EXPANSION OF IRRIGATION EFFICIENCY CONCEPT FOR PADDY RICE

EXPANSION DE CONCEPT DE l'EFFICIENCE D'IRRIGATION POUR LE RIZ PADDY

Hajime TANJI[1] and Hirohide KIRI[2]

ABSTRACT

A problem with rice paddy irrigation is that it is difficult to assess irrigation efficiency because the yield –water function lacks a clear maximum point and excess intake will not decrease yield. On the other hand, paddy rice irrigation has always faced a high risk of drought, especially in the downstream area of the irrigation scheme.

This paper discusses irrigation efficiency of paddy rice at the irrigation scheme level from the view point of performance based engineering design and management. The authors introduce a new concept of irrigation reliability based on the variance of water supply with very simple models of the level II procedure of performance based design. This modeling permits evaluation of inundation in paddy fields as a countermeasure to deal with drought risk.

This modeling adopts the normal distribution as the variance of intake. Additional data can improve statistical modeling of the probability distribution. A model of change of variance of distribution is described for large irrigation schemes in the middle reaches of large river basins.

In the authors' opinion, inundation in paddy fields should be decreased to improve irrigation efficiency. And it is possible if the risk of drought is reduced by water distribution. For that purpose, the future study of variance and the risk of irrigation water supply dependency on structure and operation of irrigation schemes should be the most important theme of studies of irrigation efficiency.

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[1] Head of Laboratory of Coastal Engineering, National Institute for Rural Engineering, NARO, 2-1-6, Kannondai, Tsukuba, Ibaraki 305-8609 Japan, E-mail: tanji@affrc.go.jp

[2] Senear researcher of Laboratory of Coastal Engineering, National Institute for Rural Engineering, NARO, 2-1-6, Kannondai, Tsukuba, Ibaraki 305-8609 Japan, E-mail: kiri@affrc.go.jp

Key words: *Paddy irrigation, Water supply variance, Irrigation efficiency, Economic irrigation.*

RESUME ET CONCLUSIONS

L'amélioration de l'efficacité de l'irrigation est considérée comme un indice important de l'utilisation efficace des ressources en eau. En dépit des activités économiques des agriculteurs, de nombreuses recherches indiquent qu'une faible efficacité prédomine, et notamment dans le cas de la riziculture en rizières. L'opinion prépondérante quant à la cause de cette efficacité réduite c'est le bas coût ou le coût nul de la consommation d'eau résultant du soutien de l'Etat. La Gestion Participative de l'Irrigation (GPI) est considéré comme constituant un moyen important pour compléter le mécanisme économique.

Toutefois, l'efficacité du Programme d'irrigation dans le Nord-Est de la Thaïlande est faible même avec la mise en oeuvre de la GPI. Comparé avec les cultures sur les hautes terres et plateaux, la culture du riz en rizière présente une réponse unique à l'eau d'irrigation. Généralement, une irrigation excessive des cultures sur les hautes terres provoque une diminution du rendement, alors que l'irrigation excessive des rizières n'affecte pas le rendement des cultures. Par contre, une irrigation limitée ou réduite des rizières provoque la chute du rendement. Les rendements des cultures sur les hautes terres constituent une fonction de second ordre avec la valeur maximale liée à l'irrigation par unité de superficie. Une pénurie d'eau même limitée provoque une chute significative du rendement des rizières. Il en résulte que les riziculteurs ont tendance à maintenir l'alimentation en eau d'irrigation à un niveau supérieur à la valeur critique afin d'assurer une plus grande efficacité.

Ce document se réfère à la différence entre l'absorption excessive et l'absorption critique. L'un des effets de cette différence est de compenser pour la variable dans l'alimentation en eau des rizières. Ceci peut s'exprimer partiellement par le paramètre : variable d'alimentation. Si la valeur critique de l'eau d'irrigation fournit à la rizière dans le secteur du projet peut être exprimée avec la variable, la fiabilité peut être exprimée pour l'absoption supplémentaire comme la valeur de la variable. En ce qui concerne la conception basée sur les performances, ISO a proposé une procédure basée sur la distribution normale dans la méthode dite du niveau II. La déviation standard peut être adoptée comme un indice d'exactitude. Dans un modèle de distribution normale, un sigma σpeut être adopté comme une valeur de tolérance de 68%. Trois σpeuvent être adoptés comme une valeur correspondant à 99%. Et ceci est désigné comme le volume de stabilité de la variable d'alimentation. Le volume de fiabilité pour l'irrigation est défini comme le volume en surplus de l'inondation par rapport au volume de stabilité de la variable d'alimentation. Dans ledit modèle, l'absorption réelle peut être exprimée comme le volume critique d'eau d'irrigation auquel s'ajoute la tolérance d'absorption. Et la tolérance d'absorption peut être divisé entre le volume de stabilité de la variable d'alimentation et le volume de fiabilité. La courbe inclinée de la variable d'alimentation est définie comme la modification de la variable d'alimentation de l'amont vers l'aval.

Pour améliore l'efficacité, les auteurs insistent sur le fait que l'efficacité doit être développée en composants capables d'exprimer la cause d'une faible efficacité ou d'une excellente efficacité de l'irrigation. Le modèle primaire proposé dans ce document constitue un outil utile en vue d'envisager des méthodes innovantes pour améliorer l'efficacité de l'irrigation.

L'inondation des rizières devrait être réduite si l'on souhaite améliorer l'efficacité de l'irrigation. Et ceci est possible si l'on réduit les risques de pénurie d'eau à cause de la distribution d'eau.

Mots clés: *Irrigation du riz paddy, variable d'alimentation d'eau, efficience d'irrigation, irrigation économique.*

(Traduction française telle que fournie par les auteurs)

1. INTRODUCTION

Improving irrigation efficiency is considered to be an important index of the effective use of water resources. Farmers are normally considered to be *homo economics*, which means that farmers select the most economical activities. If water resources are economic goods for food production, the efficient use of economical goods should be achieved naturally. Nevertheless, many researches of irrigation efficiency have indicated prevalent low efficiency, especially in paddy rice production.

Improving irrigation efficiency is a major approach to preventing water crises in this century. Worldwide, the major use of water is irrigation. And the major form of irrigation is paddy irrigation, which is practiced mainly in the Asian monsoon region. Many researches have been done concerning irrigation efficiency. In recent years, many researches have studied rice irrigation. Some new methods of improving efficiency have been proposed: SRI, aerobic rice, etc. But many researches are related to the agronomy field and few are studies from the viewpoint of irrigation engineering.

Burt et al. (1997) proposed performance from the engineering perspective. In the past decade, great progress has been achieved in the automatic operation of irrigation facilities. Regarding loop control, Harris (1989) proposed the use of the variance of residuals, i.e. control values. Concerning measurement accuracy, ISO proposed a procedure based on normal distribution. In spite of these researches, irrigation efficiency problems from the viewpoints of agronomists and engineers seem unrelated. In this paper, the authors try to expand the irrigation efficiency concept for paddy rice to close the gap between these two fields.

2. REVIEW OF IRRIGATION EFFICIENCY

The modern study of irrigation efficiency begins with Bos and Nugteren (1974,1982 based on a discussion in ICID. Since that study, many terms have been defined. But there still remain cases where one term is used with different meanings and different terms with the same meaning.

Recently Edkins (2006) and Jansen (2007) reviewed many definitions and researches about irrigation efficiency. Based on these review papers, typical irrigation efficiency can be classified into the following three main groups

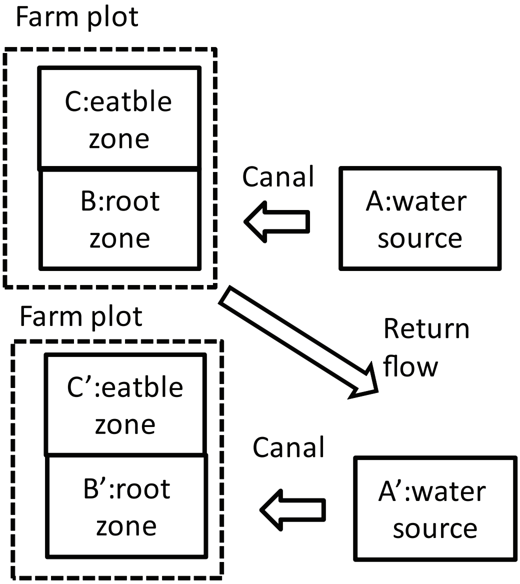

Figure 1 Concept of efficiency

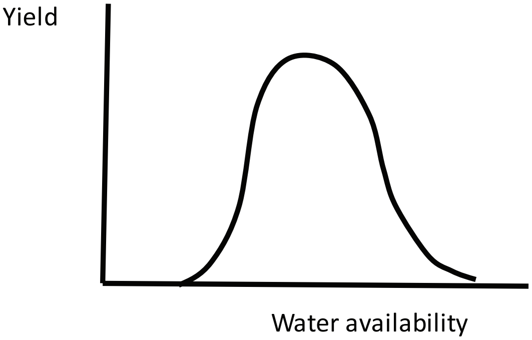

Figure 2 Typical yield-water function

1) *Water-application efficiency*: Measure the volume of water stored in the soil relative to volume applied during a single irrigation or multiple irrigations.
2) *Classical irrigation efficiency*: Measure of how well irrigation water delivered (or diverted) from a river or other source was used for its intended purpose.
3) *Net or effective irrigation efficiency*: Measure of how well water delivered was used for both its intended and non-intended beneficial purposes.

Conceptual differences between these definitions can be shown as **Figure 1**, water location. *Water-application efficiency* is C/B, *Classical irrigation efficiency* is C/A, and *Net or effective irrigation efficiency* is (B+B')/(A+A') considering the effects of return flow in the basin scale. Without considering return flow, B/A is another major index of efficiency.

On the farm plot level, *Water-application efficiency* is the basic efficiency index of water usage. Considering the efficiency for this definition, the basic characteristics are that there is the maximum yield point of water availability shown in **Figure 2**. This type of yield-water function is shared by upland crops.

3. PROPOSAL OF IRRIGATION EFFICIENCY OF PADDY RICE

For rice irrigation, the yield-water function is a monotonous increase and there is no maximum yield point. Excess water availability does not decrease yield. Based on Tuong et al. (2005) and Farooq et al. (2009), the authors show a typical yield-water function in **Figure 3**. In the figure, FC is field capacity and S is Saturation point.

Rice water availability is classified into four types.

1) Traditional upland system (TUS):
2) Aerobic rice system (ARS)
3) Alternate wetting and drying system (AWD)
4) Saturated soil cluster (SSC)
5) Traditional lowland system (TLS)

These classifications are proposed by agronomists. They study these relations in test fields with high flexibility of water supply.

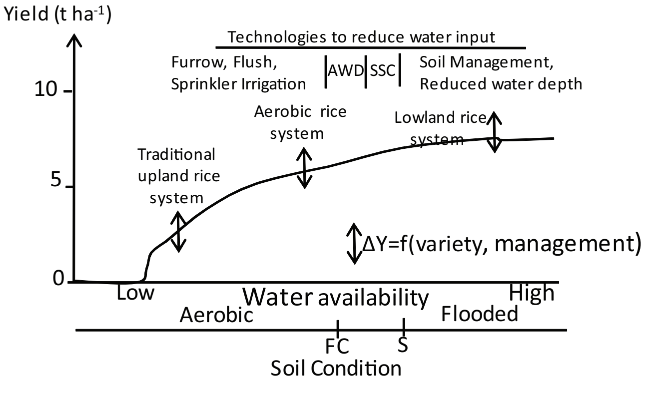

Figure 3 Yield-water functions for paddy rice

In these types, AWD, SSC and TLS adopt varieties of the same group for low land rice. The authors pose two questions regarding this proposed classification system for the low land rice variety.

1) As known by excellent farmers in Japan, the yield and quality of AWD is better than TLS because air in the root zone activates the photosynthesis of rice.
2) Judging from the experiences of irrigation engineers, without a high flexibility water supply system, low water availability poses a high drought risk ??at the shortage of water supply.

To consider these points, the conceptual yield-water function can be expressed as in **Figure 4**, but only for a low land rice variety. If water is stored in a paddy field as inundation, this stored water can be used for irrigation when no water is supplied. Inundated water can reduce the risk of drought. In rain-fed paddy fields, this lack of water supply is caused by a lack of rain or seepage caused by a lack of rain. In irrigated paddies, this lack has many causes, such as excess intake in upstream areas, or lack of river intake water. The conceptual value of this drought risk is expressed as the dotted line in **Figure 4**.

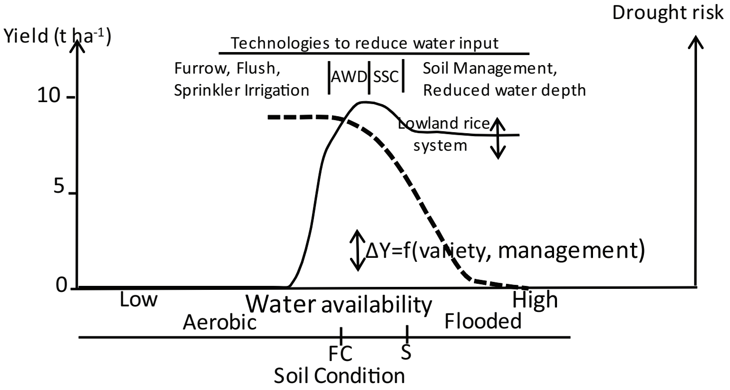

Figure 4 Yield-water functions for low land paddy rice

3.1 Economics of Irrigation Efficiency of Paddy Rice

Based on Tuong *et al*. (2005), a criterion for the minimum water availability of lowland rice under the maximum yield is Ps, saturation point. Actually lowland rice intake more water than Ps.

Tuong *et al*. describe the object of water saving or increasing of water productivity as follows:

1) To maximize crop production or its value
2) To minimize the use or the cost of expensive/scarce irrigation water without affecting the water availability to crop transpiration

This expression means that if economical condition 2) is not fulfilled, effective use of water 1) will not be achieved, and furthermore condition 1) is not a reasonable activity of farmers. Actually, condition 1) is never satisfied. The main purpose of research on irrigation efficiency is to correct this situation. In many cases, irrigation water is not supplied for a high fee or for a volume dependent water fee. Normally an irrigation water fee is strongly dependent on the irrigated area. There are few researches about condition 2). If a water fee is paid on an irrigated area, additional cost may be caused by the operation of terminal irrigation facilities. That may depend on hours of operation. Can economic condition 2) explain actual irrigation activities by farmers? The authors' answer is "No" because the following condition for irrigation reliability should be considered.

3) To minimize drought risk or to maximize irrigation reliability

Without considering economic condition 2), irrigation reliability may strongly influence the irrigation activities of farmers. Under the condition that a water fee is not paid based on irrigation volume but on irrigated area, irrigation activities of farmers may be explained mainly by irrigation reliability under the most economical activities considering irrigation efficiency.

3.2 Evaluation of Efficiency Problems for Paddy Rice

For upland crops, farmers try to fulfill the maximum yield-water point to obtain the maximum yield. **Figure 4** shows the maximum yield-water point. But a typical farmer's water management maintains inundation of paddy fields to decrease drought risk. By this water management, the naximum yield-water point cannot be achieved. The drought risk of water management should be evaluated.

Even though some percentage of the excess intake water is reused by the return flow process in the wet season, conveyance loss or excess infiltration comprises a major parts of water consumption. Intake in the classical irrigation efficiency seen in typical large irrigation schemes (for example Nong Wai irrigation Scheme) in northeast Thailand is typically, 2,000mm for dry season paddy rice. During a growing period of 100 days, mean daily water consumption is 20mm. Evapotranspitation is approximately 5mm. Therefore 15mm is excess infiltration in a paddy field or conveyance loss. The design value for classical irrigation efficiency is approximately 25%. In Japan, the mean daily water consumption is 25mm. The order of evapotranspiration is 5mm. Paddy rice is planted only in the rainy season. Therefore we must consider the effects of rainfall and return flow. Without considering rainfall and return flow, the design classical irrigation efficiency is less than 20%. The return flow ratio depends strongly on the percentage of paddy area in a basin. In advanced areas, classical irrigation efficiency may less than 25%.

Considering these situations, the main discussion points are as follows:

1) Improvement of an irrigation management control system can improve conveyance efficiency. Checking the performance of a delivery system is one important point for effective water use.
2) Inundation may cause excess infiltration. Farooq et al. (2009) discussed the effect of low water consumption of aerobic rice. Aerobic rice can grow under no inundation, which is source of evaporation from water surface. But the above discussion shows that infiltration may have a larger influence than evaporation from the water surface.
3) Return flow is caused by poor management of a water delivery system and excess infiltration. To evaluate the present irrigation efficiency on the basin scale, return flow should be considered (Molden 1997). But to practice the best irrigation, return flow should be decreased because control of this value is much more difficult than the operation and management of irrigation facilities. This means that return flow may cause low efficiency of water on the basin scale.

   If irrigation water management is done presuming that best practice guidelines—no excess infiltration, no inundation, no poor intake of upstream areas, no unused spilled water at the end of main and secondary canals—are followed, the highly efficient irrigation should be achieved.

But these best practice guidelines are actually not adopted because of the low reliability of water distribution systems. In the next section, the modeling of reliability of a water distribution system expressed as inundation depth will be discussed.

4. CONCEPT OF EVALUATION OF INUNDATION DEPTH

Stored inundation water can be used for supplemental irrigation when water is not supplied. The benefit of this water volume should be evaluated based on the reliability of the water supply and the supplemental water supply capacity. These two values should be expressed as probability distributions. Thanks to the strong advance of statistical sciences during the past decade, many parameters can now be treated and calculated as probability distributions. Nevertheless, because of a lack of observed data, actual probability distributions of parameters are difficult to define. In engineering, ISO 9001 adopted *performance based design* which considers probability distribution of parameters of design. If outer force is F and counter force S, the performance can be expressed as $S - F$. In this guideline of full set procedure, actual probability distribution of F and S shall be considered. This is called level III. If actual distribution is difficult to define, a simplified alternative method assuming the normal distribution is proposed and called level II.

In inundation, outer force is lack of water supply F and counter force is supplemental water supply S from storage water. Performance of inundation can be expressed as $S - F$.

4.1 Evaluation of Inundation as Supplemental Water Supply

Inundated water can be used as the supplemental water supply for the root zone. The minimum water supply for a low land paddy field can be delivered only from soil moisture without inundation. This is a main procedure of irrigation of AWD and aerobic rice. But this paper treats the simplest approach to evaluating soil moisture for simplification. The authors set an assumption that soil water can supply enough irrigation water to irrigate paddy rice for one day when no inundation has occurred.

Daily evapotranspiration and infiltration are modeled as constants for simplification. In future modeling, the variance of these parameters should be considered. If daily water consumption, infiltration and evapotranspiration in a paddy field are assumed to be x mm/d and inundation depth is assumed to be y mm, the assumed supplemental irrigation period is x/y days. This potential irrigation period can be used as the index of supplemental irrigation as a measure to counter a lack of water supply. Therefore;

$$S = \frac{x}{y}$$

In the minimum intake condition, there is no inundation. Though x is called *intake allowance*.

4.2 Evaluation of Instability of Water Supply

Lack of a water supply is modeled as instability of water supply. In the level II approach, variance of water supply can be modeled as normal distribution. Normal distribution can be defined by two parameters: mean and standard deviation. Considering several days during the irrigation period, if water supply and water consumption is balanced, the mean water supply should be y mm/d. In the case of intake water, the maximum possible intake is limited by the size of intake facilities. Variances will appear not for the larger value but for the smaller value. Therefore in this paper, normal distribution of one-side value that is the distribution less than a mean is used and called normal distribution.

Standard deviation depends on irrigation conditions. Supposing is given, the probability of less water supply of $y - \sigma$ is 32%, $y - 2\sigma$ is 5% and $y - 3\sigma$ is 1%. If irrigation period of rice is 100 days, roughly speaking, water supply less than $y - 3\sigma$ may happen only one day. $y - 2\sigma$ may happen 5 days and $y - 3\sigma$ may happen 32 days. Under the former assumption, soil moisture can supply irrigation water of one day. Therefore if supplemental irrigation can cover the variance 3σ of water supply, the risk performance level design can permit the instability of the water supply. The value 3σ is a critical value called z .

By using above concept, inundation depth x can separated into two parts if $x > z$.

$$x = z + (x - z)\ (x > z)$$

The volume z is inundation as a countermeasure to prevent instability of the water supply. The value $x - z$ is inundation to increase the reliability of the water supply under unexpected conditions or external conditions by normal distribution models. Therefore z is named *stability volume for delivery variance* σ (in short *stability volume*) and $x - z$ is named *reliability volume*.

If $x < z$, this irrigation system cannot fulfill its required performance.

With this framing, estimation of becomes a basic parameter of reliability of irrigation that expresses the conceptual drought risk in **Figure 4**. Based on normal distribution $n(y, \sigma)$, the probability density function of normal distribution is written as $dnorm\ (x, mean = 3\sigma, sd = \sigma)$.

4.3 Most Economical Irrigation Activities

Based on the risk function, the most economical intake condition can be calculated. This result shows that a decrease of intake is not economically suitable under present conditions.

Drought risk w can be calculated as follows:

$w = 1 - dnorm\ (x, mean = 3\sigma, sd = \sigma)$

Expected yield b as benefit of irrigation can be expressed as follows;

$b = ym \times (1 - w)$

ym is the maximum yield. If the maximum yield ym is set as 1.0 for standardized expression, expected relative yield b van be expressed as follows;

$$b = 1 - w$$

Figure 5 shows the calculated drought risk w and relative benefit b of this model by x axis as inundation of σ (sd) scale.

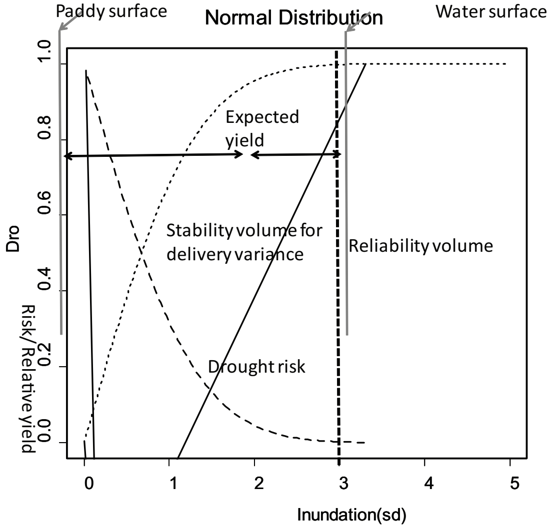

Figure 5 Calculation of drought risk and relative yield

5. CAN IRRIGATION RELIABILTY BE MODELED AS NORMAL DISTRIBUTION?

There are few papers about the study of variance of delivery. Irrigation reliability depends on the difference between expected intake (irrigation demand) and actual intake. The record of actual intake is retained if measuring instruments and data loggers are provided. But regarding the expected intake, no data is retained. Therefore to evaluate variance, estimation of the expected intake or similar method should be treated as an important issue.

Secondly, variances are caused by many factors. Statistical study indicates that variance can be modeled by normal distribution if the phenomena are caused by only one factor. If there are many factors at work, variance caused by each factor can be approximately modeled as a normal distribution, while the probability distribution of composition cannot be modeled by a normal distribution. Combined distribution of some normal distribution should be considered. Even in that case, if the effect of one factor is strong, composition can be modeled by normal distribution. If a normal distribution model is insufficient, a probability distribution must be considered and performance based design of level III should be used instead of level II.
Under this condition, at first, the study of delivery variance should focus on the causes of factors.

5.1 Operational Variance and Observation Variance

One method of indirectly estimating expected intake is to use intake records to consider the differences of intake. Normally, operation of intake gates at a river has some allowance of accuracy. Openings of gates can adopt some step values such as multiples of 3 cm because of the limitations of mechanical structures. On the other hand, the water level on a river changes from time to time. For these reasons, there are some gaps between targeted intake water and actual intake water. If this gap value is larger than the criterion, new operation of gate openings starts. If the gap value is smaller than the criterion, no operation will start and a small change of intake will be recorded. Intake changes in two ways, with and without gate operation. Below, the former is called *operational change* and the latter is called *observation change*. As for variance, the former is called *operational variance* and the latter is called *observation variance*. The authors' main concern is operational variances. The observation variance may be smaller than the operational variance.

Figure 6 shows the distribution of intake difference. If daily intake data is shown as $d(i)$ (i = 1,..., n), intake difference $D(i)$ can be defined as follows:

$$D(i) = d(i) - d(i - 1) \quad (i = 2,...n)$$

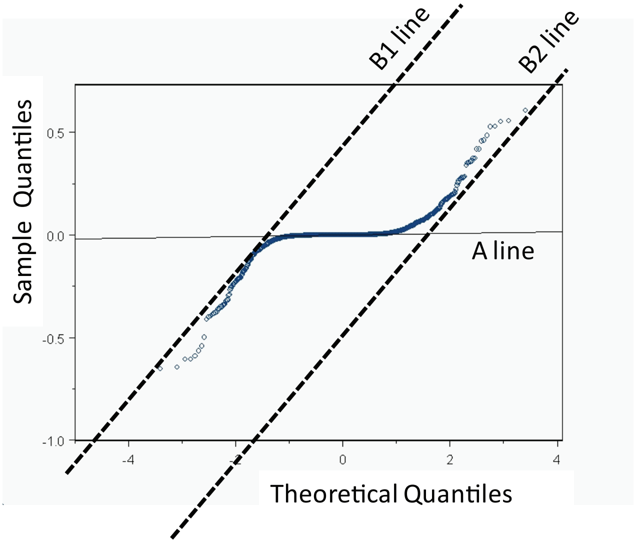

Figure 6 Q-Q plot of intake difference

Data in **Figure 6** shows a distribution along line A, line B1 and line B2. Line B1 and line B2 are located in parallel positions. In a quantile – quantile plot, if data is distributed along a line, normal distribution can be applied. A line shows *observation variance* that can be caused by instability of measurement or by a small change of surface water level of the intake river without the operation of intake gates. Lines B1 and B2 show *operational variance* plus variance of change of operation that can be caused by operation of intake gates. If *observation variance* can be omitted, *operational variance* plus variance of change of operation can be modeled as normal distribution. There are no data for distribution of change of operation. It is impossible to separate distributions of change of operation and of operational variance. This separation should be done in a future study. In this paper, the authors maintain the assumption that intake variance can be modeled as normal distribution if observation variance is operation as expected from observed data.

5.2 Variance Depending on Location

Because of upstream intake, reliability of intake decreases from upstream to downstream. But actual irrigation reliability is not measured because expected intake is not recorded. Therefore the deduction approach cannot be applied to this problem. If each intake *Q*(*i*) has the operational variance that can be modeled as normal distribution, the effect of upper intake can be calculated. But these approaches depend on the schematic structure of irrigation facilities. In the irrigation scheme study in the Mekong River, irrigation schemes in northeast Thailand have high hierarchy from upstream to downstream. But irrigation schemes on the Mekong delta in Vietnam have weak hierarchy from upstream to downstream. **Figure 7** shows a simple model of this expansion of variance in the case of northeast Thailand. At the upstream end of a main canal, there is an intake weir from the river. For simplicity, the expected maximum intake condition is discussed. Variance of intake from the river can be modeled as a normal distribution caused by change of the water level of the river and operational errors. Expected intake *Q*(*i*) of secondary canals is modeled as normal distribution. Variance of the expected intake is caused by operational errors at the maximum intake conditions. If reached water of a main canal at each intake point is larger than the expected intake of each secondary canal, actual intake is equal to the expected intake. But if reached water is smaller than expected intake, actual intake should be smaller than the expected intake. Expected intake will be equal to reached water. Therefore considering the intake of secondary canals on a certain day from upstream to downstream, until the point where water cannot be taken into a secondary canal, actual intake equals expected intake. At that point, actual intake is less than expected intake and actual intake is equal to zero at downstream areas of main canals. This phenomenon can be modeled as change of variance from upstream to downstream.

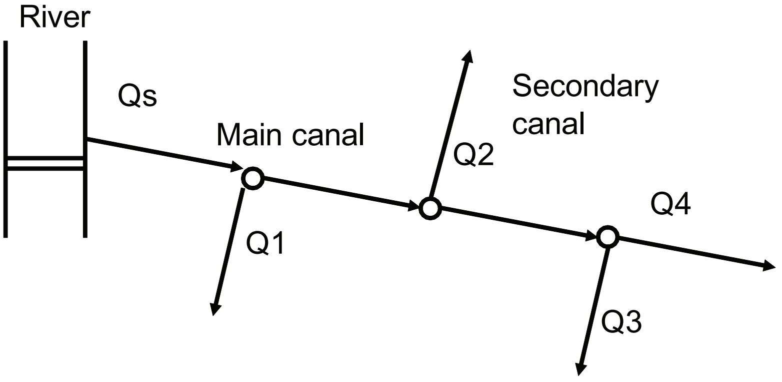

Figure 7 Simple model of intake variance change

5.3 Water Distance

Most popular irrigation schemes take water from a river and convey the water through open canals with many distributers. Reliance on intake volume decreases as water passes through distributers. Upstream intake is stable and downstream intake is unstable because of excess intake or incorrect operation of upstream canals.

This extension of instability of intake is called delivery variance in this paper. This change of delivery variance is very important for irrigation management and actually very complex. The authors try to express this characteristic as a simple linear model of the first order. The terms upstream and downstream are ambiguous because irrigation canals expand like the roots of a tree. The actual critical meanings of upstream or downstream is the order of intake facilities. In this sense, the actual distance from an upstream intake to a downstream intake cannot express the hierarchy between upstream and downstream. The major factor of hierarchy of intake priority from upstream to downstream is intake discharge. If upstream intake discharge is large, upstream priority is high and the disadvantage of downstream intake is large.

Total intake is expressed as Qs and each intake is expressed as $Q(i)$ ($i = 1,\dots, n$). $Q(i)$ is intake to the secondary canals or direct intake from the main canal. In this assumption, $Q(i)$ is excusive and not a duplicated count of intake discharge. That is,

$$Qs = \sum_{i=1}^{n} Q(i)$$

Considering intake k of intake discharge $Q(k)$, the whole irrigation scheme can be separated into the upstream part Pu and the downstream part Pd as shown in **Figure 8**. $Q(k)$ belongs to the downstream part.

The sum of intake of upstream and downstream is defined as follows:

$$Qsu = \sum Q(i)(i \in Pu)$$

$$Qsd = \sum Q(i)(i \in Pd)$$

Therefore Qs can be expressed as follows:

$$Qs = Qsu + Qsd$$

The advantage of upstream priority can be expressed as the ratio between Qsu and Qsd. Virtual distance of the normalized max as 1 can be introduced as an index of upstream priority as follows:

$$Wd = \frac{Qsu}{Qs}$$

This virtual distance of upstream priority is called water distance in this paper.

If a normal distribution assumption can be applied, variance of intake can be expressed as standard deviation. From upstream to downstream, reliability of intake discharge decreases. Mean intake discharge decreases and variance of intake increases.

Of these two factors, decrease of mean intake discharge is difficult to include in design because normalized illegal intake upstream cannot be a basic assumption for irrigation design. On the other hand, operational error can be assumed to be a basic assumption for irrigation design. For this reason, in this paper, only variance of intake is considered.

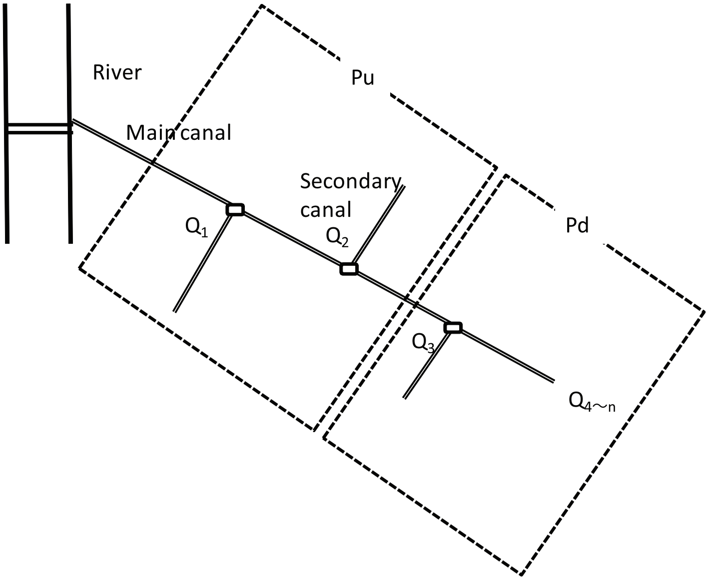

Figure 8 Water distance concept

If standard deviation of intake residuals σ is increased from upstream to downstream, the simplest assumption between these two parameters are linear relations.

$$\sigma \propto Wd$$

Otherwise,

$$\sigma = s \times Wd$$

Where, *s* : coefficient of linear function called water *delivery variance slope*.

6. CONCLUSIONS AND RECOMENDATIONS

A problem with rice paddy irrigation is that it is difficult to assess irrigation efficiency because the yield –water function lacks a clear maximum point and excess intake will not decrease yield. On the other hand, paddy rice irrigation has always faced a high risk of drought especially in the downstream area of the irrigation scheme.

This paper discusses irrigation efficiency of paddy rice at the irrigation scheme level from the view point of performance based engineering design and management. The authors introduce a new concept of irrigation reliability based on the variance of water supply with very simple models of the level II procedure of performance based design. This modeling permits evaluation of inundation in paddy fields as a countermeasure to deal with drought risk.

This modeling adopts the normal distribution as the variance of intake. Additional data can improve statistical modeling of the probability distribution. A model of change of variance of distribution is described for large irrigation schemes in the middle reaches of large basins.

The authors recommend that inundation in paddy fields should be decreased to improve irrigation efficiency. And it is possible if the risk of drought is reduced by water distribution. For that purpose, the future study of variance and the risk of irrigation water supply dependency on structure and operation of irrigation schemes should be the most important theme of studies of irrigation efficiency.

REFERENCES

Burt, C.M., A.J. Clemmens, T.S. Sttrelkoff, K.H.Solomon, R.D. Bliener, L.A.hardy, T.A. Howell, D.E. Eisenhauser, 1997. Irrigation performance measures: efficiency and uniformity, Journal of irrigation and drainage, vol.123, no.6, ASCE, 423-442

Edkins, E., 2006. Irrigation efficiency gaps – review and stock trade, Proposal for sustainable farming fund and irrigation in New Zealand, Aquatic research ltd.,39p.

English, M.J., K.H. Solomon, G.J. Hoffman, 2002. A paradigm shift in irrigation management, Journal of irrigation and drainage engineering, vol.128, No.5, ASCE, 267-277

Farooq, M., N.Kobayashi, A.Wahid, O.Ito, S.M.A. Basra, 2009. Strategies for producing more rice with less water, Advance in Agronomy, Vol.101. 351-388, Elservier

Harris, T.J., 1989. Assessment of control loop performance. Canadian Journal of Chem. Eng., 67(10), 856-861.

Jansen, M.E. 2007. Beyond irrigation efficiency, Irrigation Science, 25, Springer, 233-245

Moledn (1997): Accounting for water use and productivity. in: IWMI/SWIM paper no.1, 25p.

Passiouna, J. 2004. Increasing crop productivity when water is scarce – from breeding to field management, new directions for a diverse planet, Proceeding of the 4th international crop science congress, 17p.

Seng, C.C., S. kimi, A. man, Z. Hassain, 2009. Aerobic rice: producing more rice with less water, Malaysian national committee of ICID, 9p. , http://www.mancid.org.my/abstract.php

Tuong, T.P., B.A.M. Bouman, M. Mortimer, 2005. More rice, less water – integrated approaches for increasing water productivity in irrigated rice-based systems in Asia, Plant. Prod. Sci. 8(3), 231-241, Crop Science Society of Japan