# ENVIRONMENTAL CONSERVATION EFFECTS OF FOREST ROADS

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**Abstract:** *Forest roads are useful not only for forestry management but also for environmental conservation as follows. Opening up by road construction can be regarded as the formation of continuous canopy gap. The gap accelerates the increase of stock volume in front of road, and the extracted volume on the right of way will be recovered in due course of time. This time for recovering is calculated 5.5 years when the width of road bed is 8 m in a 25 year-old planted coniferous forest. Similarly the theoretical appropriate time for the next line thinning can be concluded as 11.4 years in the above young forest. Appropriate time of road network construction can be obtained from the width of road, construction cost, benefit of timber on the right of way, tree volume and the density of trees. Side ditch and drainage well of forest roads can catch soil from forest site. For example, soil caught by side ditch and drainage well during three years was estimated 28.5 tf/ha from our experiments. If a road has high ability of drainage, ordinary density of roads will have enough function of dispersal drainage. It is possible to invest aggressively for road construction when the forest has high land productivity and the road cost can be kept in low. Appropriately constructed forest road will fulfill its function of environmental conservation.*

## 1. Introduction

Forest roads are useful not only for forestry management but also for environmental conservation. Opening up by road construction can be regarded as the formation of continuous canopy gap, and forest roads can behave similarly to row or line thinning. The gap accelerates the increase of stock volume in front of road. And if a road has high ability of drainage, it will have enough function of dispersal drainage. Side ditch and drainage well of forest roads can catch soil from forest site (Aruga et al, 2000). It is intended to verify that appropriately constructed forest road will fulfill its function of environmental conservation.

## 2. Site and Methods

The site was located at Ohbuchi area in the foothills of Mt. Fuji. The area covered 140 ha on a south-facing 8 % slope between 500 m and 690 m above sea level. Annual precipitation was 2500 - 3000 mm. The soil consists of a mixed scoria layer and volcanic ash layer, so it was permeable and fertile. Because of the foothills of Mt. Fuji, rainwater flew down at the same time from the upper hillside so that the quantity of soil and water was too great. *Sugi, Cryptomeria japonica* and *hinoki*, *Chamecyparis obtusa*, were planted on the grassland in 1952.

Forest road network was constructed for thinning in 1996 with a road density of 110 m/ha. This network was designed and named “prevention against disaster and water conservation road system” by S. Watanabe (Watanabe, 1998). The objectives were to make both public benefit and economic efficiencies compatible, to realize sustainable forestry management, and to promote mountain conservation and water conservation.

The cross-section diagram of this new idea is shown in Figure 1. Cross-sectional grade, that is cant in this system, whose valley side is higher, is arranged for preventing accumulation of rainwater on the road surface and erosion of road bed. When water flows along unsurfaced L-shaped side ditches and accumulates in drainage wells, it drains away through the permeable soil. Drainage wells are placed at the intersection of roads or that of roads and valleys. Road surface with gentle gradients of 2 – 3.5 % limits water flow and soil movement, and prevents erosion. Eroded soil accumulates in side ditches and drainage wells, and is prevented from flowing out of this area. In case of too much rain, water in a drainage well can be lead to a stream or outside of forest area through a drain pipe.

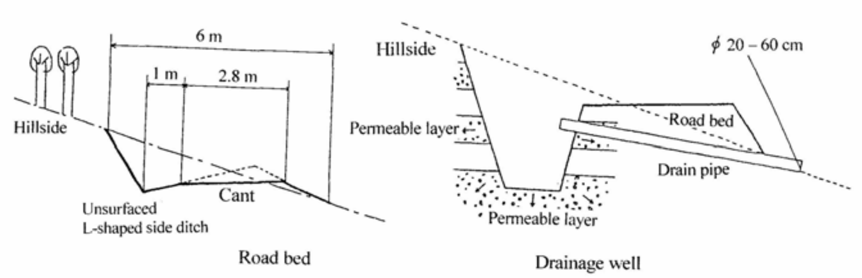


**Figure 1: Cross-section diagram of “prevention against disaster and water conservation road system”**

In 1999, the weight of deposited soil in side ditches and drainage wells was measured, and the deposited soil weight reached 28.5 tf/ha since the construction of road network for three years (Aruga et al, 2000). The relationship between the catchment area, x (ha) and deposited soil weight, y (tf) is y = 25.624 x. This amount of soil will surely be produced even with no road network, but it is observed that the side ditches and drainage wells can catch the soil from upper slopes and prevent from flowing out of the forest. Soil and debris stocked in side ditches can be eliminated easily because they are along road sides.

## 3. Results and discussion

### 3.1. The increase of stock volume in front of road accelerated by the gap

Indeed the area of forest land decreases by a forest road construction, but photosynthesis in front of road increases (Amemiya et al, 2002). And leaves increase, so the stock volume will be accelerated. If road construction can be considered as the formation of continuous canopy gap, the extracted volume on the right of way will be recovered by the accelerated increase of stock volume in due course of time.

Let p be the annual growing rate of stock volume in the forest, and q be that of trees in front of forest road after road construction in a planted forest ($p < q$). Both p and q are affected by the age and the planting density, but we assume them constant in a certain period.

Present volume of trees neighboring both sides of roads and the extracted volume on the right of way are 2vD/d ($m^3$/ha) and vWDN/10000 ($m^3$/ha), respectively, where v is stand volume ($m^3$/tree), N is the number of trees per hectare, d is average tree space (m), D is road density (m/ha), and W is width of road area (m), then WD is road area per hectare ($m^2$/ha), and 2D/d is the number of trees neighboring both sides of roads (trees/ha). After t years, volume of trees neighboring both sides of roads will be 2vD $(1+q)^t$ /d (m3/ha), and the extracted volume on the right of way will be vWDN$(1+p)^t$/10000 ($m^3$/ha) if trees on the right of way were not extracted and remained in the forest. The extracted trees on the right of way after road construction are sold and utilized.

The condition that the increased volume of trees neighboring both sides of roads by subtracting natural increase of volume in case of no road construction exceeds the expected increase of volume of the extracted trees on the right of way are as follows.

$$2vD\{(1+q)^t - (1+p)^t\}/d > vWDN\{(1+p)^t - 1\}/10000 \quad (1)$$

At the investigated site of a hinoki plantation where thinning was carried out at 25 year-old, it is observed that p = 0.021 and q = 0.058 between 25 and 37 years of age (Sakai et al, 2002).

According to a report on *Abies sachalinensis* (Abe et al, 1989), it can be calculated that q = 0.136 between 25 and 35 years of age with the thinning interval of 5 years. And in the unthinned plots, p was 0.108 between 20 and 25 years of age, 0.107 between 25 and 35 years of age, and 0.058 between 40and 50 years of age, and q was 0.169 between 20 and 25years of age thinned at 20 year-old, and 0.091 between 40 and 50 years of age with the second thinning at 40 year-old.

If road is constructed when the stand is 25 years of age for the first commercial thinning, Equation (1) is always right when $W \leq 4$, and $t > 5.5$ when W = 8, where average distance of stands d (m) = $\sqrt{}$(10000/N), N= 2500, p = 0.021, and q = 0.058. The above t will be shorter because there will be much mortality if the trees on the right of way left unthinned.

The calculation shows that the construction of roads results in accelerated growth in the residual stands as the road behaves similarly to a line thinning. The extracted volume on the right of way will be recovered in due course of time. As for thinning, canopy gap will be recovered even with strong intensity after enough years, and its growth will be nearly equal to that of unthinned or lightly thinned stand (Tadaki and Shidei, 1959).

In case of young forest immediately after plantation, trees are too young to utilize. The condition corresponding to Equation (1) is as follows.

$$2vD\{(1+q)^t - (1+p)^t\}/d > vWDN(1+p)^t/10000 \quad (2)$$

If p = 0.108, q = 0.169, and N = 4000 from the above example of *Abies sachalinensis* of 20 years of age, $t > 15.3$ where W = 4, and $t > 19.9$ where W = 6. Though it will take a long time for recovery, most of yield regulation on the right of way will be recovered until the next thinning. The results from Equations (1) and (2) do not depend on the road density.

Though the thinning time must be decided from the density and growth of trees, similarly the appropriate time for the next thinning can be calculated as follows by regarding lines as a gap.

The condition that the increased volume of trees neighboring felled lines exceeds the thinned volume and the expected increase of volume of thinned trees is as follows. Natural increase of volume of trees neighboring felled lines if there were no thinning is subtracted.

$$(2h/100) \cdot vN(1-WD/10000)\{(1+q)^t-(1+p)^t\} > (h/100) \cdot vN(1-WD/10000)(1+p)^t \quad (3)$$

where N is planted tree density (trees/ha) and N (1－WD/10000) is tree density after road construction, h is thinning intensity by the number of trees equal to one line (%), and (2 h /100)・N (1－WD/10000) is the approximate remaining trees neighboring felled lines (trees/ha).

Equation (3) can be simplified as the function of p and q.

$$(1+q)^t > 1.5(1+p)^t \quad (4)$$

If p = 0.021 and q = 0.058 in the above young forest, the appropriate time for the next thinning is 11.4 years.

And in case of two lines thinning, the remaining trees neighboring the thinned line is ( h /100)・N (1－WD/10000), then Equation (4) is as follows.

$$(1+q)^t > 2(1+p)^t \quad (5)$$

where thinning intensity h is as same as Equation (3). The result, t＞19.5, can be obtained, however this t will be shortened because p will be smaller in the long interval of t.

### 3.2. Effects of harvesting cost reduction by road construction

As the road network increases, the harvesting cost is reduced by reducing the logging distance.

The harvesting costs (yen/$m^3$) of thinning for a two person crew with a small sized mobile yarder with 200 m mainline drum capacity is

$$f(L) = 7.21L + 2130/L + 377, \quad (6)$$

where L is the maximum harvesting distance (Sakai et al, 1989).

Then let R be road construction cost (yen/m), y be annual stock volume increment ($m^3$/ha/yr), and s (%) of R be annual road cost of maintenance and repair (Sakai, 1987). The road cost for producing wood r(D) (yen/$m^3$) is as follows.

$$r(D) = R \cdot D \cdot (s/100) / y \quad (7)$$

As the relationship between L and D is

$$D = 5000k/L, \quad (8)$$

where k is a coefficient of road network (Sakai, 1987), then

$$r(L) = 5000k \cdot R \cdot (s/100) / (y \cdot L). \quad (9)$$

By adding Equations (6) and (9), the most appropriate harvesting distance which minimize the harvesting cost can be obtained. And the density also can be obtained from Equation (8).

For example, in case of R = 4,000 (yen/m), s = 0.4 (%), y = 11 ($m^3$/ha/yr), and k = 1.75, the minimum harvesting cost 1,032 (yen/$m^3$) can be obtained when D is 193 (m/ha) or L is 45.4 (m). And when R = 15,000 (yen/m), the appropriate density is 105 (m/ha).

And from Equations (6) and (8),

$$f(D) = 63087.5/D + 0.243\,D + 377 \qquad (10)$$

as shown in Figure 2. By adding Equation (7), the most appropriate road density can be obtained.

Let the fixed cost independent of road density, such as felling and bucking and delimbing costs, be C (yen/$m^3$), and timber market price be P (yen/$m^3$), then the difference between P－C and f(D) + r(D) will be the income of forest owner, T (yen/$m^3$). This is shown as hatched area in Figure 2.

When D is about 20 (m/ha), the effect of road density increase, and when more than 100 (m/ha), the effect becomes smaller.

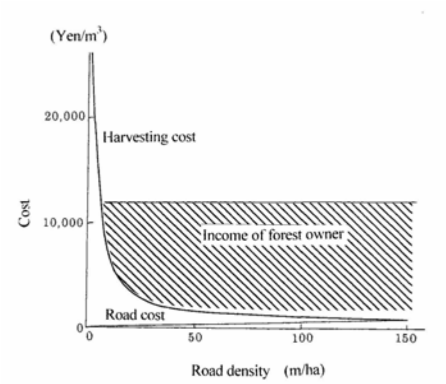


**Figure 2: Road density and harvesting costs of a mobile yarder**

### 3.3. Water conservation and drainage ability of forest road

Road area WD is only 8 (%) of forest area even if D = 100 (m/ha) and W = 8 (m), so that the loss by road density can be considered small on forest land.

Let us assume that a road has a high drainage capacity to prevent overland flow by the side ditch and drainage well, and that the road surface has not so sufficient infiltration capacity as forest soil.

If $F > G$ where F is water conservation capacity of forest land（tf/hr/ha）with no road and G is precipitation (tf/hr/ha), the condition of maintaining water conservation is

$$F(1 - WD/10000) > G, \qquad (11)$$

where the ratio, WD/10000, is the area used for road site. Then,

$$D < 10000\,(1 - G/F)\,/W. \qquad (12)$$

When the permeability of forest soil is 100 mm per hour, and when the ordinary maximum G is 50 mm, Equation (12) is D＜5000/W. If precipitation is critical and G/F = 0.9, D＜1000/W. When the width of road area W = 8 (m), D should be 625 (= 5000/W) m/ha and 125 (=1000/W) m/ha. These values are within the above 105～193 m/ha. And in case of large G/F , by making narrow W = 4（m）, D will satisfy D＜1000/W. As a result, density of usual 100m/ha will not restrict the road density from the view point of the effect of water conservation.

If the maximum precipitation exceeds the infiltration capacity (G＞F), the drainage ability will be important. Let the drainage ability be A (tf/hr/ｍ), then the quantity of drainage per hour is AD (tf/hr/ha). And the condition of drainage by the road is as below.

$$G - F(1 - WD/10000) < AD \qquad (13)$$

When WD/10000 is negligible,

$$D > (G - F)/A. \qquad (14)$$

For example, when permeability of forest soil is 50 mm, F = 500 (tf/ha). When precipitation is 100 mm, G = 1000 (tf/ha). In Manning's formula

$$V = 1/n \cdot R^{2/3} \cdot I^{1/2}, \qquad (15)$$

where V is the average velocity of flow (m/sec), n is a coefficient of roughness, R is hydraulic mean depth (m), and I is inclination, let n = 0.02, R = 0.031, that is, the area of side ditch is 0.01 (㎡), and I = 1/33, then V can be calculated as 0.86 (m/sec). Therefore, the drainage ability, A, is 31 (tf/hr/ｍ), and from Equation (14), D＞16.1 (m/ha).

This means that the drainage of the road system with an ordinary road density exceeds the runoff and reduces the likelihood of disaster even in case of G＞F. It is possible to invest aggressively in road construction if the road has a high drainage ability.

### 3.4. Time for road network construction

As the plantation forest grows, the stock volume and the value increase. Before the growth of value exceeds the growth of volume, that is, when forest is still young, it is suitable to construct forest road network. In other words, the most suited time for road network construction is when the amount sold of timbers on the right of way can exceed the road construction cost.

The condition of the amount sold of timbers on the right of way can exceed the road construction cost is as follows.

$$PvWDN/10000 > RD \qquad (16)$$

where R is the road construction cost (yen/m) including extraction cost of trees on the right of way and P is the income of timber (yen/$m^3$). The difference between right and left side of Equation (16) is the profit from road construction. From Equation (16),

$$PvN/10000 > R/W. \qquad (17)$$

Right side R/W is the cost of road construction (yen/$m^2$).

For example, let R = 4,000 (yen/m), width of road area W = 8 (m), and P = 22,000 (yen/$m^3$), vN＞500/2.2. vN equals to the stock volume per hectare. In case of the investigated site, the condition is satisfied when the forest is about 40 years of age. And this result corresponds to the actual time of preparing infrastructure.

From Equation (17), the standard of road or the road construction cost also can be determined according to the status of forest resources. If P is high, infrastructure can be advanced in an early stage. If P is low or forest is young, R must be reduced or road construction must be kept in a low standard.

As the annual road cost is R・s (yen/m) and the annual increment of stock volume per 1 m of road is y/D ($m^3$/m), the upper limit of R (yen/m) can be derived from the following equation.

$$R < T \cdot y / (s \cdot D) \quad (18)$$

where T is the income of forest owner (yen/$m^3$).

## 4. Conclusions

The access provided by forest roads make all forestry operations possible. Thinning can be carried out efficiently. And income of forest owner will increase by the lowered cost. It is possible to realize low intensity and high frequency of selection cutting, and to realize the healthy forest condition and high land productivity even in case of natural forest.

When road is constructed, the gap accelerates the increase of stock volume in front of road, and the extracted volume on the right of way will be recovered in due course of time. Increased photosynthesis in front of road increases the amount of leaves, and this means the roots also will grow. Increased roots will make porous soil and hold soil and rocks. Porous soil and increased litter retain more water. This effect realizes water and soil conservation. This is namely the environmental conservation effect of forest road. And forest road has a high public quality because it has the above high ability of environmental conservation.

In Japan dispersal drainage on steep slopes is invented by the other excellent foresters, for example, Oohashi Keizaburou's forestry in Osaka (Oohashi, 2001). The common concept is small earth work, cheap material of logs for stable road bed, and dispersal drainage by road surface.

## 5. Acknowledgements

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[*] only in Japanese; [**] title is tentative translation by the author.; [***] in Japanese with English summery.