SUPPLEMENTARY IRRIGATION TO RAIN-FED PADDY -
A CASE STUDY OF KG. BEBULOH PADDY SCHEME

K. B. M. Shafiuddin

MIEAust, CPeng, FIEB
Sr. Lecturer, Civil Engineering Department
Institute of Technology Brunei (ITB)
The Tunku Link, Gadong BE1410
Bandar Seri Begawan Brunei Darussalam

ABSTRACT

Kg. Bebuloh Paddy Scheme is a small rain-fed paddy project run by part-time farmers facing the risk of little or no harvest every year.

There is no supplementary irrigation facility provided in case of draughts. A non-perennial stream originating in the hilly adjoining area runs through the project area inundating the paddy fields at almost every heavy rainfall event in the hills. Capacity of the existing channel is too inadequate to contain the flood flow within the channel.

Rainfall in Brunei in general is plenty and runoff generated eventually flows down the stream untapped and wasted whereas a nearby rain-fed paddy suffers for lack of water and irrigation.

Student projects taken up in the last two years to study this project, reveals the following:

- the catchment of the project area is a typical hilly terrain of rainforest where Sg. Bebuloh, a non-perennial stream originates; the runoff generated by a major rainfall event (of say 20 yr ARI) passes over the project area uncontrolled and causing severe damage to crops;
- the project suffers from drought as well for lack of water due to dry spell in between rains
- with channel improvement and compartmentalization by low level flood dykes, effective flood mitigation of the project is possible
- possibility is positive to recommend irrigation & drainage facility for the project area and provide supplementary irrigation by channel storage in Sg. Bebuloh.

This paper looks into the results of the three student projects. It reveals positively the possibility of an integrated approach of water resources development for the Kg. Bebuloh Paddy Scheme encompassing safe passage of flood flow, protection of the project from flooding and damage to crops, providing supplementary irrigation and drainage network for improved farming and guarantied harvest, and thus gain
confidence of the farmers to convert into full time farmers and generate employment. It would lead to many-fold increase of the harvest from the present insecure harvest of less than a ton to about three tons per hectare per crop. The success of this project could be a milestone for development of irrigated agriculture in Brunei.

**Keywords:** drought, drainage, irrigation, rain-fed paddy.

### 1. INTRODUCTION

Kg. Bebuloh Paddy Scheme under the Department of Agriculture, Govt. of Brunei Darussalam is a small rain-fed paddy project run by part time farmers. It regularly faces a risk of little or no harvest in absence of rain. No supplementary irrigation facility is provided in case of droughts happening in between two rainfall events. A non-perennial stream originating in the adjoining hilly terrain passes right thru the project area. Existing steam capacity is too inadequate to contain the flash flow in the channel section and thus causing flood damage to crops.

Kampong Bebuloh Paddy scheme is located in Brunei Muara District. It is a rural area about 30 kilometers south west from Bandar Seri Begawan. The topographical feature of Kampong Bebuloh is hilly area at the western part and lowland area to the east of the village. In Kampong Bebuloh, the Agriculture Department has identified an area suitable for paddy scheme. Part time farmers do rain-fed paddy cultivation presently for only about 30 hectares. The area is more or less flat and has the potential to expand paddy cultivation to about 100 hectares or more in future.
Rainfall in Brunei is in plenty. Runoff generated in this project catchment is substantial and concentration time is quick. Consequently, the paddy fields suffer from flooding and then again, it suffers from drought as well in between rainfalls for lack of any effective rain harvest arrangement. A huge amount of water flows down the stream untapped and wasted where as a nearby rain-fed paddy suffers for lack of water during drought.

This case study looks at the possible flood protection measures for the scheme area during heavy rains and provides supplementary irrigation in case of a drought. Few student projects carried out during the last couple of years reveal that:
- The project catchment generates huge runoff that presently passes over the paddy fields uncontrolled. With the channels re-sectioned, the flash flow can be regulated and contained within the channel and thus damage of crop minimized.
- The paddy fields can be effectively poldered by low cost flood dykes around. The residual stream flow after the peak flood can be adequately stored in the channel for possible supplementary irrigation by constructing control structures at key locations of the stream.
- Supplementary irrigation can be provided by maintaining adequate Full Supply level (FSL) in the storage channel. Irrigation application would be partly by gravity when FSL is maintained above the ground level and partly by low lift pump when the FSL falls below ground level.
- Study of the rain fall data reflects that about 80% of drought periods are 2 days or less considering the Antecedent Moisture Condition (AMC) and the $\phi$- index of rainfall.
- Paddy yield is expected to increase manifold from less than a ton /hectare at present to over 3 tons /hectare when supplementary irrigation would be provided.
- Part time farmers will be motivated to full time farming and employment generation would be substantial. The success of this pilot scheme could thus be an eye opener and more rain-fed paddy projects could be brought under supplementary irrigation.

There are many paddy schemes being cultivated in Brunei Darussalam depending entirely on rainfall only. The risk and uncertainty associated with rain-fed paddy is very high. Rainfall intensity, duration and timing are all very uncertain. There is risk of loosing entire paddy harvest if there is no rainfall on time.

Paddy farming is done part time in this village and it is planted once in a year in the rainy season. The size of the paddy field is about 30 hectares. According to the concerned agriculture officer this paddy scheme has just been in operation for about 2 years. Each farmer was provided with 2 plots comprising about 2 hectares. The boundary of each plot was made of earth dune. Paddy planting is done by the month of October every year during the rainy season and harvesting the yield is done by the month of February.
There is a small non-perennial stream named Sungai Bebuloh passing through the paddy area. It originates in the hilly catchment nearby. According to the farmers, the paddy area gets flooded and damaged every year when there is a big rainfall in the catchment. Again during dry spell, this paddy gets burnt and damaged due to droughts.

Since there is plenty of water flowing down the stream during the rainy season, the flash flow can possibly be controlled and harvested for better use especially during the drought periods in between the rainfall event.

2. PROJECT AREA

The project has been divided into two phases, namely, Phase 1 and Phase 2.

Phase 1 has an area of 20 ha. of existing paddy farming and phase 2 has 40 ha. approx. where the area is not being fully brought under rain-fed paddy.

The present irrigation and drainage study (Adi [3]) was conducted on Phase 1 where rain-fed paddy farming has been started. Similar student study projects would be taken up for Phase 2 based on the results of Phase 1 study.
3. CATCHMENT AREA

There are two independent catchment areas affecting the project.

The catchment 1 having an area of 194 ha was studied in 2005 (Solaiman [1]) to assess the amount of runoff generated from this catchment and its effect on the paddy project.

Catchment 2 study was taken up in 2007 by another student group (Amalia [2]). It has an area of 27 ha with no defined stream alignment. A short stream has been identified on the map for the purpose of runoff calculation. The entire runoff of catchment 2 is coming on to phase 1 of the Paddy project as overland runoff and flowing uncontrolled over the paddy area causing severe damage to crops.

4. METHODS OF IRRIGATION

There are many types of irrigation that can be considered to be applied in a project. Types and techniques of irrigation differ in their method as to how water is obtained from the source and the way distributed within the field. In general, the irrigation goal is to supply the entire field uniformly with water, so that each plant has the amount of water it needs, neither too much nor too little.
Some of the most common irrigation methods are, namely, Surface irrigation, Drip irrigation, Sprinkler irrigation, Sub-irrigation, Manual irrigation, etc. The type of irrigation method that can be applied in the Kg. Bebuloh Paddy project is surface irrigation of basin flooding type which means water will be allowed to flow in as overland sheet flow in the basin to a certain height of standing water as per design and for a designated period of time. The excess irrigation application will flow back to the adjoining drainage channel within the paddy polder. This will maintain a proper water balance of irrigation and drainage which is essential for any irrigation project. If there is lack of proper drainage, the irrigated area will get water logged, salt level will come up and accumulate, and in few years the project will soon be useless for cropping due to salinisation.

5. SUPPLEMENTARY IRRIGATION

Supplementary irrigation is the application of water to plant when natural precipitation is not adequate to secure crop. Depending on the size of the farm and the types of the irrigation system, application of the water is possible by using the modern power sources and/or by storage of large quantities of the water in streams, reservoir, pond and rivers to supplement irrigation by rainfall.

Paddy and vegetables crops are 80 to 95% water dependent and hence their performance with respect to the yield and the quantity can suffer from water stress or drought. In some under-climatic condition of the Southeast Asian region, supplementary irrigation during dry spell period is essential to secure crop production. If the water shortage occurs early in the crop development stage, like in summer, maturity may be delayed and yield could be reduced significantly. If the moisture shortage occurs later in the growth seasons, the quality in growing is often reduced even though total yield is not affected.

6. DRAINAGE

Drainage is a system to flow water out of an area. It could be an earth drain or a reinforce concrete section. It is just as important to ensure that the fields do not receive too much water as it is to ensure that they do not receive too little water. If drainage is inadequate, salts may accumulate, in a process called salination. Salination occurs because the irrigation water carries salt to the fields, but the plants absorb only water and leave the salt behind. Due to lack of drainage, these excess salts remain on the fields where they can cause serious harm to the plants and even prevent the plants from growing.

Another danger of insufficient drainage is water logging. In water logged areas, the water table is raised by excess irrigation water faster than it can lower itself by natural percolation processes. Eventually, the water table is so high that it is above the level of the roots of the crops, which seriously interferes with the growth of the plants.
Additionally, when the water table is this high, more evaporation occurs, which leaves behind more salts in the upper soil profile and thus exacerbating the problem of salination.

To prevent salination and water logging, adequate drainage is essential. Excess surface water can be removed from the fields using deep ditches that run along the fields, and excess ground water can be removed using either underground drainage lines or pumped drainage wells. Drainage is absolutely essential to go hand in hand with any irrigation system.

In the Kg. Bebuloh project area there is no drainage system developed so far; but it has now turned out to be essential even if there was no paddy project. The nearby village and the project area now need drainage system. As a result drainage system in isolation of irrigation facilities would not be effective. With the idea of supplementary irrigation, an integrated approach of drainage and supplementary irrigation would be a technically feasible and economically viable option.

Sg. Bebuloh channel will serve the dual purpose of the passage of flood flow in wet season and then channel storage in dry/drought period to facilitate supplementary irrigation into the paddy project at no extra cost for storage. The benefit-cost ratio will be highly attractive.

7. RAINFALL

September to December is considered to be the usual rainy season of a year in Brunei. It is important to analyze and decide to indicate the variable drought length faced in the area.

After analyzing rainfall data from the year 1996 to 2006, it is found that December 1997 and September 2003 have the least rainfall for 10 years recorded. These months had constantly no rainfall in a week that is considering drought condition. Where as December 1998 and December 2003 has the heaviest rainfall that caused flooding to the project. This problem would be solved when redesign of drainage channels is considered.

8. RUNOFF CALCULATION AND PREL. SECTION DESIGN

The calculation for the estimation of runoff or discharge of the catchment area has been made by using the Rational Method (Geoffrey [7]). The catchment area is established by studying the features & ridges of basin divide and stream flow path in the topographical map and the marking of its boundary area which was then measured by planimeter. The Barnsby-Williams formula (Hooi [6]) is used to obtain the time of concentration of overland flow. The time of concentration and rainfall intensities are calculated for 2 years ARI to estimate the min. flow available for storage and 20 year
ARI for the designed peak flood flow using Intensity-Duration-Frequency (IDF) curves of the selected locations. The runoff coefficient is taken from the table established based on the type of land use.

For the project, two catchment areas, independent of each other that are looked into are:

1\(^{st}\) Catchment – The catchment covered an area of 194.2 hectares mostly covered by jungle, hill and only few houses located at the foot-hills within the area. The stream originates at elevation 90 m RL, the highest peak and the lowest is 8.00 m RL at the project entry point.

2\(^{nd}\) Catchment – Located west to the paddy scheme. The catchment covers about 32 hectares mostly covered with jungle and hills where the highest peak is 60 m RL and the lowest is 8 m RL with no well defined stream path.

The results are as below:

<table>
<thead>
<tr>
<th>Catchment</th>
<th>Catchment 1</th>
<th>Catchment 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area (ha)</td>
<td>194.2</td>
<td>27</td>
</tr>
<tr>
<td>Stream length (km)</td>
<td>3.67</td>
<td>0.65</td>
</tr>
<tr>
<td>Stream Slope (m/km)</td>
<td>10.6</td>
<td>73.5</td>
</tr>
<tr>
<td>Time concentration, Tc (min)</td>
<td>125</td>
<td>18</td>
</tr>
<tr>
<td>Rainfall intensity, mm/hr, (20 yr ARI)</td>
<td>60</td>
<td>170</td>
</tr>
<tr>
<td>(2 yr ARI)</td>
<td>38</td>
<td>95</td>
</tr>
<tr>
<td>Roughness coefficient, C</td>
<td>0.35</td>
<td>0.35</td>
</tr>
<tr>
<td>Discharge, Q, m(^3)/sec, (20yr ARI)</td>
<td>11.3</td>
<td>4.5</td>
</tr>
<tr>
<td>(2 yr ARI)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Channel slope</td>
<td>1:1000</td>
<td>1:1000</td>
</tr>
<tr>
<td>Manning’s N value (for RC Channel)</td>
<td>0.015</td>
<td>0.015</td>
</tr>
<tr>
<td>Bed width X Depth (RC Rect.)</td>
<td>3.50 X 2.00</td>
<td>2.50 X 1.50</td>
</tr>
</tbody>
</table>

9. RAINFALL HARVEST AND STORAGE OPTION

Reconnaissances and field survey of the hilly catchment up to the project entry point revealed (Solaiman [1]) that there is no suitable depression on line or off line of Sg. Babuloh where any storage reservoir can be recommended.
The other easy and economic storage option is channel storage in the reach of the river itself flowing through the project area. There is no proper flood mitigation and drainage facility provided so far. The drainage and flood flow plan integrated with the possibility of channel storage in Sg. Bebuloh during dry period would be a viable option. The size of the channel section for flood flow would be adequate for storage of the receding 2 yr ARI flood flow for supplementary irrigation requirement provided the designed drought period is not very prolonged.

9.1 Channel Storage

The channel storage is recommended in the following manner:

The main storage channel will be the Sg. Bebuloh channel itself (Reach 1) from point A to D. This reach of the existing drainage channel runs through the middle of the project (Ref: Fig. 3). Its length is about 910 meter.

The second proposal for channel storage is by using the peripheral catch drain BCD (Reach 2) at the boundary foot hill of catchment 2 and project Phase 1 (Ref: Fig 3) having an approx. length of 1150 meter.

There is a third stand-by Reach AB of Sg. Bebuloh channel from the existing road crossing to the project entry point (Ref: Fig. 3). This reach can also be used for channel storage if need arises due to potential increase of paddy farming area in future.

10. DROUGHT

Conceptually, drought is considered to describe a situation of limited rainfall that is substantially below normal value for the area and the type of activity concerned, leading to adverse consequences to farming and human welfare (Pandey [5]). Although drought is a climatically induced phenomenon, its impact depends on the type of farming, the social and economic context as well. Drought, therefore, can be defined on the basis of climatological, hydrological and agricultural perspectives

10.1 Estimation of Design Drought

Analysis of the periods of droughts during rainfalls of 11 years from 1996 to 2006 shown in the table below reflects that more than 80% of the droughts are 3 days or less. Considering the Antecedent Moisture Content (AMC) and φ- index of rainfalls (Geoffrey [7]) in the project area, a period of one day can be deducted of estimated drought and thus a two day drought would be a reasonable estimation for irrigation designs and channel storage calculations.
Table 2: Drought occurrences and durations
(Rain fall data series: 1996 to 2006) (Adi [3])

<table>
<thead>
<tr>
<th>Drought Duration (Days)</th>
<th>Drought Occurrences</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number</td>
</tr>
<tr>
<td>1</td>
<td>49</td>
</tr>
<tr>
<td>2</td>
<td>26</td>
</tr>
<tr>
<td>3</td>
<td>17</td>
</tr>
<tr>
<td>4</td>
<td>7</td>
</tr>
<tr>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>8</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>112</td>
</tr>
</tbody>
</table>

11. PRELIMINARY DESIGN CALCULATION

- Paddy area = 60 ha. (Considering both phase 1 and 2)
- Designed Drought Period = 2 days. - After the analysis made for the most occurrence no. of drought periods. (80% of droughts are for 2 days or less)

This is a rough estimation of storage made based on the channel sections designed for 20 yr ARI flood flows. Since the existing channel sections are inadequate and irregular, equivalent rectangular sections are considered for calculating storage volumes.

Reach 1: **Existing Sg. Bebuloh reach from B to D within the project area.**
Table 3: Storage capacity in Sg Bebuloh

<table>
<thead>
<tr>
<th>Section A-A  (Sungai Bebuloh and Existing Drain)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size: Bed Width = 3.5m</td>
</tr>
<tr>
<td>Storage depth = 2.7m</td>
</tr>
<tr>
<td>Storage Length = 910m</td>
</tr>
<tr>
<td>Storage Volume = 3.5 x 2.7 x 910</td>
</tr>
<tr>
<td>= 8599.5m³ =&gt; 8600m³</td>
</tr>
</tbody>
</table>

Reach 2: Proposed catch drain at the foot hills B C D between catchment 2 boundary and Phase 1 of project area.

Table 4: Proposed Drain storage capacity
(Refer: Fig. 7 for section A-A and Section B-B)

<table>
<thead>
<tr>
<th>Section B-B (Rectangular Drain section)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size: Bed Width = 2.5m</td>
</tr>
<tr>
<td>Storage depth = 2.2m</td>
</tr>
<tr>
<td>Storage Length = 1150m</td>
</tr>
<tr>
<td>Storage Volume = 2.5 x 2.2 x 1150</td>
</tr>
<tr>
<td>= 6325m³ =&gt; 6300m³</td>
</tr>
</tbody>
</table>

Reach 3: Sg. Bebuloh from Road crossing point A to Project entry point at B

Storage calculation for reach 3 is not taken into consideration for 60 ha of present paddy farming. It may remain stand by just in case more areas are planned for paddy farming in future.

11.1 Storage Capacity

Total Capacity = 8600 + 6300
= 14900m³, say
= 15000 m³
Storage converted to flow rate for 2 days:

15000 m³ to exhaust in 2 days by continuous irrigation application for 60 ha of paddy:

The irrigation application would be:

\[ 15000 \times 1000 \text{ lit. /2 days/24 hrs a day/ 3600 secs an hr} = 87 \text{ lit/sec} \]

For 60 ha = 1.5 lit/sec/ha which is more than required.

Considering a duty of 800 for paddy

\[ Q_{\text{required/ha}} = \frac{60\text{ha}}{800\text{ha}} = 0.075 \text{ m}^3/\text{sec} = 75.0 \text{ lit/sec}. \]  

(less than available 87 lit/sec)

Calculation for 12 hr schedule

\[ Q_{\text{required (in 12 hr schedule)}} = \frac{75 \text{ lit/sec}}{2} = 37.5 \text{ lit/sec} \approx 40 \text{ lit/sec} \]

In extreme cases of 4 four days drought, if at all happens, this storage would also be enough for even 4 days drought, but with 12 hrs scheduling @ 40 liter/sec.

12. IRRIGATION APPLICATION DESIGN CONCEPT

Design concepts related to control systems for irrigation management purposes as well as water storage, pumping and pipe irrigation is described as below:

12.1 Preliminary Design Proposed

[Diagram of storage and supply channel]

GL is considered as TBM
Temporary datum: 0.0m

Water storage (Sg. Bebuloh)

Fig. 4 Sectional view of storage and supply channel
13. FEATURES OF THE PROPOSED PROJECT

13.1 Channel A

Channel A is the main channel of Sg. Bebuloh that originates in the hilly catchment of the project and is running parallel along the side of the project road. This is an existing earth channel inadequate for flood flow and causing flood damage to standing paddy crop every year. The department is considering to re-design the channel section for the passage of peak flow after heavy rains from the catchment.

The drain A is Sg. Bebuloh in this study and designated as channel A) will be used as storage channel during drought and as a normal river channel during heavy rainfall for flood discharge. The flow would be controlled by road and bund height on either side, so that flood water cannot enter paddy field under any condition of flooding height. The crest of the road and embankment would be designed high enough with proper free board for storage and to contain the flood flow within the channel. It will be serve dual purposes of drainage & flood flow and also as dry weather storage for irrigation with hardly any extra cost except for the controls at key locations.

13.2 Channel B

The paddy fields will be protected from flooding by constructing flood dyke all around the project area as shown in the map. Supply channel B would be constructed on the inner side of the flood dyke to act as secondary channel for irrigation. For preliminary design sketch of full supply level, please refer to sketch shown above to control the water flowing in and also flowing out. The pump will be used when the full supply level (FSL) in the storage drain A is not enough to irrigate at low irrigation velocity throughout the field so that the water can spread evenly.

13.3 Area C

Area C represents the paddy fields having irrigation water depth approximately 0.10 m. Pipe inlet from B to C would operate by gravity at a u/s and d/w head difference of roughly 0.10m. The contour map of the project was prepared by the student group from field survey (Fig. 6) indicates a regular land slope towards the out fall of the Sg. Bebuloh. This is an advantage for irrigation planning of the detail lot sizes and land leveling for basin irrigation system.

13.4 Control Structures

It is absolutely essential to plan and design few control structures at key locations of Sg. Bebuloh channel and regulate for creating effective afflux and storage and also to maintain FSL in the storage channel for supplementary irrigation. The regulation and supply of irrigation water to field will depend on the FSL and efficient regulation of the control structures.
13.5 PROPOSED OPERATIONAL OPTIONS

- During heavy rainfall all control structures will be fully opened for the flood discharge to flow out. Sg. Bebuloh channel will carry flood flow confined between road and flood dyke.
- As flood starts to recede, the gates of the control structures will be gradually closed and regulated for storage to achieve and maintain an F.S.L at 0.70 above GL and keeping a free board 0.30 from the road crest.
- Between FSL 0.70 to 0.20 above GL, water transfer from storage channel A to supply channel B will be by gravity flow through regulators.
- From FSL 0.20 above GL to until 0.70 below GL, water will be transferred from storage channel A to supply channel B by low lift pump while the pipe regulator gates will remain closed to stop reverse flow.
- As the FSL approaches to fall to 0.70 below GL, the next rainfall is expected to occur and replenish the storage to FSL in the storage channel.
- Irrigation application from the supply channel B to the paddy fields will always be by gravity for a head difference of roughly 0.10 m or less.
- This operation will continue for the designed drought period of 2 days. If drought continues to be more than 2 days, scheduling of irrigation supply can be started reducing from 24 hours irrigation application to 12 hours or even 6 hours depending on drought situation and paddy areas.

14. RECOMMENDATION

Based on the preliminary designs and investigations at pre-feasibility level, the case study of Kg Bebuloh Paddy Scheme appears to be an attractive proposition in that it can be easily converted into a fully irrigated paddy cultivation scheme by providing the following:

- Flood protection and drainage network to the paddy project, and supplementary irrigation using channel storage in Sg. Bebuloh.
- Storage of runoff and provide supplementary irrigation to rain-fed paddy.
- Many-fold increase of harvest and part-time farmers motivated to full time farming of paddy.
- Economic activity around the project will enhance and generate employment
- A milestone towards irrigated agriculture in Brunei Darussalam.
- Scope for further detail study of the scheme for a comprehensive, integrated and sustainable agro-based project development.
REFERENCES


Acknowledgement

The author respectfully acknowledges the references made to the publications above.
Fig. 5 Prel. Plan view sketch of proposed dyke, road and channels
Appendix B

Fig. 6 Kg Bebuloh project area contour map
Appendix C

Fig. 7: Kg. Bebuloh Paddy Project Map