Basic Energy Conversion in Farmland and Water during Development

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ABSTRACT

Taiwan is an island with more hills and fewer plains. The land utilization of Taiwan was deeply influenced by her terrain. In Taiwan the majority of land that are mountain or hillside area had been restricted to develop for their environmental sensitivity. Under the pressure of agricultural land released by the effect of WTO engagement for Taiwan, many of the farmlands located on the region of alluvial plain have become one of the main sources for land demand. However, the original natural and ecological characteristics of farmland, such as water environment, may be sacrificed easily during the process of development. Since it is not easy to establish a scientific evaluation tool with proven data, both of the standard procedure for evaluation and the guideline for development have not been clear yet. How to maintain the balance between the development and preservation usually becomes a sensational disputing argument. In this paper, the author tried to apply the prospect from basic energy conversion in classic thermodynamics for the developing change of agricultural lands. It was focused particularly in their water and farmland characteristics. Those topics of changes, such as land grading, soil reposition, subsurface saturated flow, and surface runoff, have been discussed in this paper. Based on these physical indexes, the energy conversion and entropy variation might be estimated.

KEYWORDS: farmland development, entropy, energy conversion

1. INTRODUCTION

Taiwan is an island with more hills and fewer plains. The land utilization of Taiwan was deeply influenced by her terrain. Increasing pressure for the needs of land comes from the social end economical development. However, the majority of land in Taiwan that is mountains or hill area had been deeply restricted to develop, because of repeatedly serious disasters by improper development in sensible environment. Under the pressure of agricultural land released by the effect of WTO engagement for Taiwan, many of the farmlands located on the region of alluvial plain have become one of the main sources for land demand. However, the original natural and ecological characteristics of farmland, such as soil and water environment, may be sacrificed easily during the process of development. It could easily become a sensational disputing argument between the developers and the protectionisms. The physical index from classic thermodynamics may be a common concept to balance these kinds of dispute (Yu, 1996).

It is well known that the law of energy conservation and the law of increasing entropy in an open environment system from classic thermodynamics. The physical index derived from basic thermodynamic laws was most applied for energy conversion and entropy change. In following deliberations, the basic energy conversion and entropy change in soil and water during the alluvial farmland development will be reasoned and discussed.

2. CHARATERISTICS OF SOIL AND WATER IN ALLUVIAL PLAINS

Alluvial Plains were formed mainly by the sedimentation of aggregates carried by water flushing from upper regions. Different depths of soil layers were generally found in the stratum of alluvial plain due to various aggregate transported by diverse flood events. Because mudflows usually came along with the floods, it was easily found that muddy soil layers were mingled with sandy and gravels layers. In the restriction of muddy layer, groundwater mostly flowed along the higher hydraulic conductivity sandy-gravel layers. Therefore, seepage infiltrated from precipitation above the muddy layers normally became the perched aquifer; in the same time, groundwater existed among constrained layers became the confined aquifer.
According to the soil and water characteristics, most of the alluvial plains in Taiwan have been developed by agriculture cultivation. Under the paddy farming custom, layered-soils effect has been enhanced. Plentiful groundwater in alluvial plains can supply the agricultural water usage under low water season; on the other hand, gentle farmland may improve the groundwater recharge at high water season. In other words, farmland utilization in alluvial plains was quite compatible with their soil and water characteristics.

3. ENGINEERING EFFECTS IN FARMLAND DEVELOPMENT

The development of farmland was usually that gentle fields were graded to become regulated block and buildings replaced the cultivated area. The farmland development made the terrain more regular and uniform, at the same time; it reduced the original coverage and increased more impervious area.

3.1 Changes from Construction in Earth Works

For farmlands, it was usually kept the slightly mild slope to maintain the surface runoff direction for irrigation and drainage. For regulated developed blocks, it was constructed almost horizontally to stabilize the building foundation. During the process of land grading, earth works about the cut and fill as well as the soil compaction were all necessary. In addition, earth works included the foundation excavation of buildings and the dumping treatment of some excess earth volume.

3.2 Changes in Runoff and Infiltration

The soil surface of farmland needs to be turned over regularly within the cultivated period. When it rains on the cultivated farmlands, water may infiltrate more easily into the soil according to mild land slope, crop coverage, and sparse structure of soil, and the runoff may be reduced. The fine soil particles flushed along with the runoff settled usually on the lower location or washed out from field. The original perched groundwater table of farmlands moved up and down complied with the irrigation schedule. When the infiltration becomes less, the averaged groundwater table would be lower. At the same time, the permeability will become much less once the soil surface after compaction. Therefore, after farmland development, the volume of subsurface saturated flow will commonly be less.

4. VARIATION OF BASIC ENERGY AND ENTROPY DURING DEVELOPMENT

To discuss the variation of basic energy and entropy during farmland development, it was necessary to be defined that the change of the system of soil and water by means of classical thermodynamic laws.

4.1 The First and the Second Laws in Thermodynamics

The main meaning of the first law in thermodynamics displays the idea of energy conservation. Simply says, the change of total energy within a confined system, ΔE, was composed with the work, W_{in} from surrounding done to the system, W_{out} from system exported to surroundings, and the absorbed heat Q_h by system. It may be expressed as

$$\Delta E = W_{in} - W_{out} + Q_h \quad (1).$$

This change of energy must be consistent with the conservation principle. In the second law of thermodynamics, it is stated that the transformation process in energy must be orientated as the increase of system entropy. The increased entropy, ΔS, may be defined as the integration of the ratio between the energy change and system temperature, T, during the transformation, expressed as,

$$\Delta S = \int_1^2 \frac{dE}{T} = S_2 - S_1 \quad (2).$$

It was represented in equation (1) that S_1 was the entropy before transformation, and S_2 was the one after. Hence, the meaning of second law was usually extended as that all of the energy transformation in nature would produce somewhat unavailable heat more or less, which would not be recoverable or reusable by the system.

4.2 Energy in Soil and Water System

The total energy E_t in the whole system of soil and water may be defined as,

$$E_t = \left\{U + \frac{1}{2}mv^2 + mgz\right\}_{water} + \left\{U + \frac{1}{2}mv^2 + mgz\right\}_{soil} \quad (3).$$

In which, U is the system internal energy, m is the system mass, v is the flow velocity, g is gravitation acceleration, and z is the represented elevation. In general, the internal energy changed only with its physical status was assumed as invariable. Therefore, equation (1) may combined with equation (3) to become as following,

$$W_{in} - W_{out} + Q_h = \left\{\frac{1}{2}m\Delta v^2 + mg\Delta z\right\}_{water} + \left\{\frac{1}{2}m\Delta v^2 + mg\Delta z\right\}_{soil} \quad (4).$$

Since the position of soil particles was regarded as stationary, its kinetic energy might be neglected. Thus, if the soil and water in the system separated by their different density, equation (4) could also be expressed as,

$$W_{in} - W_{out} + Q_h = \frac{1}{2}\rho_w V_w \Delta v^2 + \rho_w g V_w \Delta z_w + \rho_s g V_s \Delta z_s \quad (5).$$

Whereas ρ_w and ρ_s represented the density of water and of soil, V_w and V_s were the represented volume of theirs, respectively.

4.3 Energy Conversions by Development

From the engineering effect of development, the energy transformation of soil and water during farmland development might be discussed in different aspects as following.

4.3.1 Land grading

Land grading was the primary process of changing farmland terrain during development. Within the process, the energy conversion involved might be categorized into two types. The first kind of energy transformation was the potential energy of soil and the second kind of that was the intervened work from the earth engineering construction. The change of the potential energy of soil could be expressed as,

$$(\Delta mgz)_{soil} = \int \rho_s g V_s dz_s = \int \gamma_s V_s dz_s \qquad (6),$$

In which, γ_s was the unit weight of soil in its related location. The scope of earth cut and fill in land grading might be related by it changing volume and elevation variables. The volume conversion of soil compaction level might be correlated with its unit weight.

The engineering practice such as cut-fill, compaction-consolidation, and transport of earth in land grading needed a lot of machinery application. All of the required energy for the machinery was just the input work W_{in} of the system. In other term, this part of input work was represented the consumed energy of engineering machinery. Hence, the input work $W_{in,m}$ from surrounding could be displayed as the function Ψ of consumed energy of construction expressed as,

$$W_{in,m} = \Psi[(E_m)_i] \quad i = 1,2,3.... \qquad (7).$$

In which, $(E_m)_i$ was the consumed energy of the i^{th} kind of machinery. In practice at Taiwan , the type fuel of most of the engineering machinery consumed was refined diesel. It would be easily to be computed from energy conversion database by combining the working efficiency on site of machinery with the scope of field works (Lee et al, 1998). The working efficiency was related with the power of machinery, the working terrain, geological conditions, climate, and working duration etc., even with the habitual behavior of the operator. The scope of field works was mainly the magnitude of cut-fill volume engaged in earth works. In brief, the machinery consuming energy could be express as the function Θ of consumed efficiency ε and the magnitude function M of the scope,

$$W_{in,m} = \Psi[(E_m)_i] = \Theta[\varepsilon_i, M(\gamma, V)_i] \quad i = 1,2,3.... \qquad (8).$$

Hence, it would be estimable for the consumed energy from the detail land-grading plan. In experience, the varied range of consumed efficiency was quite limited; however, the larger magnitude of engineering, the more energy consumed. That implied the magnitude of earth-working volume might have more important impact for the energy consumption.

4.3.2 Soil reposition

The soil reposition was indicated to the erosive or deposited change of soil surface by development. This kind of energy transformation basically was similar with the situation of land grading only mainly caused by natural rainfall not artificial work. Then the calculation of its energy conversion was same with equation (6).

4.3.3 Subsurface saturated flow

Subsurface saturated flow was resulted by the effect of gravitation and soil matrix on the movement of soil moisture increased due to the rainfall infiltration. From the water resource conservation and usage point of view, the comprehension of subsurface saturated flow was the basis to understand the variation of underground water resource and to estimate the design capacity of subsurface drainage system. Subsurface saturated flow was complied with Darcy's law expressed as,

$$q_u = -K_u \frac{\Delta Z}{L_u} \qquad (9).$$

Whereas, q_u was the unit flux of flow, ΔZ was the total potential energy difference, K_u was the saturated hydraulic conductivity, and L_u was the length of flow path. After the influence of development, average groundwater table would be lower due to the less surface infiltration. In other words, land development would result in decreasing potential energy of subsurface saturated water. This might be expressed as,

$$(\Delta mgz)_{water} = \int_{z_1}^{z_2} \gamma_w V_w dz = \int_{z_1}^{z_2} \theta \gamma_w A_w \bar{z} dz \qquad (10).$$

In which, γ_w was the unit weight of water, θ was the soil porosity, z_1 and z_2 represented averaged groundwater table before and after development respectively, and A_w and $\bar{z}$ denoted the area and average elevation difference, respectively, of affected groundwater table during the time of impact. If taking into consideration of affected groundwater table through the reduction of surface infiltration, and by that surface infiltration rate eventually close to the saturated hydraulic conductivity from the Philip's theorem (Philip, 1969) as well, the infiltration reduction might be expressed as,

$$\theta A_w \bar{z} = \int_0^{t_e} \kappa \overline{K_u} A_d dt \qquad (11).$$

In which, t_e was the affected time, κ was the portion of decreasing infiltration, A_d was the area developed, and $\overline{K_u}$ was averaged saturated hydraulic conductivity of A_d. Once $\overline{K_u}$ and A_d during the period of t_e were known, it was possible to estimate the decreasing potential energy due to the development.

4.3.4 Surface runoff

Rainfall was the primary source of work from the surrounding into the system. The work for rainfall input, $W_{in,r}$, might be expressed by its rainfall intensity, I_r, rainfall duration, t_d, and the terminal velocity of raindrops, v_t, as

$$W_{in,r} = \int_0^{t_d} \rho_w I_r A_e \cdot \frac{v_t^2}{2} dt = \frac{\rho_w A_e}{2} \int_0^{t_d} I_r v_t^2 dt \qquad (12).$$

As the excess rainfall becoming surface runoff, overland flow occurred first. Uniform overland flow could be used to estimate the average flow velocity for overland. Overland uniform discharge over unit flow width, q_o, might be expressed as,

$$q_o = (I_r - f)L_o \cos\alpha = (I_r - f)L_p \qquad (13).$$

Whereas, f represented surface infiltration rate, L_o was the length of overland flow, α was the inclined angle of land surface, and L_p was the horizontal projected length of overland flow. By the overland flow equation from Roberson et al (1985), the friction energy loss due to overland flow, E_{of}, could be expressed as (Chow et al, 1988),

$$E_{of} = \frac{24\nu}{q_o} \cdot \frac{L_p}{4z_o} \cdot mv^2 \qquad (14).$$

In which, z_o was the depth of overland, ν was the kinematic viscosity of water, and v_o was the average overland flow velocity.

Once overland flow was collected into some drainage system such as ditches or culverts that did not reach their flow capacity, the condition of flow was generally simplified as uniform open channel flow. If the capacity of culverts was reached, then the flow condition might become to pressured pipe flow. Ultimately, the collected runoff would come out from some outlets to downstream. All of discharge from outlets represented the output work $W_{out,r}$ by the system. This $W_{out,r}$ could be expressed as,

$$W_{out,r} = \int Q_c \left(g\Delta h + \frac{v_c^2}{2} \right) dt = \gamma_w \int A_c v_c \left(\Delta h + \frac{v_c^2}{2g} \right) dt \quad (15).$$

In which, Q_c was the outflow discharge, Δh was the flow depth difference at the outlet, v_c was velocity of outflow, and A_c represented the outflow section at the outlet.
The other energy conversion would come from the friction loss E_{cf} in the channel or pipe flow. The E_{cf} could be obtained through Bernoulli equation. In general, E_{cf} was closely related to the flow velocity and the friction coefficient of the flow path.

The overwhelming majority of surface runoff comes from precipitation. From a long-term view, the energy conversion for water flow was dominantly influenced by the total mass of flow and the layout of drainage system. When the mass allocation between the subsurface flow and surface runoff was changed, the portion of each energy loss would be different. Once the change becomes larger, the relevant energy loss, such as the decreasing potential energy of groundwater table or friction energy loss of runoff, would vary intensively simultaneously. The adjustable layout of a drainage system might be helpful to balance the variation somewhat to reduce the overwhelming effect (Yu, 1996).

4.4 Entropy Increasing

The energy conversion during farmland development including total energy loss E_f and no external heat engaged, under invariable internal energy assumption, could be expressed as,

$$W_{in} - W_{out} + E_f = \Delta mgz + \frac{1}{2}\Delta mv^2 \quad (16).$$

The mechanical energy, including potential energy and kinematic energy, could be transformed and reused. However, the energy converted into friction heat during the development would be released in background and could not be useable. This lost energy mainly consisted of consumption of land-grading machinery energy, decreasing potential energy of groundwater table, and friction energy of water flow in various forms. In terms of previous definitions, the total lost energy could be expressed as,

$$E_f = \Theta[\varepsilon, M(\gamma, V)] - \int_{z_1}^{z_2} \left(\int_0^{t_e} \kappa \gamma_w \overline{K_u} A_u dt \right) dz + \sum \left(E_{of} + E_{cf} \right) \quad (17).$$

It was almost insensible for the variation of internal energy of soil and water in the process of development. Thus, the change of entropy ΔS would be expressed as,

$$\Delta S = \int_1^2 \frac{dE}{T} = \frac{E_f}{T} = \frac{1}{T_o} \left\{ \Theta[\varepsilon, M(\gamma, V)] - \int_{z_1}^{z_2} \left(\int_0^{t_e} \kappa \gamma_w \overline{K_u} A_u dt \right) dz + \sum \left(E_{of} + E_{cf} \right) \right\} \quad (18).$$

Whereas, T_o was the averaged temperature of system in the developing process.
In the discussion of increased entropy in view of the second law of thermodynamics, the more lost energy during farmland development, the more entropy increasing of the entire system. In replacement of increased entropy with waste heat, the more entropy increasing indicated the more waste heat and the less "usable quota" of energy in the future. Finally, once no more available energy would be left, it should reach the state called "Thermal Death" in thermodynamics (Garg et al, 1993). This is surely unfavorable from the point of sustainable resource management.

5. SUMMARY

Traditional farmland utilization in alluvial plains was very compatible with their soil and water characteristics. If the pattern of land use was changed under the developing pressure, in addition to engineering effects engaged in development, the soil and water environmental system should be affected. By the means of some basic physic indexes in thermodynamics, the changes for land grading, soil reposition, subsurface saturated flow, or surface runoff could be defined, and the energy conversion and entropy variation might be estimated as well. By the analysis of thermodynamics, the more energy consumption introduced in farmland development, the less favorable impact for soil and water system. Particularly, the worse influence would be, the more engaging earth work which intensified the soil reposition and produced more drop of groundwater table and aggravated surface runoff. Therefore, if it could be estimated in advance for these physic indexes that the changed level before the practical developing engineering, it would be possible to reduce the unfavorable effect and to improve the sustainability of soil and water resources in farmland.

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