# A STUDY ON THE WATER RESOURCES ASSESSMENT FOR IRRIGATION SCHEME DEVELOPMENT IN MALAWI

SungSick, AHN[1], RaeChul, LEE[2] and ChangHyun, CHOI[3]

## ABSTRACT

In general, for the development or rehabilitation of irrigation scheme, the efficient water resource management that supplies the irrigation water considering the required time and accurate quantity for growing the crop should be conducted. Therefore, the water resource assessment that is composed of the water requirement analysis and water availability assessment should precede in order to supply the irrigation water efficiently, when the irrigation scheme is developed. In particular, since the African region of the tropical climate is weak in the climate exchange considering because of the high temperature and evaporation, etc., the water resource assessment should be reviewed more thoroughly. In this study, Matiti scheme in Blantyre District of the southern Malawi was selected as the study area. The meteorological data were collected from the meteorological station, where is located around the study area., The evapotranspiration was analysed estimated by the Penman-Monteith Method and the effective rainfall was analysed by the USDA Soil Conservation Service Method. This study displays the results that for study area, the evapotranspiration varies from 3.57 mm/day to 6.72 mm/day and the effective rainfall varied from 1.2 mm to 135.3 mm. The unit water requirement and water demand were estimated to be 0.0016 $m^3$/s/ha and 0.024 $m^3$/s respectively, based on the selected crops (Green Maize, Dry Maize) considering the irrigation efficiency, irrigation time and irrigation area. The water availability assessment reviewed revealed that whether the irrigation water can be supplied or not in accordance with the difference between the inflow at the intake and total water demand at the scheme. The inflow of Matiti scheme was estimated by the specific yield method, and the water availability was evaluated through reviewed differences of discharge between $Q80_{intake}$ and total water demand (Total WD). Because theTotal water demand and $Q80_{intake}$were calculated as 0.03071 $m^3$/s and 0.06711 $m^3$/s ($Q80_{intake}$> Total WD)., The irrigation water can be supplied to 15 ha of the existing area sufficiently. There fore, the Matiti scheme can be extended from 15 ha to 37 ha in the dry season considering the $Q80_{intake}$.

**Keywords:** Unit water requirement, Water availability assessment, Extensibilityof irrigable area

## 1. INTRODUCTION

In the most of African countries, which has a tropical climate, the agriculture depends mostly on the rain-fed and therefore vulnerable to the effects of climate change. If the irrigation water is sufficient, more than double cropping can be expected in consideration of the climate condition and crop characteristics. However, in the dry season, since it is difficult to supply sufficient irrigation water, the irrigation area shows a clear distinction between dry season and rainy season.

[1] General Manager, Department of Water Resource & Agricultural Civil Engineering, Dasan Consultants Co., Ltd., Dasan B/D 15 Songi-ro 30 gilSongpa-gu Seoul 05800 Korea; E-mail: ssshce@gmail.com

[2] General Manager, Department of Water Resource & Agricultural Civil Engineering, Dasan Consultants Co., Ltd., Dasan B/D 15 Songi-ro 30 gilSongpa-gu Seoul 05800 Korea; E-mail: leerc@dasan93.co.kr

[3] Executive Manager, Department of Water Resource & Agricultural Civil Engineering, Dasan Consultants Co., Ltd., Dasan B/D 15 Songi-ro 30 gilSongpa-gu Seoul 05800 Korea; E-mail: choich@dasan93.co.kr

For the development of irrigation scheme, the supply and efficient management of irrigation water is a very important element. Therefore, the efficient water resource management that supplies the irrigation water considering the required time and accurate quantity to grow the crop should be required. The water resource assessment for irrigation scheme development needs a variety of information, such as crop type, climate condition, soil type and irrigation method, etc. Especially the rainfall and evapotranspiration are key factors in order to analyse the crop water requirement and water demand. The water demand is the quantity consumed in the soil under the crop and means the quantity necessary for the growth of the crop. The water demand is calculated by subtracting the effective rainfall actually used in the scheme from the evapotranspiration due to the growth of the crop. Because the water demand of crop is occurred by region, crop and climate condition, it is weighty element that estimates the reasonable water demand.

Various studies related to the water demand considering the effective rainfall and evapotranspiration have continued. However, usually previous study focused just on the yearly water demand regarding the crop type. In terms of water resource assessment, the water demand of Acala Cotton in the irrigation scheme in Sudan was evaluated by using the FAO Penman-Monteith (Abdelhadi et al. 2000), and the water requirement of the barley was calculated in the Ksar-Chellala irrigation scheme in the northern Algeria by CROPWAT8.0 (Laouisset et al. 2016). Considering the climate change scenario, the design water requirement of the paddy rice was estimated in Korea that the yearly water requirement of each zone was estimated in accordance with the variation of effective rainfall and evapotranspiration in the paddy area (Yoo et al. 2012). These studies did not evaluate whether the water requirement for the irrigation scheme can be secured. The unit water requirement and water demand, which is essential for the development of the irrigation scheme considering the irrigation efficiency has not been appropriately evaluated. Moreover, the integrated water availability assessment by the water balance analysis was not conducted. Therefore, this study wants to present the method that analyses the reasonable unit water requirement and decides the irrigable area of scheme in Malawi considering the water availability assessment. This method will be the most applicable method in other African countries extensively as well as in Malawi, and this study presents a guideline and procedure of water resources assessment to develop or rehabilitate the irrigation scheme.

## 2. METHODOLOGY

### 2.1 Procedure of Water Resource Assessment

Generally, the water resource assessment consists of the water requirement analysis and water availability assessment as an essential element in order to develop or rehabilitate the irrigation scheme. According to the water resource assessment, the current utilization level, net irrigation area and extensibility of the irrigable area are evaluated. In terms of water resource assessment, this study presented the method and application standard, and the procedure of the water resource assessment such as water requirement analysis and water availability assessment, which is presented in the Figure 1.

The water requirement is estimated by adding the efficiencies to the crop requirement in the field. The unit water requirement (UWR) by crops depends not only on climate, field and farming practice, but also on the type of irrigation canal and stages of crop growth. The water availability assessment evaluates the capacity of the irrigation water supply; how much water can be supplied as per the calculated water demand of scheme. 80% exceedance probability discharge (Q80) and environmental flow requirement (EFR) should be considered in order to review the water availability.

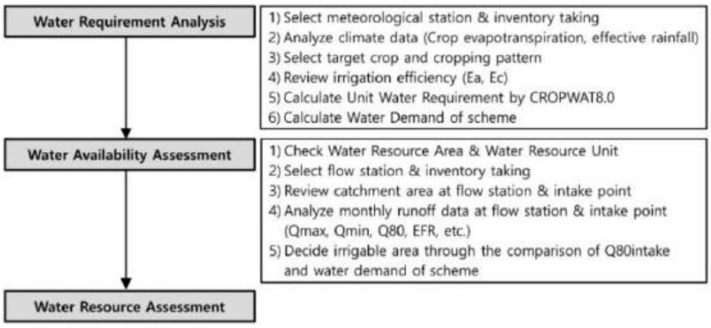


**Figure 1.** Methodology procedure for water resource assessment

## 2.2 Study Area

Among the scheme with existing irrigation facilities, in this study, the Matiti irrigation scheme where is located in Blantyre District was selected as the study area. Matiti scheme has 15ha of scheme area that is gravity fed from the river, and the major crop is maize. This study reviewed the water resource assessment of Matiti scheme in accordance with the above mentioned methodology. The layout of Matitischeme is presented in the Figure 2.


**Figure 2.** Layout of Matiti irrigation scheme

# 3. RESULTS AND DISCUSSION

## 3.1 Water Requirement Analysis

(1) Climate station and data analysis

For the analysis of water requirement, climate data were collected from the climate station, which is closer to the Matiti scheme and has recorded data for least 20 years. The Chileka climate station was selected in consideration of the reliability and continuity of data.

The crop evapotranspiration (ETo) represents the potential evaporation of a well-watered grass crop. The water needs of crops are directly linked to this climatic parameter. The Penman-Monteith Method recommended by FAO was selected as the appropriate combination method to determine ETo from climatic data such as temperature, humidity, sunshine and wind speed. Effective rainfall is the water quantity from rainfall, subject to rainfall intensity, topography, soil and contained water, utilized for farming by the irrigation system. To account for the losses due to runoff or percolation, the effective rainfall was calculated by USDA Soil Conservation Service

Method. In this study, ETo and effective rainfall were analysed using a CROPWAT8.0 program by FAO, and results are shown in Table 1.

**Table 1.** Monthly crop evapotranspiration (mm/day) and effective rainfall (mm)

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ETo | 4.41 | 4.30 | 4.17 | 4.17 | 3.94 | 3.57 | 3.72 | 5.10 | 6.04 | 6.72 | 5.97 | 4.78 |
| Eff. Rain. | 135.3 | 128.8 | 115.0 | 42.5 | 9.7 | 2.1 | 2.4 | 1.2 | 3.5 | 27.8 | 79.2 | 127.3 |

(2) Cropping pattern and crop coefficient

A major crop of Matiti scheme is Green Maize in the dry season and Dry Maize in the wet season. In this area, the development days of Green Maize and Dry Maize are 90 days and 145 days respectively. Maize can be cultivated 3 times a year, Green Maize 2 times and Dry Maize 1 time. The cropping pattern is shown in Figure 3.

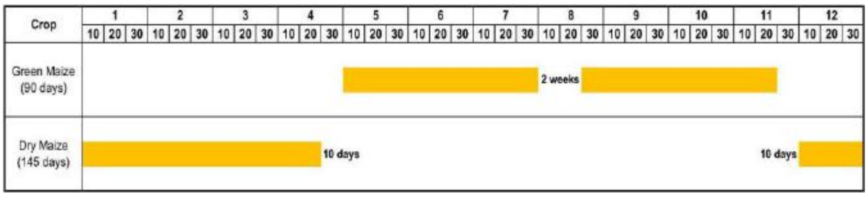


**Figure 3.** Cropping pattern of Maize at Matiti irrigation scheme

The crop coefficient (Kc) incorporates crop characteristics and averaged effects of evaporation from the soil. Changes in vegetation and ground cover mean that the Kc varies during the growing period. The Kc required to describe and construct the crop coefficient curve; the initial stage $Kc_{(ini)}$, the mid-season stage $Kc_{(mid)}$, and the end of late season $Kc_{(end)}$. As the Irrigation and Drainage Paper No.56 (FAO, 1998), the Kc and maximum height of Maize is presented in Table 2.

**Table 2.** Crop coefficient (Kc) and maximum height (m) for Maize

| Crop | $Kc_{(ini)}$ | $Kc_{(mid)}$ | $Kc_{(end)}$ | Maximum Height |
|---|---|---|---|---|
| Green Maize | 0.30 | 1.15 | 1.05 | 1.50m |
| Dry Maize | 0.30 | 1.15 | 0.60 | 1.50 m |

(3) Irrigation efficiency

The main factors that affect the irrigation efficiency are application, conveyance and distribution losses. In case of small scale schemes, because the distribution losses are limited, this study did not consider the distribution losses. The application efficiency is the ratio of water stored in a particular soil layer to the amount of water arrived at paving from source for cropping. The application efficiency mainly depends on the irrigation method and the level of farmer discipline. Since the irrigation method of Matiti scheme is furrow irrigation, the application efficiency was takenas 60%. The (FAO, 1989) of application efficiency under different irrigation methodsare shown in Table 3.

**Table 3.** Standard of application efficiency (Ea) of different irrigation methods

| Irrigation Method | Application Efficiency (Ea) |
|---|---|
| Surface Irrigation (Furrow, Border, Basin) | 60% |
| Sprinkler Irrigation | 75% |
| Drip Irrigation | 90 % |

The conveyance efficiency represents the efficiency of water transport in canals, and is the ratio of water arrived from the water source to the field. The conveyance efficiency mainly depends on the length of the canals, the soil type or permeability of the canal banks and the condition of the canals. The following table provides some indicative values of the conveyance efficiency, considering the length of the canals and the soil type. In case of Matiti scheme, the main canal that supplies irrigation water from the intake to field is lined canal, and then conveyance efficiency was decided 90%.

**Table 4.** Standard of conveyance efficiency (FAO, 1989)

| Length | Earth Canal | | | Lined Canal |
|---|---|---|---|---|
| | Sand | Loam | Clay | |
| Long (>2,000 m) | 60 % | 70 % | 80 % | 90~95 % |
| Medium (200 ~ 2,000 m) | 70 % | 75 % | 85 % | 90~95 % |
| Short (< 200 m) | 80 % | 85 % | 90 % | 90~95 % |

Irrigation efficiency is calculated by multiplying the application efficiency and the conveyance efficiency. The irrigation efficiency is 54% (Ea 60% x Ec 90%), but this study decided the overall irrigation efficiency of 50% considering the safety factor in order to secure the stability of irrigation water supply. Generally, the irrigation efficiency is divided into good (50~60%), reasonable (40%), and poor (20~30%).

(4) Irrigation time

The daily time for irrigation depends on the irrigation methods. For pivot irrigation system, irrigation time can be 24 hours, the whole day. For furrow irrigation, the water application is normally 12 hours, during the day time. The irrigation method of Matiti scheme is furrow irrigation by manpower. In addition, the furrow irrigation during the night-time is inefficient in its water utilization and inconvenient to farmers. Therefore, in case of furrow irrigation, the selected irrigation time is 12 hours in consideration of water availability and experience of farmers.

(5) Unit water requirement and water demand of scheme

The unit water requirement of scheme calculated by CROPWAT8.0 in consideration of basic factors.The basic factor of Matiti scheme for the water requirement analysis is indicated in Table 5.

**Table 5.** Basic factor for water requirement analysis

| Scheme | Area | Climate Station | Major Crop | Irri. Efficiency | Irri. Time |
|---|---|---|---|---|---|
| Matiti | 15 ha | Chileka | Green Maize, Dry Maize | 50 % | 12 hours |

For the Matiti scheme, the peak unit water requirement was estimated to be 0.0008 $m^3/s/ha$ (0.8 l/s/ha) in October, but it is determined based on 24 hours irrigation time of daily basis. Therefore, the unit water requirement (UWR) and water demand (WD) for the Matiti scheme estimated to be 0.0016 $m^3/s/ha$ and 0.024 $m^3/s$ respectively, considering 15 ha of total scheme area and 12 hours of irrigation time. The results of the water requirement analysis for Matiti scheme are presented in Table 6.

**Table 6.** Monthly water requirement analysis of Matiti irrigation scheme

| | | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UWR ($m^3/s/ha$) | 24hr | 0.00003 | 0.00006 | 0.00013 | 0.00014 | 0.00012 | 0.00041 | 0.00048 | 0.00010 | 0.00046 | **0.00080** | 0.00024 | 0.00000 |
| | 12hr | 0.00006 | 0.00012 | 0.00026 | 0.00028 | 0.00024 | 0.00082 | 0.00096 | 0.00020 | 0.00092 | **0.00160** | 0.00048 | 0.00000 |
| WD (m3/s) | | 0.00090 | 0.00180 | 0.00390 | 0.00420 | 0.00360 | 0.01230 | 0.01440 | 0.00300 | 0.01380 | **0.02400** | 0.00720 | 0.00000 |

### 3.2 Water Availability Assessment

The water availability assessment is estimated by a specific yield method between the catchment area at representative flow station and catchment area at intake point. According to the water availability assessment, the extensibility of irrigable area is reviewed by comparing water demand of scheme and Q80 at the intake in consideration with the environmental flow requirement (EFR).

(1) Flow station and data analysis

The runoff data were collected from the flow station, which is closer to the study area firstly and then belonged to the same Water Resource Units (WRUs). The 2B6 flow station, which has a catchment area of 26.7 $km^2$ is selected as a representative flow station, and daily recording data (1980~2009) were collected from the HYDSTRA database of Surface Water Division of Ministry of Agriculture, Irrigation and Water Development.For the assessment of water availability, this study calculated Qmax, Qmin, Q80, and EFR by using the recording data during 30 years. The EFR is used to describe the component of flows in awatercourse that are required to sustain some level of ecological functioning such as flora and fauna, purification, sediment transport etc., so that water resourcesare developed in a sustainable way. In Malawi, EFR is considered generally 10% of Q80, and the results of runoff analysis are presented in Table 7.

**Table 7.** Runoff ($m^3/s$) analysis result at the 2B6 flow station

| Q ($m^3/s$) | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Qmax | 104.28 | 18.43 | 710.29 | 11.07 | 2.20 | 0.81 | 0.23 | 0.59 | 0.54 | 1.78 | 3.54 | 125.07 |
| Qmin | 0.0155 | 0.0209 | 0.0558 | 0.0392 | 0.0304 | 0.0304 | 0.0304 | 0.0304 | 0.0140 | 0.0051 | 0.0018 | 0.0358 |
| Q80 | 0.1492 | 0.2465 | 0.2003 | 0.1482 | 0.1068 | 0.0968 | 0.0703 | 0.0703 | 0.0587 | 0.0638 | 0.0638 | 0.1107 |
| EFR | 0.0149 | 0.0246 | 0.0200 | 0.0148 | 0.0107 | 0.0097 | 0.0070 | 0.0070 | 0.0059 | 0.0064 | 0.0064 | 0.0111 |

**(2)** Catchment area

The catchment area of flow station and intake point of study scheme has to be calculated in order to transfer the runoff characteristics. The catchment area of 2B6 flow station is 26.7 km$^2$, and the catchment area at the intake point of Matiti scheme is 28.09 km$^2$ by using the 1:50,000 digital map.

**(3)** Water availability assessment

For the water availability assessment, the runoff data of Matiti scheme was analysed. It was calculated by a specific yield method between the catchment area at 2B6 station and catchment area at the intake point of Matiti scheme. As mentioned above, the water availability was evaluated through reviewing differences of discharge between $Q80_{intake}$ and Total WD (water demand of scheme + EFR). In terms of 15 ha of scheme area, the results of runoff analysis and water availability assessment of Matiti scheme are presented in Table 8.

**Table 8.** Water availability assessment of Matiti irrigation scheme

| Q (m$^3$/s) | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $Q80_{2B6}$ | 0.14916 | 0.24649 | 0.20033 | 0.14818 | 0.10675 | 0.09683 | 0.07031 | 0.07031 | 0.05871 | 0.06378 | 0.06378 | 0.11070 |
| $Q80_{intake}$ | 0.15692 | 0.25932 | 0.21076 | 0.15589 | 0.11231 | 0.10187 | 0.07397 | 0.07397 | 0.06177 | **0.06710** | 0.06710 | 0.11646 |
| $EFR_{intake}$ | 0.01569 | 0.02593 | 0.02108 | 0.01559 | 0.01123 | 0.01019 | 0.00740 | 0.00740 | 0.00618 | 0.00671 | 0.00671 | 0.01165 |
| WD | 0.00090 | 0.00180 | 0.00390 | 0.00420 | 0.00360 | 0.01230 | 0.01440 | 0.00300 | 0.01380 | 0.02400 | 0.00720 | 0.00000 |
| Total WD | 0.01659 | 0.02773 | 0.02498 | 0.01979 | 0.01483 | 0.02249 | 0.02180 | 0.01040 | 0.01998 | **0.03071** | 0.01391 | 0.01165 |
| Assess. | O.K | O.K | O.K | O.K | O.K | O.K | O.K | O.K | O.K | O.K | O.K | O.K |

According toTable 8 above, Matiti scheme can be suppliedenough irrigation water consistently throughout the year. To estimate the extensibility of irrigable area, 80% exceedance probability discharge at the intake point determined the appropriate scheme area to cover Total WD. Therefore, Matiti scheme can be extended from 15 ha to 37 ha in the dry season in consideration of the $Q80_{intake}$. In this case, $Q80_{intake}$(0.0671 m$^3$/s) can cover total water demand (0.06591 m$^3$/s) of the scheme. The results of extensibility of irrigable area and trends in available discharge and irrigable area for Matiti scheme are presented in Figure 4 and Table 9.

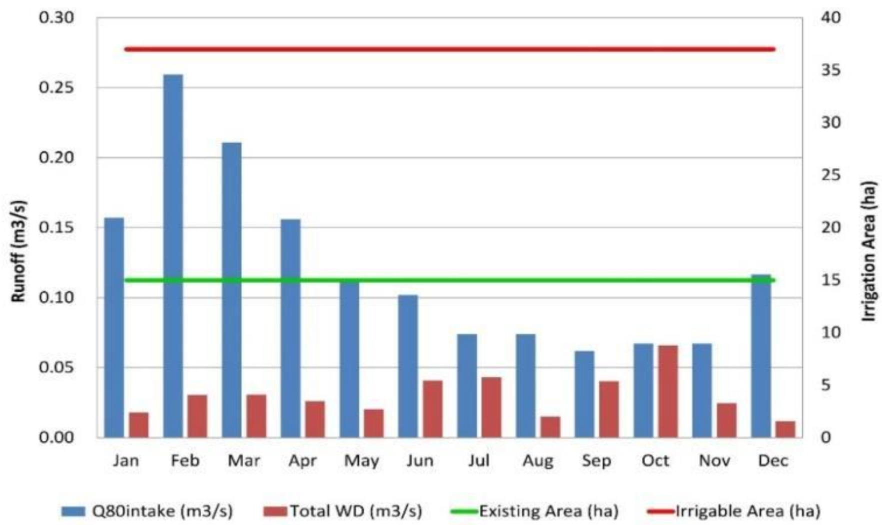


**Figure 4.** Trends in available discharge and irrigable area for Matiti irrigation scheme

**Table 9.** Review of the extensibility of irrigable area for Matiti irrigation scheme

| Q ($m^3/s$) | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $Q80_{intake}$ | 0.15692 | 0.25932 | 0.21076 | 0.15589 | 0.11231 | 0.10187 | 0.07397 | 0.07397 | 0.06177 | **0.06710** | 0.06710 | 0.11646 |
| $EFR_{intake}$ | 0.01569 | 0.02593 | 0.02108 | 0.01559 | 0.01123 | 0.01019 | 0.00740 | 0.00740 | 0.00618 | 0.00671 | 0.00671 | 0.01165 |
| WD | 0.00222 | 0.00444 | 0.00962 | 0.01036 | 0.00888 | 0.03034 | 0.03552 | 0.00740 | 0.03404 | 0.05920 | 0.01776 | 0.00000 |
| Total WD | 0.01791 | 0.03037 | 0.03070 | 0.02595 | 0.02011 | 0.04053 | 0.04292 | 0.01480 | 0.04022 | **0.06591** | 0.02447 | 0.01165 |
| Assess. | O.K | O.K | O.K | O.K | O.K | O.K | O.K | O.K | O.K | O.K | O.K | O.K |

## 4. CONCLUSIONS

This study proposed the procedure and methodology of water resource assessment to develop and rehabilitate the irrigation scheme for Malawi in Africa, which has a tropical climate. According to the presented methodology, the water resource assessment, such as unit water requirement, water demand of scheme, and water availability were estimated for the selected study area. This method will be the most applicable method in other African countries extensively as well as in Malawi, and this study presented a guideline and procedure of water resources assessment to develop or rehabilitate the irrigation scheme.

The climate and runoff station, which has a reliable long term dataover 20 years were selected, and the basic data required to analyse were collected from the selected station.Through the field investigation, the target crops and cropping pattern suitable for local condition were also determined. In terms of the irrigation time, it was selected 12 hours in consideration of farmers' working conditions and irrigation method. Based on these factors, the unit water requirement and water demand of scheme were calculated, and the result is 0.0016 $m^3/s/ha$ and 0.024 $m^3/s$ respectively.

In addition, the availability to supply the irrigation water was evaluated, an accordingly water availability assessment that estimated the optimum irrigable area was analysed. In case of Matiti scheme, the irrigation water can supply enough to the existing scheme area of 15 ha in consideration of $Q80_{intake}$. Therefore, the extensibility of irrigable area was studied in accordance with the dry season, and then Matiti scheme was reviewed to be able to extendthe irrigation area from 15 ha to 37 ha.

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