METHODOLOGICAL STEPS IN URBAN ECOSYSTEM STUDIES AND WATER-ORIENTED APPROACH

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ABSTRACT

In our study of urban ecosystems, there have been four steps: such as 1) on the impact of urban environment on vegetation, animals, microorganisms and man, 2) an interdisciplinary and integrated study with the biocentric viewpoint, 3) the similar study as 2) with the anthropocentric concept, 4) to achieve an integration of structure and function in an urban ecosystem through the role of water. For the four steps of our study, water was considered as not only urban hydrology with an input and output of water, but water as a throughput which is used in the production process, flowing out of the system as waste water or in the form of products. Besides this, a new idea of water balance analysis was proposed. There, the original units of water use were estimated for agricultural production and industrial goods. The water balance in a watershed including cities was studied, and some items were proposed to maintain a desirable cycle in large cities.

1. WHAT IS AN URBAN ECOSYSTEM?

It is well-known that Tansley (1935) proposed the term "ecosystem", however there are similar concepts and terms, such as microcosm (Forbes 1887), biome (Clements 1916), Holocoen (Friederichs 1930), biogeocoenosis (Sukachev 1942), etc. I proposed the term "biocentric environmental system" (Numata 1953), criticizing the popular use of ecosystem as an arithmetic summation of biotic and abiotic factors. The leading factor of an

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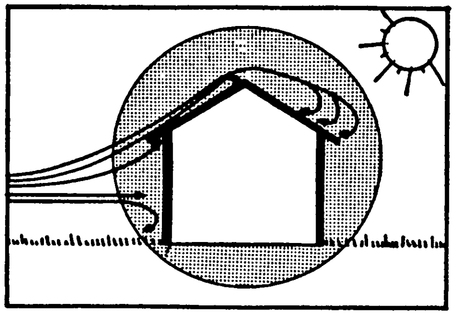
ecosystem, man, animals, plants or microorganisms, should be recognized, and biotic factors other than the leading factor and abiotic factors should be structured and organized in relationship to the leading factor. That is what is meant by the biocentric concept of the environment. If the situations are understood well either the terms ecosystem or biosystem will be sufficient. Müller (1979) stated in his paper on "Basic ecological concepts and urban ecological systems" the city as a complex system with man as the center point. It is similar to my anthropocentric idea.

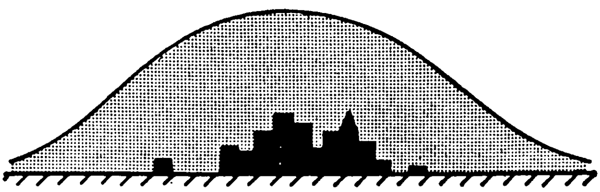
In our study of urban ecosystems, we studied in the first stage the impact of urban environment on vegetation, animals, microorganisms and man along with the guideline of the MAB projects on the impact of human activities. In the second stage of our study, an interdisciplinary and integrated study of urban ecosystems was conducted with zoocentric and phytocentric viewpoints as well as anthoropocentric viewpoints. It is like the Clementsian bio-ecological approach of action and reaction. In the third stage of the study, the anthropocentric concept was stressed even more in relationshop to ecosystem management and planning.

From this point of view, an urban ecosystem will basically be an anthropocentric environmental system, however, if circumstances require, it may be treated as a phytocentric or zoocentric environmental system. In this case, "urban" means an areal range or ecological characteristic and does not mean the leading factor of the system. The lake ecosystems, earth ecosystems, etc. are similar in this respect. The climatological dome with the inversion layer shows an areal range of a city (Fig. 1). The terms, natural, artificial, agricultural ecosystems, etc. indicate ecological characteristics. The term "urban ecosystem" is sometimes used in this way, in contrast to "rural ecosystem". In any case, urban and rural ecosystems are anthropocentric and artificial, and analogies of natural ecosystems. This was discussed at a UNESCO/UNEP Workshop on the integrated ecological study of human settlements in 1974 in Paris (UNESCO 1975). The meaning of analogy is : 1) an urban ecosystem consists of biotic factors (plants, animals, microorganisms, and man) and abiotic factors (air, water, soils, etc.), 2) man plays the leading role in the system. However, 3) an urban ecosystem is not always understood as a holistic entity which is ecologically integrated and metabolized.

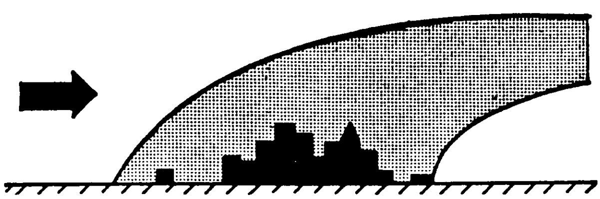
A city is an administrative unit, however an urban ecosystem is a kind of terrestrial ecosystem having a dense human population. According to the Expert Panel of Project 11, MAB (1973), the term "urban system" was interpreted as any human settlement



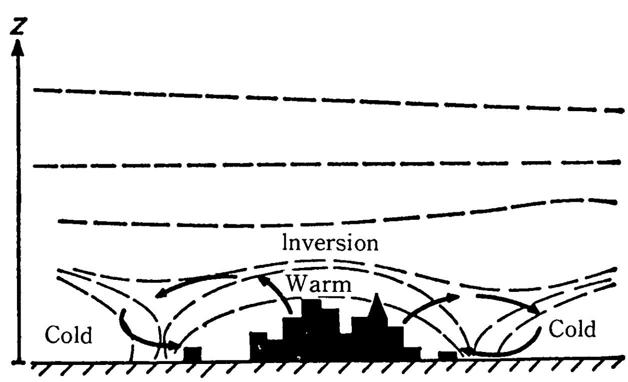
The climatological sheath around a structure.
Source : Ryd, 1970.



The urban dome.



The urban thermal and pollution plume occurring when a regional wind is blowing.



The urban circulation developing when regional winds are light. Source : Landsberg, 1970.

Fig.1 Climatological sheath and dome in urbanized areas (MIT 1971) containing 20,000 or more inhabitants living in close contiguity and exhibiting a considerable degree of social, economic and political organization. This urban system concept is intermediate between the concepts of urban ecosystem and city as an administrative unit.

During the discussion at the Paris meeting (1975), it was said that the term "urban ecosystem" was merely an analogy to natural ecosystem with the former being different from the latter basically due to the fact that complex self-sustaining, natural systems of which living organisms are a part are termed ecosystems, according to Clapham (1973). Benneh (1974) studied agricultural systems using this as a guideline. In the Paris meeting, there was another opinion that systems grow, but ecosystems are in equilibria without growth.

Certainly an urban ecosystem is different from a natural ecosystem in that it is not a self-regulating, self-sustaining system. However, it is an ecological system with biotic (particularly densely populated human settlements) and abiotic components. Systems are holistic entities which are able to be separated into isolated components for the purpose of study, but they act as a whole in their real activities, e. g. solar system, enzyme system, etc. in natural science. Tansley (1935) applied this philosophical concept to ecological systems including biota and abiotic environment and called them "ecosystems". Thus we do not call them urban systems but rather urban ecosystems in order to consider human settlements and their internal and surrounding environments from the viewpoint of ecological integration. Man is a biological being that has evolved as a part of nature, yet has become a socio-economic and cultural being different from all other biota. Human beings have reacted to nature altering its natural ecosystems into man-modified and man-made ecosystems. Urban ecosystem is one of those altered ecosystems.

2. APPROACHES TO URBAN ECOSYSTEMS

Among the conceptual frameworks developed at the Paris meeting on human settlements, one common opinion was that human settlements combine to become a city. A city or cities and their immediate environment combine to form an urban ecosystem into which matter, energy, people and information flow from other urban ecosystems and out of which organized and degraded matter, degraded energy, people and information flow. Project 11 of MAB originally aimed at only the energy flow of urban and industrial systems, however the title of the project has been changed to include more integrated studies. The objectives of MAB are closely linked with decision-making and planning, however at the earlier stage of study we conducted problem-oriented basic research for those purposes.

I started research on urban ecosystems with more than 30 colleagues in 1971. In the first step of the study our research was concentrated on the impact of the man-made urban environment (quality and quantity of air, water and soil) on plants, animals and microorganisms. Many people gather in a city, building skyscrapers and factories as I stated earlier, developing an urban center with banks, governmental offices, amusement facilities, etc. With this kind of urban development, air becomes polluted with sulphur dioxides, nitrogen oxides, etc. , the pervious area of surface soil is decreased by the pavement and concrete jungles, soils in the vicinity of roads are polluted with heavy metals from the exhaust gases of automobiles (Table 1) and are alkalized with dissolved concrete. Water is polluted, too, the hydrological cycle is changed, and the water table is lowered. According to the degree of urbanization, particularly the increase of impervious areas in a watershed area, the time between the beginning of rainfall and the runoff peak is shortened. Along the baycoast cities, the area of landfills increases, and the natural coast and dry beach are almost lost.

Table 1. Contents of heavy metal elements in soils corresponding to the distance from the road and the sampling months at Tojo, Matsudo City (Shimada et al. 1973)

Heavy metal	Distance from the road	Sampling month			
		April	July	September	November
	m	ppm	ppm	ppm	ppm
Pb	1	357	255	199	150
	30	68	60	56	43
	300	37	52	41	66
Zn	1	369	346	309	240
	30	484	1169	465	147
	300	299	241	284	208
Cd	1	2.22	1.67	1.35	1.39
	30	0.90	1.44	1.15	1.62
	300	1.35	1.44	1.32	1.42

Corresponding to the change in the abiotic environment, the condition of the health of evergreen trees is degraded (in the first step of study, the survival ratio of trees in a nature park in Tokyo was studied). Their vigor is gradually declining due to defoliation by leaf miners and other noxious insects which attack the trees in the spring every year. Such every year defoliation of an evergreen tree is similar to that of a deciduous tree. This abnornal and unseasonal defoliation accelerated the deterioration of the vigor of the tree. One of the causes of the outbreak of such noxious insects may be disappearance of insectivorous birds in the area. The disappearance of some birds is caused by the effects of urbanization, such as noise, air pollution, decrease of habitat, etc. The network of such complex causal relations brings about the lowering of the survival ratio of the tree (Fig. 2).

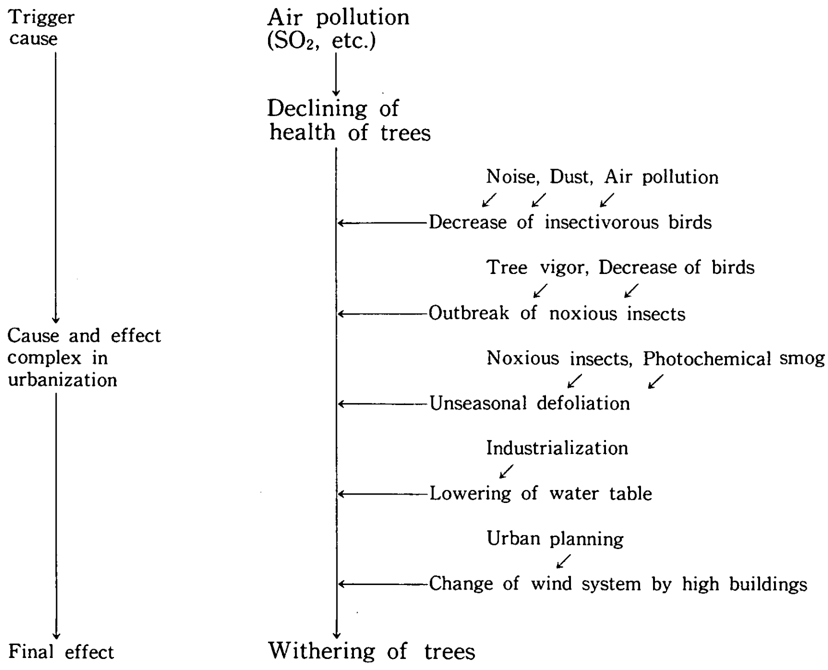


Fig.2 The cause and effect relationship resulting in the withering of trees in an urban ecosystem (Numata 1982)

On the other hand, mankind gradually changes its nature under such circumstances. This is self-domestication by which mankind adapts to the new environment created by himself. People living in cold climate wish to live in modern apartments with heating facilities, and a social welfare policy is necessary. However, people living in the arctic lose their resistance to the cold as an adaptation, and are sometimes frostbitten. Recently, children cannot use a knife to sharpen a pencil in Japan, because they use electric sharpeners. We use an escalator or elevator instead of walking up the stairs, and so our walking ability may be degraded. These are all examples of self-domestication.

In the second and third step of our study, an anthropocentric as well as zoocentric and phytocentric approaches were sought. The approach is somewhat similar to the

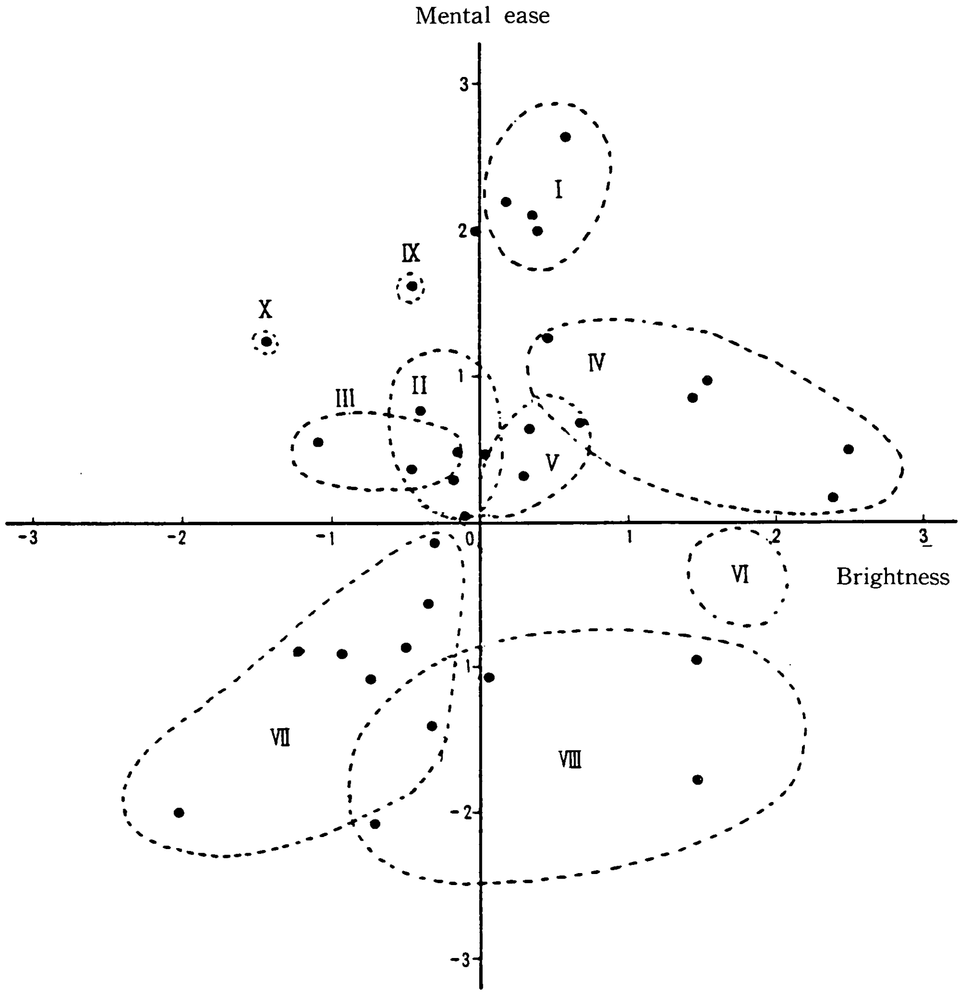


Fig.3 Visual evaluation of various types of vegetation in summer (Shinada 1985)
I. Moorland, II. Deciduous broad-leaved forest, III. Tallgrass meadow,
IV. Shortgrass pasture and lawn, V. Street trees, VI. Garden,
VII. Evergreen broad-leaved forest, VIII. Forest edge, IX. Paddy field,
X. *Cryptomeria japonica* plantation.

Uexküll's idea on environment (J. von Uexküll and G. Kriszat 1934). It is completely oppsite to the approach of the first step which focused on human impacts. It is an anthropocentric and biocentric concept. For example, the visual evaluation of nature with the semantic differential method verifies that lawns, paddy fields, street trees of *Platanus*, and deciduous oak forests are ranked higher from the viewpoint of mental ease and bringhtness conditions (Fig. 3). Such an evaluation of vegetation was shown with factor loadings of the factor analysis. There are naturalness rating (1－10) of vegetation adopted by the Environment Agency of Japan (Table 2). This is a natural scientific rating, however the visual evaluation is not natural scientific but sociopsychological as is the evaluation of vegetation from the human viewpoint.

Table 2. Vegetation naturalness rating

Degree of naturalness	Remarks
1	Urban, housing area
2	Farmland
3	Orchard, tea and mulberry plantation
4	Shortgrass grassland
5	Tallgrass grassland
6	Afforested land
7	Secondary forest
8	Secondary forest close to climax forest
9	Climax forest
10	Climax grassland such as alpine meadow

There is biological time vs. physical time as well as biological space vs. physical space. From the standpoint of the biocentric or anthropocentric concept, biological scale is very important compared with physical scale. As a popular example, inner man has a kind of biological time. An experiment to measure biological time was proposed by wound healing time (de Nouy 1936). Nevertheless to say, the biological time as the wound healing time is shorter in younger ages, and longer in older ages.

Man as the leading factor of an anthropocentric environmental system should be considered from the different levels of the individual, family, local community, nation, region and global (*Homo sapiens*) in general. There frequently are contradictions that benefit for individuals and families but do not benefit for local communities and nations. Motorcars are very convenient for individuals and families, however they are the cause of air pollution at the level of local communities. Besides organismic levels like these, ethic goals and the happiness of human society are important in considering environmental problems. This was seen in the difficult process of finalizing the human environmental problems. This was seen in the difficult process of finalizing the Human Environment Declaration (1972) with different backgrounds of various countries. We must deeply consider the goal of an urban ecosystem as a human habitat.

In the first step of the research, vegetation in a city was studied following the principles of plant science, and animals were studied with the methods of animal science. Meteorology and climate were studied metorologically and climatologically. For example, temperature and humidity were measured physically by a thermometer and a hygrometer. However, to evaluate temperature and humidity in terms of man is difficult. The concepts of sensitive temperature and comfort index are in this direction. The same thing is seen in plants and animals as well as in water and soil. Raunkiaer's plant climate based on life-forms is a similar idea (Raunkiaer 1934). Then, we may call plant soil, plant water, etc. in the sense of plant climate.

3. WATER–ORIENTED APPROACH

Attention has been paid to the fourth step mentioned above as we have been trying to achieve an integration of structure and function in an urban ecosystem through the role of water (cf. Hengeveld and De Vocht 1982). This shows that concept of positive production which means ordinary production, and that of negative production of waste water, etc. (Tamanoi 1981 – Fig. 4). This does not mean only urban hydrology with an input and output of water, but water as a throughput which is used in the production process, flowing out of the system as waste water in industry. Water as a throughput is not included in products but is mostly used in the production process as a potential water. Besides this, a new idea of "water balance analysis" was proposed by Sueishi (1983). It is an attempt to reevaluate the values of goods production and human activities from the standpoint of total water use of direct and indirect amounts for goods production and urban activity. The regional water balance–supply and consumption is defined in four levels as follows:

1) Zero-level balance : ordinary natural water balance in the hydrological sense,
2) Primary balance : water resources allocation to agricultural, industrial and

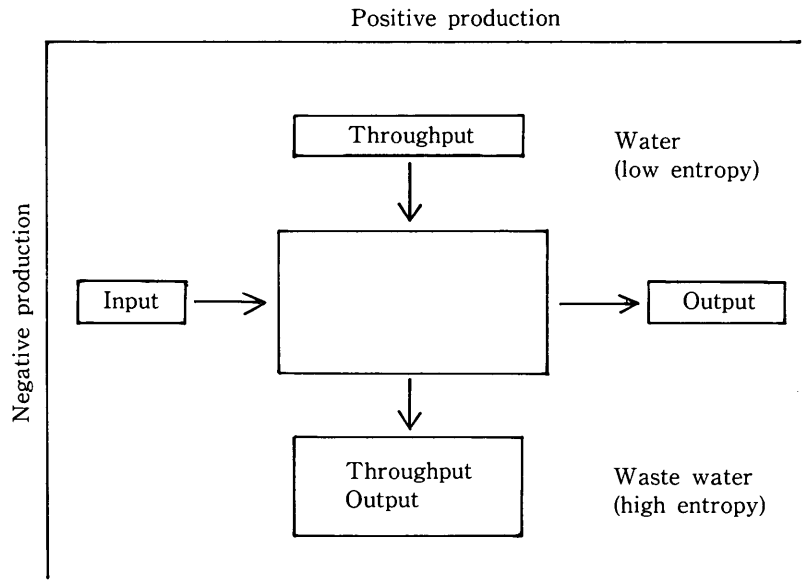


Fig.4 The role of water in the positive and negative production (Tamanoi 1981)

residential uses. There are in-region balance and export/imports across a region's boundary.

3) Secondary balance : indirect water consumption for which the final user of the produced goods and services is liable.

4) Tertiary balance : indirect water consumption to accomplish the secondary water balance, for example, direct and indirect water used by transportation systems.

Population density and economic activity are not even in Japan. Therefore, the water resource endowment and water consumption in the primarily balanced water use in Japan are different according to the regions (Table 3 − Sueishi 1983). Here, TU is the total water use and NS is the net supply which is TU minus recovered waste. The calculated results of secondary import and export of industrial and agricultural water uses, in which production amount was counted in monetary basis (Table 4− Sueishi 1983). The sum of primary and secondary water balances may represent the total human activity in each region in the water consumption level. The activity potential in the Kanto coastal zone is over twice of the natural endowment. Therefore, the industrialization and urbanization in the Kanto and Kinki coastal zones have been advanced with the

Table 3 Primarily balanced water use in Japan
(1978; ℓ/capita・day)(Sueichi 1983)

Region	Population (1000)	Natural endowment (drought yr.)	Living use *)	Industrial use		Agriculturial use	Total			
							Amount		Ratio to endowment(%)	
				TU	NS		TU	NS	TU	NS
Kanto, inland	8869	8518	242	837	248	2219	3298	2709	38.7	31.8
Kanto, coastal	28043	985	264	793	150	342	1399	756	142.0	76.8
Tokai	13102	8435	2578	1870	609	858	2985	1724	35.4	20.4
Hokuriku	2980	18976	241	1434	796	2457	4132	3494	21.8	18.4
Kinki, inland	4599	6888	248	434	236	1091	1773	1574	25.7	22.9
Kinki, coastal	14638	2686	283	1263	255	379	1935	927	72.0	34.5
others	42843	13367	242	1261	372	2471	3974	3085	29.7	28.1
Whole Japan	115174	7941	256	1155	326	1427	2838	2009	35.7	25.3

*) includes household use (evenly 175 ℓ/capita・day) and for urban activity.

Table 4. Secondarily balanced water use in Japan
(1978; ℓ/capita・day)(Sueishi 1983)

Region	Production (billion yen)		Secondary water import			Sum of primary and secondary water use			
	Industrial	Agricultural	Industrial		Agricultural	Amount		Ratio to endowment(%)	
			TU	NS		TU	NS	TU	NS
Kanto, inland	14303	973	−94	−28	−804	2400	1877	28.2	22.0
Kanto, coastal	43940	573	−69	−13	+1033	2363	1776	239.9	180.3
Tokai	29238	582	−671	−281	+530	2844	2036	33.7	24.1
Hokuriku	3082	256	+102	+56	−1116	3118	2434	15.4	12.8
Kinki, inland	6474	202	+18	+9	+244	2035	1827	29.5	26.5
Kinki, coastal	25910	262	−49	−49	+1012	2705	1890	100.7	70.4
others	40963	4344	+625	+185	−964	3616	2586	27.1	17.1
Whole Japan	164810	7192							

externalization of the agricultural water use and decreasing of the secondary industrial water export with higher recycling and its efficient use. The secondary import of agricultural water from foreign countries has increased depending on the import of agricultural products. The per capita average of agricultural water is 1427 ℓ/day in 1978

(Table 3), but it was 2174 ℓ/day in 1965. The original units of water use : 3.6 m³ for 1 kg of rice and 1.5 m³ for 1 kg of wheat were obtained from the agricultural water demands and crop harvests in 1978. However, the water requirement or transpiration efficiency is 1 : 710 for rice and 1 : 436 for spring wheat in plant physiology (Maximov 1959). The figures are bigger than the original units of water balance analysis. Probably the transpiration efficiency includes only transpiration as throughput, but water use in the water balance analysis includes more water supplied. The throughput of water in the production process of plants is different from the throughput polluted in the industrial process, or the agricultural water demand.

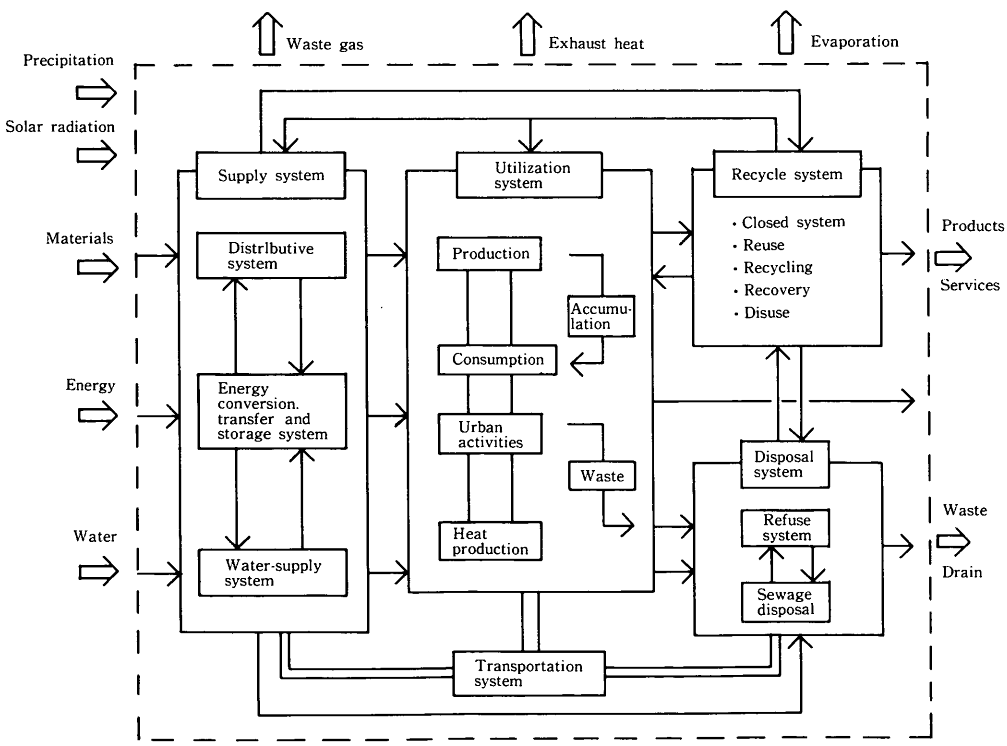


Fig.5 Metabolism of a city (Hayakawa 1984)

A large amount of energy and materials as well as water is input from outside for a city to maintain complicated human activities. Metabolism of a city is shown in Fig. 5 (Hayakawa 1984). Energy both in flow and in a state of preservation will finally be emitted to environment as the exhaust heat. Heat and water are generated by the combustion of fuel and they are emitted to environment. Thus, energy use occurs the emission of heat and water, and it will be related to urban environment in various levels. The annual average of relative humidity in Tokyo is decreasing from 70%, the average of five years from 1953 to 1957, to 63% in recent years. Especially in winter, relative humidity is decreasing in connection with air temperature rise, though vapor tension is moving almost unalterably (Hayakawa 1984).

Considering the water balance in a city including heat budget, the water as input is precipitation + service water + industrial water + water generated by combustion, and the water as output is evaporation from the ground surface + aboveground service water and undergound (sewage) leakage of water + evaporation and spraying from the cooling water in the combustion process + runoff of service water, sewage and river water. Evaporation from the ground surface includes transpiration from plants.

To estimate the water balance of a watershed including a city or cities, it is necessary to know the amount of evapotranspiration according to the cllasification of land category. The amount of evapotranspiration is assumed 1.5mm/day(=548mm/year) in forests, 3.5mm/day in upland fields, 5mm/day in paddy fields during the growing season, and 3.5 mm/day in cities and other areas. Then, the total amount of evapotranspiration from terrestrial parts (722mm/year) and evaporation of the Suwa Lake (central Japan) is 53.7% of the annual amount of precipitation (1753 mm/year). According to the water balance of the Suwa Lake watershed area (Okino 1984), input is precipitation + underground water + service water + surface water from gas field + hot spring + secondary water balance of agricultural and industrial products, electric power, foods and daily goods, and output is evapotranspiration from terrestrial parts + evaporation from the lake + runoff from the lake, etc. + undergound water + waste water + secondary water balance.

The hydrological and water supply data in Tokyo shows the macro-estimation on water balance as follows: water pumped from groundwater was about 140,000 m^3/day in 23 wards of 591km^2 and 630,000m^3/day in the Tama Suburlan District of 1,161km^2, in 1982. That is, 0.23mm/day in 23 wards and 0.54mm in the Tama District. The data for 1970 were 1.06mm/day in 23 wards and 0.75mm/day in the Tama District, because the utilization of groundwater has been regulated to prevent land subsidence (Takahashi 1984).

In considering the supply to groundwater, the leakage water from the pipes of water supply system cannot be ignored. The leakage water was 259,000,000 m^3 per year in 23 wards of Tokyo, that is about 1.2 ㎜/day which is equal to about five times the pumped volume as in 1982. On the other hand, the amount of water supply from outside of Tokyo was about 30 ㎜/day in 1982 which was about 7 times of precipitation (Takahashi 1984).

According to urbanization, the impermeable area increased compared with the catchment area of the basin, and the ratio of runoff to precipitation has also increased. With the progress of sewage systems, the discharge in rather small scale revers is decreasing throughout the year. Overpumpage from ground water leads to severe land subsidence, however the land subsidence ceased in lowland areas due to the controllng of groundwater utilization. Based on these results on urban waters, the followings were proposed to maintain a desirable water cycle in large cities (Takahashi 1984), as recommendations to urban planning.

1) It is advisable that the precipitation infiltrates directly to the ground as much as possible instead of flowing to the sewage system.
2) It is also desirable that the streamflow infiltrates into the reverbed as much as possible, and to attain this purpose do not concrete completely the riverbed in river improvement works.
3) It is desirable to build facilities to reserve rainfall waters on surface and into underground as much as possible, for example at playgrounds and into undergound ponds.

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