	97.7	52.7	52.7	117.2		293.0	222.7	515.7	176.0%	
14	13	SS. Ranggon (B.R.10)	IV	679.0		226.2	228.0	224.8	122.2	122.2	271.6		679.0	516.0	1,195.0	176.0%	
15	14	SS. Cilebar (B.Clb.1-2)	V	303.0		93.0	103.7	106.2	54.5	54.5	54.5		303.0	163.6	466.6	154.0%	
16	15	SS. Tanjung Sari (B.Tjs.1-2)	V	420.0		140.0	139.5	140.5	75.6	75.6	75.6		420.0	226.8	646.8	154.0%	
17	16	SS. Ranggon (B.R.11-13)	V	1012.0		340.8	341.4	329.7	182.2	182.2	182.2		1,012.0	546.5	1,558.5	154.0%	
18	17	Sal.Tersier B.Tut.1-3	I	265.0		90.3	87.4	87.3	106.0	106.0	53.0		265.0	265.0	530.0	200.0%	
19	18	SS. Telagasari (B.Tls.1-4)	I	818.0		287.6	274.3	256.2	327.2	327.2	163.6		818.0	818.0	1,636.0	200.0%	

Figure 11 Crop Intensity Output

3		Predictive Qmax (m^3/s) required in each Block/Bangunan																										
4																												
5					October		November		December		January		February		March		April		May		June		July		August		September	
6					1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
7					1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
8				Qavailable	50.98	53.14	68.38	72.27	76.81	74.49	68.97	48.32	49.37	49.85	48.82	51.48	64.77	64.86	67.93	69.78	72.18	76.40	75.11	66.31	76.49	64.71	63.18	47.86
9																												
10	No	Block/Bangunan	Area (ha)	Q max	Predictive Qmax (m3/s) required in each Block/Bangunan																							
11	1	B. Lws	94,025.27	72.18	5.66	16.77	25.14	38.31	48.90	56.02	40.51	37.97	45.60	37.89	41.36	37.55	26.98	33.45	47.68	55.05	72.18	65.33	56.02	44.16	28.94	13.14	3.41	
12	2	B.Ml.1	490.00	0.42	0.17	0.30	0.32	0.30	0.30	0.31	0.18	0.14	0.12	0.06	0.16	0.26	0.26	0.27	0.35	0.36	0.42	0.23	0.07					
13	3	SS. Majalaya (B.Ml.1-2)	490.00	0.42	0.17	0.30	0.32	0.30	0.30	0.31	0.18	0.14	0.12	0.06	0.16	0.26	0.26	0.27	0.35	0.36	0.42	0.23	0.07					
14	4	B.Bengle.1	1,307.00	1.11	0.48	0.82	0.85	0.80	0.80	0.82	0.47	0.38	0.30	0.14	0.43	0.68	0.70	0.71	0.94	0.95	1.11	0.62	0.20					
15	5	SS. Bengle 1-7	1,065.00	0.91	0.39	0.67	0.69	0.65	0.65	0.66	0.38	0.31	0.25	0.12	0.35	0.56	0.57	0.58	0.76	0.77	0.91	0.51	0.16					
16	6	B.Bengle.2	242.00	0.21	0.09	0.15	0.16	0.15	0.15	0.15	0.09	0.07	0.06	0.03	0.08	0.13	0.13	0.13	0.17	0.18	0.21	0.12	0.04					
17	7	SS. Palawad.1	242.00	0.21	0.09	0.15	0.16	0.15	0.15	0.15	0.09	0.07	0.06	0.03	0.08	0.13	0.13	0.13	0.17	0.18	0.21	0.12	0.04					
18	8	Ciwadas	8,843.00	6.95	0.88	2.16	2.95	3.93	4.75	5.26	3.76	3.42	3.96	3.16	3.61	3.62	2.84	3.46	4.86	5.31	6.95	5.94	4.74	3.52	2.22	0.95	0.28	
19	9	B.R.1	8,843.00	6.95	0.88	2.16	2.95	3.93	4.75	5.26	3.76	3.42	3.96	3.16	3.61	3.62	2.84	3.46	4.86	5.31	6.95	5.94	4.74	3.52	2.22	0.95	0.28	
20	10	SS. Kawista	551.00	0.47	0.19	0.34	0.36	0.34	0.33	0.34	0.20	0.16	0.13	0.06	0.18	0.29	0.30	0.30	0.39	0.40	0.47	0.26	0.08					
21	11	SS. Ranggon (B.R.0-3)	1,835.00	1.56	0.68	1.17	1.19	1.13	1.12	1.14	0.66	0.53	0.42	0.20	0.60	0.96	0.98	1.00	1.31	1.33	1.56	0.88	0.28					
22	12	B.R.4	6,457.00	4.92		0.65	1.40	2.46	3.30	3.77	2.90	2.74	3.40	2.90	2.83	2.37	1.57	2.17	3.15	3.58	4.92	4.80	4.38	3.52	2.22	0.95	0.28	
23	13	SS. Ranggon (B.R.4-6)	932.00	0.88		0.36	0.45	0.63	0.53	0.59	0.41	0.35	0.39	0.22	0.14	0.32	0.31	0.59	0.61	0.68	0.88	0.81	0.51	0.29				
24	14	B.H.1	1,846.00	1.62		0.29	0.66	1.05	1.13	1.11	0.81	0.78	0.89	0.67	0.51	0.45	0.42	0.83	1.24	1.18	1.62	1.58	1.32	0.91	0.36			
25	15	SS. Huma (B.H.1-2)	485.00	0.46		0.18	0.22	0.33	0.27	0.31	0.21	0.18	0.21	0.12	0.08	0.17	0.16	0.31	0.32	0.35	0.46	0.42	0.27	0.15				
26	16	B.H.3	513.00	0.43			0.15	0.25	0.33	0.30	0.23	0.23	0.27	0.23	0.18	0.09	0.08	0.16	0.35	0.29	0.42	0.43	0.43	0.32	0.17			
27	17	SS. Huma (B.H.3)	513.00	0.43			0.15	0.25	0.33	0.30	0.23	0.23	0.27	0.23	0.18	0.09	0.08	0.16	0.35	0.29	0.42	0.43	0.43	0.32	0.17			
28	18	B.Pt.1	848.00	0.73		0.11	0.29	0.47	0.53	0.51	0.37	0.37	0.42	0.32	0.25	0.19	0.18	0.36	0.57	0.53	0.73	0.72	0.63	0.44	0.19			

Figure 12 Peak Discharge Output

3.2. Crop Intensity and Peak Discharge under Climate Change Scenario

The crop intensity for all scenarios is summarized in Table 1. From Table 1 we could see, climate change will decrease cropping intensity. For planting time P1: October to March, the existing baseline 100%, it will decrease to 71% in scenario RCP_2.6 in 2071-2090. The same pattern also for planting time P2: April to September. The existing cropping intensity 83%, it will decrease to 54% in all RCP scenarios.

Climate change will increase evapotranspiration, and in several months will decrease precipitation. Consequently, the peak discharge in the irrigation area will also increase. The summary for peak discharge for each climate change scenario is shown in Baseline (Table 2), RCP-2.6 (Table 3), RCP-4.5 (Table 4), RCP-6.0 (Table 5), and RCP-8.5 (Table 6).

In Bendung Leuweung Seureuh, the existing peak discharge of 72.18 m^3/s will increase up to 76.14 m^3/s in RCP_8.5. Consequently, the discharges in the canal downstream are also increasing. In primary canal North Citarum East (SI TUT), the discharge will increase from 29.58 m^3/s to 30.63 m^3/s, while primary canal North Citarum West (SI TUB), the discharge will increase from 34.12 m^3/s to 36.18 m^3/s.

Table 1 Summary of Crop Intensity in NTC for Each Climate Change Scenario

Scenario	P1 (ha)	P1 Intensity (%)	P2 (ha)	P2 Intensity (%)	Total (ha)	Total Intensity (%)
Baseline 1974 - 2010	94,025.3	100%	77,866.0	83%	171,891.2	183%
RCP_2.6 2011-2040	93,295.9	99%	75,008.8	80%	168,304.7	179%
RCP_2.6 2041-2070	81,445.4	87%	62,185.4	66%	143,630.9	153%
RCP_2.6 2071-2090	66,878.5	71%	50,773.7	54%	117,652.3	125%
RCP_4.5 2011-2040	92,951.0	99%	75,117.9	80%	168,068.9	179%
RCP_4.5 2041-2070	81,311.5	86%	62,070.2	66%	143,381.7	152%
RCP_4.5 2071-2090	70,070.0	75%	50,774.1	54%	120,844.1	129%
RCP_6.0 2011-2040	93,212.3	99%	75,056.0	80%	168,268.3	179%
RCP_6.0 2041-2070	81,766.5	87%	61,985.0	66%	143,751.4	153%
RCP_6.0 2071-2090	70,726.8	75%	50,773.8	54%	121,500.6	129%
RCP_8.5 2011-2040	91,351.0	97%	74,969.3	80%	166,320.3	177%
RCP_8.5 2041-2070	81,279.9	86%	60,281.2	64%	141,561.1	151%
RCP_8.5 2071-2090	69,459.0	74%	50,779.2	54%	120,238.2	128%

Table 2 Peak Discharge for Baseline

No	Block/Bangunan	Area (ha)	Q max
	Baseline 1974 - 2010		
1	B. Lws	94,025.27	72.18
2	B.Ml.1	490.00	0.42
4	B.Bengle.1	1,307.00	1.11
31	S.I. T.U.T.	37,844.61	29.58
156	S.I. T.U.B.	45,540.66	34.12

Table 3 Peak Discharge for RCP-2.6

No	Block/Bangunan	Area (ha)	Q max
	RCP_2.6 2011-2040		
1	B. Lws	94,025.27	72.18
2	B.Ml.1	490.00	0.43
4	B.Bengle.1	1,307.00	1.16
31	S.I. T.U.T.	37,844.61	29.11
156	S.I. T.U.B.	45,540.66	34.49
	RCP_2.6 2041-2070		
1	B. Lws	94,025.27	72.18
2	B.Ml.1	490.00	0.61
4	B.Bengle.1	1,307.00	1.63
31	S.I. T.U.T.	37,844.61	28.34
156	S.I. T.U.B.	45,540.66	34.86
	RCP_2.6 2071-2090		
1	B. Lws	94,025.27	73.18
2	B.Ml.1	490.00	0.76
4	B.Bengle.1	1,307.00	2.02
31	S.I. T.U.T.	37,844.61	29.44
156	S.I. T.U.B.	45,540.66	34.77

Table 4 Peak Discharge for RCP-4.5

No	Block/Bangunan	Area (ha)	Q max
	RCP_4.5 2011-2040		
1	B. Lws	94,025.27	72.18
2	B.Ml.1	490.00	0.43
4	B.Bengle.1	1,307.00	1.16
31	S.I. T.U.T.	37,844.61	29.14
156	S.I. T.U.B.	45,540.66	34.47
	RCP_4.5 2041-2070		
1	B. Lws	94,025.27	72.18
2	B.Ml.1	490.00	0.61
4	B.Bengle.1	1,307.00	1.63
31	S.I. T.U.T.	37,844.61	27.80
156	S.I. T.U.B.	45,540.66	34.87
	RCP_4.5 2071-2090		
1	B. Lws	94,025.27	74.13
2	B.Ml.1	490.00	0.75
4	B.Bengle.1	1,307.00	2.04
31	S.I. T.U.T.	37,844.61	29.82
156	S.I. T.U.B.	45,540.66	35.22

Table 5 Peak Discharge for RCP-6.0

No	Block/Bangunan	Area (ha)	Q max
	RCP_6.0 2011-2040		
1	B. Lws	94,025.27	72.18
2	B.Ml.1	490.00	0.43
4	B.Bengle.1	1,307.00	1.16
31	S.I. T.U.T.	37,844.61	29.11
156	S.I. T.U.B.	45,540.66	34.49
	RCP_6.0 2041-2070		
1	B. Lws	94,025.27	72.18
2	B.Ml.1	490.00	0.61
4	B.Bengle.1	1,307.00	1.64
31	S.I. T.U.T.	37,844.61	28.49
156	S.I. T.U.B.	45,540.66	34.87
	RCP_6.0 2071-2090		
1	B. Lws	94,025.27	74.66
2	B.Ml.1	490.00	0.77
4	B.Bengle.1	1,307.00	2.11
31	S.I. T.U.T.	37,844.61	30.04
156	S.I. T.U.B.	45,540.66	35.48

Table 6 Peak Discharge for RCP-8.5

No	Block/Bangunan	Area (ha)	Q max
	RCP_8.5 2011-2040		
1	B. Lws	94,025.27	72.18
2	B.Ml.1	490.00	0.43
4	B.Bengle.1	1,307.00	1.16
31	S.I. T.U.T.	37,844.61	29.11
156	S.I. T.U.B.	45,540.66	34.50
	RCP_8.5 2041-2070		
1	B. Lws	94,025.27	72.18
2	B.Ml.1	490.00	0.62
4	B.Bengle.1	1,307.00	1.66
31	S.I. T.U.T.	37,844.61	28.12
156	S.I. T.U.B.	45,540.66	34.52
	RCP_8.5 2071-2090		
1	B. Lws	94,025.27	76.14
2	B.Ml.1	490.00	0.74
4	B.Bengle.1	1,307.00	2.01
31	S.I. T.U.T.	37,844.61	30.63
156	S.I. T.U.B.	45,540.66	36.18

IV. CONCLUSION

The tool for climate-proof irrigation infrastructure has been developed and tested in the North Tarum Irrigation Scheme. The tedious part of calculating the decrease in crop intensity and the increase of peak discharge in each irrigation block has been resolved by using the automatic tool. It will take time to calculate manually the crop intensity and peak discharge for 126 secondary blocks. Assuming the calculation for each block manually takes 2 minutes, then for all 126 blocks, it will need 252 minutes or equivalence to 4 hours and 12 minutes. It is only for one climate change scenario. If we have six climate change scenarios, then we have to do it six times, which means more than one day calculation hours. It is prone to error due to doing the calculation manually. However, with the help of the tool, it could be done in less than two minutes with consistent calculation results.

From the output, we could also have information on which secondary block to increase cropping intensity, and which canal stretch to increase its discharge capacity.

It will be interesting to apply the tool in other irrigation schemes. With the help of the tool, we could assess whether our irrigation scheme is climate-proof. Further, we will have additional information about our canal capacity and whether it is adequate to cope with the increasing peak irrigation discharge requirements.

The next improvement of the tool will be integrated with the Geographical Information System (GIS), so that the cropping pattern in each seconder block, and canal layout is directly input from the maps, and the output can be shown spatially.

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