RELATIONSHIP OF COMMUNITY GRASS COVERAGE AND SOIL AND WATER CONSERVATION IN BEIJING PROPER

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Abstract
Water shortage and drainage are conflicts now facing Beijing development, which has been *ad hoc* in preparation for the green Olympics in 2008. With the acceleration of urbanization over China at the same time, construction of infrastructure and public buildings intensively destroys the vegetation and aggravates soil erosion. In Beijing, the drainage pipe diameter is increasing once again, and water shortage is pronounced. The area of paved ground in city proper has increased from 61% in 1959 to 77% at present, and aggravates the problem further. However community grass coverage as the key factor in large open green spaces curbing water and soil erosion is rarely addressed, although green open space has received much attention. This paper identifies the relationship between community grass coverage and yield runoff of rain and sediment in city proper of Beijing. It proves our notion that runoff and sediment decreases when the grass coverage increases. Grass coverage even at low levels reduces runoff dramatically, and when grass coverage increases to a high level, sediment drops substantially. The capability to hold the runoff and sediment increases slowly when grass coverage rises to certain density, in this site, around 60%.

Additional Keywords: yield of runoff, sediments, rainfall, water shortage, water drainage, efficient coverage

Introduction
The significant practices witnessed in Beijing at present are demolishing buildings and transforming them into large plots of open space in the name of preparing for the 29th Olympic Games in 2008. Large coverage of news focused on the second green belt area, Olympic Park, Changpu River Park and others where the Beijing Municipality has attached great importance on (Xinhua, 2003a; Xinhua, 2003b; Tang, 2002), while community grass coverage reflected by green coverage rate is still regulated by the land use code enacted by the year of 1990. The role of curbing runoff, recharging ground water and easing drainage of community grass coverage, however, is totally ignored. The groundwater bury depth has been increasing and there has been no runoff on the whole on farm land since the 1980's (Sun *et al.*, 1999). Nonetheless, the runoff of the built up area increases dramatically and the diameter of drainage pipe enlarged once again and again. This was caused by the growing paved area collecting more rain water than before, on the one hand, and the soil flowed into the drainage pipe silting up the space and cutting down the transporting capacity, on the other. We carefully studied the area within the 5th Ring Road and the land use pattern shows in Figure 1 that 72% is built up or bared ground. If the rain water onto this land were collected by way of grass coverage, it recharges underground water and filters sediments into the drainage as well. So understanding the relationship between community grass coverage and soil and water conservation is crucial and of far-reaching significance.

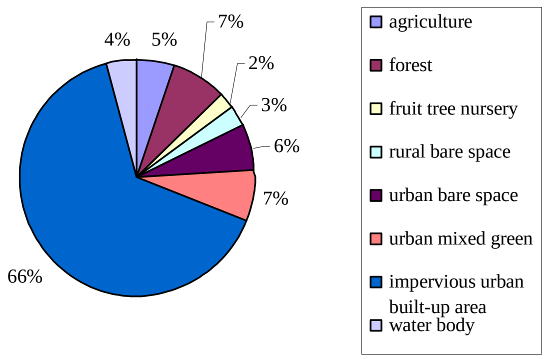

Figure 1. Land use within 5th ring, Beijing

Study Background
Beijing's annual rainfall is 595 mm or 9.996 billion m^3 (within the area of 16800 km^2) (He, 2003a), producing local water resource output at 4.047 billion $m^3 yr^{-1}$ on average (Liu and Chen, 2001), omitting the recalculation of the

surface and ground water, i.e. less than 300 m^3 per capita per year, which is 1/8 of the average in China, and 1/30 in the world, and dramatically below the definition of water shortage at 1000 m^3 per capita internationally.

Uneven distribution of rainfall is one characteristics of Beijing. Severe drought in spring, flood in the summer almost occur every year. As illustrated in Figure 2, rainfall in flood period from June to September accounts for 85% of annual precipitation, whereas none-flood period is of little rainfall (Beijing Statistics Bureau, 2002a). Furthermore, beside the uneven temporal distribution, spatial and yearly uneven distribution is also observed in Beijing year by year due to the effect of water vapor, geographic and topographic condition. The minimum annual rainfall was 242 mm, while the maximum 1406 mm. The interval between plentiful and scarcity water period is often 2-3 years, even with successive years of plentiful up to 6 years, and scarcity 9 years, the longest scarcity last for 20 years.

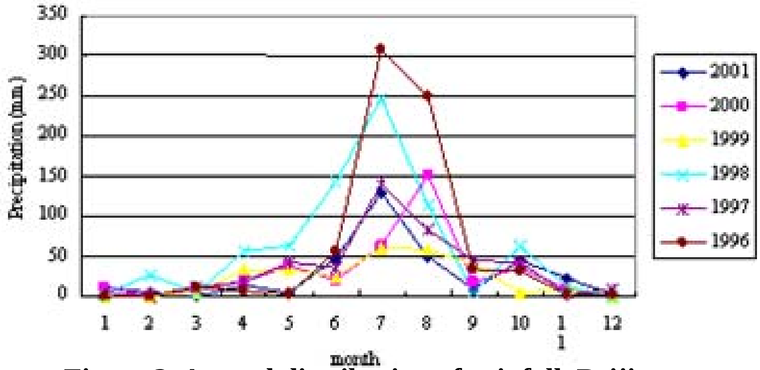

Figure 2. Annual distribution of rainfall, Beijing

Co-existence of flood and water scarcity is another attribute of water resource in Beijing at present. The layer of water circulation has been changed due to the acceleration of urbanization and the fast development of buildings, roads, and squares in Beijing proper. The increasing of the watertight area leads to the increasing of the flood flux and reduction of the flood conflux time. The ratio of watertight area increased from 61% in 1959 to 77% at present, whereas the flood flux in 1980s is twice of that in 1950s in the same rainfall of same type (Wang *et al.*, 2001).

The water crisis in Beijing is aggravated not only by the natural uneven distribution of precipitation, but also by urbanization. Rapid economic development of Beijing, together with population increment, pushes built-up area increasing at a high speed (He, 2003b). This trend will not change based on present technology and institutions. The increasing of watertight layer and area leads to artificial drainage expanding at both length and pipe diameter, and ground water table decreasing at fast rate as well. The precipitation of Beijing in 2002 is only 345 mm, which decreased 30% compared with the average of regular years and caused the capital's water table reduced 0.6 m (Wu, 2002).

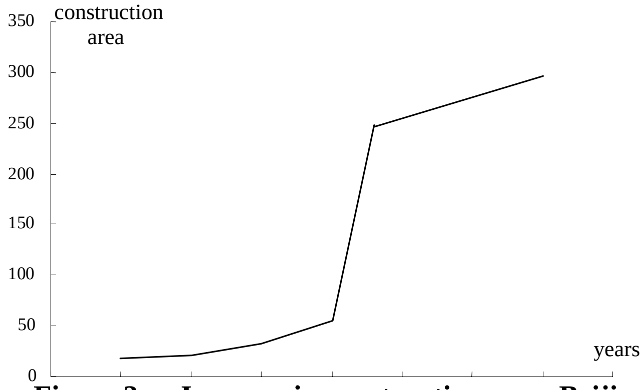

Figure 3. Increase in construction area, Beijing

Our Notion

The rainfall on built-up area used for production and living is called rainfall resource. The formula of the rainfall resource in community is:

$$S=P\square R_a=P(1\square R_a/p)=P(1\square\square)$$

Where S is the rainfall resource intercepted by urban community grass or other infiltrative layer from draining to water body and waste water plant; P is precipitation; R_a is runoff; □is urban runoff coefficient, which denotes the amount of urban surface runoff of rainfall. The larger ☐ is, the more runoff produces, the more possible flood occurs, and the more advanced drainage system is needed; on the contrary, the smaller ☐ is, the more rainfall is seeped and held back as resources.

If we exclude the area of roads in built-up area and take into account only the construction area including the lands for residence and working, the trend is shown in Figure 3 (Beijing Statistics Bureau, 2002b). Since 1996, the increasing speed of construction area is higher than that in the past. It is presumed that the construction area will be up to 300 km^2 until 2010. If all the rainfall turned to be rainfall resources it would be 0.1785 billion m^3.

Field Observation and Methods

According to weather forecast, it will rain on 28 July 2002. Preparation including laboratory and fieldwork was done one day before. In the laboratory, two sets of distilling apparatus and two scales were arranged. For the field work, seven pieces of land in same size of 4 m^2 and slope of 10 degree with different degree of grass coverage were selected (one is barren land, the others grasslands of the same species *Poa annua Linn* for comparative purpose) between the university campus and Dongwangzhuang, a near neighborhood in the south, to allow short distance from the field sites to the laboratory. Every pieces of land was encircled along the four trims by hard plastics about 10 cm high and fixed by pointed sticks at four corners to prevent the rain from flowing out other than the hole we made to collect them, and prevent rain from outside flowing into the test land as well. Leave a hole in the middle of the trim along the lower end of the land to collect runoff. One thing should be emphasized is that the hole on the barren land be large enough to let the runoff flow out once it formed. Pits were dug in front of every test land along the lower end to allow space for runoff buckets. On the day of July 28, the rain was surveyed at 0.53 mm/min. The staffs were organized in to two groups, one in laboratory and the other field sites. Seven numbered runoff buckets with scales were laid at the lower end of the test lands and the level of runoff was read every 2 min after runoff formed and accurately documented accordingly. At the same time 50 ml sample water from the runoff was collected every 2 min with numbered test tubes when available. All the samples were sent to the laboratory for distilling and their weights recorded respectively and correspondingly.

Results and Conclusions

Table 1 is the records of runoff yield during the rainfall and Table 2 the regression equations based on them. Table 1 shows that the grassland even at very low density, at 28% for example, its runoff interception is significant compare to the barren land. With the increment of density, the ability to hold back rainwater of grass lands increases.

Table 1. Results of runoff yield in the process of the rainfall (unit: l)

Time after runoff formed (m)	Barren land	Grassland one	Grassland two	Grassland three	Grassland four	Grassland five	Grassland six
2	1.03	0.86	0.79	0.7	0.58	0.46	0.42
4	2.56	1.55	1.67	1.44	1.39	1.02	0.89
6	4.44	3.53	3.15	2.35	2.04	2.22	1.75
8	7.96	6.69	4.82	4.56	3.5	3.21	2.99
10	13.65	9.52	8.45	7.66	5.86	5.64	4.87
12	18.86	15.86	13.66	10.87	8.96	7.89	6.45
14	30.12	21.78	19.57	17.89	13.21	10.85	9.55
16	50.68	31.21	27.22	23.19	19.58	16.32	14.68
coverage %	0	28	32	40	45	56	70

Regression analysis of the data got the similar results. The formula of runoff yield process on barren land is an exponential equation like $R=\exp(a+bt)$, and those of grasslands power equations like $R=at^b$. It implies that runoff in grasslands shrink instantly than that in barren land. The constants in regressive equations, however, are getting smaller and smaller with the increasing of coverage on the same type of grassland. In other words, the marginal capability of interception declines with the rising grass density.

From Figure 4, after the abrupt increase of marginal capability of holding back runoff of grassland at low density, a peak is evident at 45% and declines thereafter with the increasing of density. Obviously, the ability to hold back rainwater of grasslands at density of 60% is very close to that of 70%.

Table 2. Regression equations of runoff yield when rain

Land types	Coverage (%)	Intensity (mm/m)	Regressive equation	Coefficient
Barren land	0	0.53	$R=0.0814e^{0.2647t}$	0.9923
Grassland one	28	0.53	$R=0.177t^{1.78595}$	0.9850
Grassland two	32	0.53	$R=0.1765t^{1.7277}$	0.9840
Grassland three	40	0.53	$R=0.1514t^{1.7295}$	0.9813
Grassland four	45	0.53	$R=0.1395t^{1.6734}$	0.9819
Grassland five	56	0.53	$R=0.1116t^{1.7165}$	0.9911
Grassland six	70	0.53	$R=0.0992t^{1.705}$	0.9886

$t=T-t_p$,, T is duration of rainfall t_p is the critical time of runoff formed, R is runoff

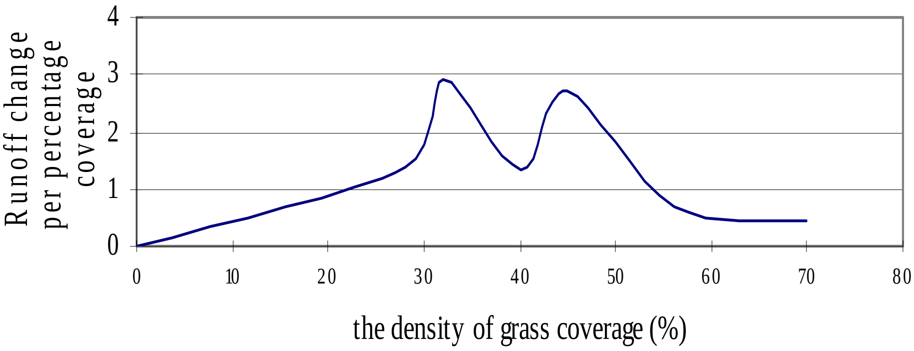

Figure 4. Marginal increase of runoff interception of different coverage

Table 3 is the results of sediment yield in the process of the rainfall and Table 4 the regression equations based on them from the field and laboratory works. Table 3 shows that grasslands have more strength to hold back sediment from flowing into drainage system than that of barren land. The capability of the grasslands rises with the density of the grass coverage increasing.

Table 3. Results of sediment yield in the process of rainfall (unit: g)

Time after runoff formed (m)	Barren land	Grassland one	Grassland two	Grassland three	Grassland four	Grassland five	Grassland six
2	1.322	0.855	0.732	0.604	0.554	0.423	0.322
4	3.712	1.584	1.454	1.288	1.072	0.856	0.704
6	5.183	2.753	2.419	2.151	1.856	1.588	1.000
8	7.708	4.462	4.115	3.418	2.662	2.221	1.553
10	9.543	6.962	6.088	5.662	4.228	3.375	2.337
12	13.465	9.188	8.382	6.862	6.229	4.419	3.048
14	17.563	11.923	11.229	9.456	7.789	5.783	4.788
16	21.783	15.419	13.229	12.295	10.012	8.45	7.242
Coverage (%)	0	28	32	40	45	56	70

Table 4. Regression equations of sediment yield when rain

Land types	Coverage (%)	Intensity (mm m^{-1})	Regressive equation	Coefficient
Barren land	0	0.53	$S=1.4597e^{0.1813t}$	0.9671
Grassland one	28	0.53	$S=0.2543t^{1.4328}$	0.9901
Grassland two	32	0.53	$S=0.2208t^{1.4475}$	0.9918
Grassland three	40	0.53	$S=0.1838t^{1.468}$	0.9928
Grassland four	45	0.53	$S=0.1677t^{1.4235}$	0.9893
Grassland five	56	0.53	$S =0.1337t^{1.42}$	0.9920
Grassland six	70	0.53	$S=0.0961t^{1.4366}$	0.9799

The regression results in Table 4 illustrate that the formula of sediment yield process in barren land is an exponential equation like $R=\exp(a+bt)$, and that of grasslands power equations like $R=at^b$, with close correlativity. A decline of constants of the equations is implying that marginal increase of sediment reduction decreases while the density of grass coverage increases.

Figure 5 shows similar pattern with runoff yielding process, sediment yield shrinks suddenly from barren land to grasslands. Thereafter, further declines were seen with increasing of grass density. Nonetheless, a peak of marginal increase of the ability of sediment reduction is evident at 45 % of density follows with a down slope. If we combine Figure 4 with Figure 5, it is evident that the marginal increase of sediment reduction and runoff impedance weaken at certain point along with the increasing of grass coverage. According to economic rules, the most efficient grass coverage lies on the point where marginal increment equals zero. It is evident in this case zero is inaccessible. The cost-effective point exists around a level last, where 60% density is observed.

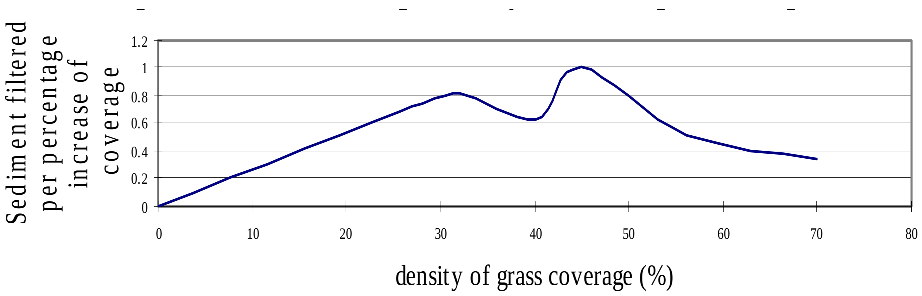

Figure 5. Sediment filtering efficiency of different grass coverages

Discussion

The conclusion that the most efficient coverage lies around 60% is drawn in the case when the rainfall is 0.53 mm/min and duration at about 16 min. More tests are required to apply this to other circumstances. It at least monitored the real situation of the rainfall in the community where green coverage is mainly landscape or garden oriented. It is difficult to exactly measure a natural event like a rainfall and its effect on other parts of the system. For example, when to measure the rainfall is important, as the rainfall start with a drizzle, turning to storm and then dying away. How to eliminate the disturbance of rainfall before we start our observations? What is the condition of the underground layer of the community? There are also other aspects of community grass coverage that need to be further addressed, including pollutants in runoff and how these affect plants and ground water, other grass species and how they affect runoff and sediment yielding. The conclusion drawn here is only fit to indigenous condition of the community in Beijing. If the rainfall was heavier or lighter, the result would need modification.

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References

Beijing Statistics Bureau. (2002). Beijing Statistical Yearbook 2002. China Statistics Press, Beijing.
He, Y. (2003). Ecological water problems and urban planning in Beijing. Proceedings of the internet conference on Eco-city development. http://www.ias.unu.edu/proceedings/icibs/ecocity03/papers/heyong/.
He, Y. (2003). Research on spatial development ecological strategy for Beijing. Beijing City Planning & Construction Review (in Chinese) 6, 26-31
Liu, C.M. and Chen, Z.K. (2001). Water resources assessment and trend analysis of water supply and demand in China. Water Publication House, Beijing.
Sun, S.J., Ding, Y.Y., Wang, S.H., Cao, B. and Tian, Y. (1999). Study on using precipitation and runoff in the flood period to regulate and control groundwater in the plain area of Beijing, Proceedings of 99' International Conference on Agricultural Engineering, Beijing, China. www.lib.ksu.edu/depts/issa/china/icae/part2/sw92.pdf.
Tang, T. (2002). An age-old river regains past glory. http://www.china-pictorial.com/chpic/htdocs/English/content/200212/1-2.htm.
Wang, D.M., Zhang, W.Y. and Su, X.Q. (2001). Urban water and soil erosion in Beijing & its countermeasures. Urban Studies (in Chinese) 8(5), 49-53.
Wu, N.L. (2002). Decrease of Beijing's precipitation and water table. http://www.china.org.cn/english/China/44301.htm.
Xinhua. (2003). Beijing to invest 4.2 billion Yuan in greening projects. http://www1.chinadaily.com.cn/en/doc/2003-10/19/content_273377.htm.
Xinhua. (2003). Beijing Olympic forest park designs invited. http://www1.chinadaily.com.cn/en/doc/2003-07/22/content_247260.htm.